



CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 09-049
UILU-ENG-2009-2023
ISSN: 0197-9191

IMPROVING THE SAFETY OF MOVING LANE CLOSURES

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Research Report ICT-09-049

A report of the findings of
ICT-R37-32
Improving the Safety of Moving Lane Closures
Illinois Center for Transportation

June 2009

Technical Report Documentation Page

1. Report No. FHWA-ICT-09-049	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Improving the Safety of Moving Lane Closures		5. Report Date June 2009	
		6. Performing Organization Code	
7. Author(s) Douglas A. Steele and William R. Vavrik		8. Performing Organization Report No. ICT-09-049 UILU-ENG-2009-2023	
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit (TRAIS)	
		11. Contract or Grant No. ICT-R27-32	
		13. Type of Report and Period Covered	
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 East Ash Street Springfield, IL 62704-4766		14. Sponsoring Agency Code	
15. Supplementary Notes Study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.			
16. Abstract Moving lane closures are an increasingly utilized and inherently hazardous traffic control procedure for highway maintenance and operations activities. To improve the safety of moving lane closures for workers and motorists, this research studied driver behavior around moving lane closures and the effect of different components of current traffic control scenarios, including the number, configuration, and spacing of shadow vehicles, and the effect of various traffic control devices and sign messages. This report presents the results of Phase I of this study and includes the findings of full-scale field experiments performed at four locations. A future Phase II of the research will expand on these findings and produce specific recommendations for revisions to current traffic control standards to improve the safety of moving lane closures for highway workers and the travelling public.			
17. Key Words Moving lane closures, mobile lane closures, rolling lane closures, work zone safety, highway maintenance, highway operations, truck-mounted attenuators, portable changeable message systems, traffic control standards		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

ACKNOWLEDGEMENT

This publication is based on the results of ICT-R27-32, **Improving the Safety of Moving Lane Closures**. ICT-R27-32 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

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This research was supported through services-in-kind by the Illinois State Toll Highway Authority (ISTHA).

DISCLAIMER

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

EXECUTIVE SUMMARY

PROJECT GOALS AND APPROACH

This study was conducted to improve the safety of moving lane closures. The project approach focused on studying driver behavior around lane closures established at multiple locations to capture a range of conditions. Traffic patterns were documented through videotape and speed monitoring. At each location, the research team studied driver reactions to the typical lane closure scenario used by the traffic control crews (truck configurations, message boards, and so on), as well as the influence of modifications to the setup, such as changes to the spacing between trucks, number of trucks, police presence, and changes to the message board.

The project goal was to identify possible modifications to current practices to make moving lane closures safer for work crews, traffic control providers, and the traveling public. The project scope included a literature review, identification of hazards, rollahead distance analysis, field tests at four sites, and data analysis to identify potential improvements.

FINDINGS AND RECOMMENDATIONS

Hazard Identification

- Moving lane closures are inherently dangerous due to their dynamic nature and the complex interaction between roadway, environmental, and human factors.
- A moving lane closure consists of three main components—the advance warning area, a transition zone, and the work area. Each component is important with respect to the interaction of motorists and the traffic control devices used to guide them safely around the work area. All three areas were analyzed as part of this study.
- Reduction of injuries and fatalities to motorists and highway workers is the greatest concern. Accidents happen with moving lane closures when motorists fail to vacate the closed lane and collide with the traffic control vehicles, commit incursions into the work area, or strike other vehicles and equipment, sending them into the work area.

Rollahead Distance

- Determination of safe distances between traffic control trucks, and from truck-mounted attenuators (TMAs) to workers on foot, should take into account the distance that TMAs will be displaced (or roll ahead) if struck by moving vehicles. Rollahead distances vary greatly depending primarily on the size and speed of the moving vehicle. Calculations based on the principles of energy absorption show that, while rollahead distances for passenger cars and pickups generally are not significant, single unit trucks traveling at normal highway speeds can displace a parked TMA more than 100 ft. Tractor-trailer combinations traveling at highway speeds can displace TMAs several hundred feet. This shows the inherent danger for workers on foot in the event of a collision, as they generally are working within this range.

Findings from the Field Tests

Full-scale field tests were conducted at four locations representing a range of roadway and traffic conditions. Three of the sites were high-volume, urban settings; two of these sites were tested during the day, and the other was tested at night. The fourth site was a rural interstate, and data collection was performed during the day. At each location, two to three days of testing were conducted using multiple traffic control configurations.

Urban vs. Rural Settings

- The type of setting (urban vs. rural) had a significant effect on traffic characteristics, driver behavior, and consequently, traffic control practices used by the local maintenance personnel. In general, urban motorists drive more aggressively than their rural counterparts, approaching the work zone closer before vacating the closed lane and reentering the lane quickly after passing the work area. Traffic volumes are higher in urban areas, and congestion occurs quickly after closing a lane. Many work activities are scheduled for nighttime in urban areas to avoid congestion, exposing workers to hazards such as fatigued drivers. Current traffic control standards do not necessarily distinguish between urban and rural settings; however, it may be beneficial to do so.

Cut-in Distance and Work Area Length

- In terms of cut-in distance (the distance beyond the work area where drivers reenter the lane) in urban areas, drivers began returning to the lane at 50 ft beyond the work area, and the peak cut-in distance was 100 ft. Cut-in distances for rural motorists were slightly longer, beginning at 100 ft and peaking at 225 ft. This reflects the relatively higher aggressiveness of urban vs. rural drivers, as well as factors such as traffic volumes and congestion. The implication for workers is that traffic returns to the lane at very short distances beyond the perceived end of the work area. Work crews have adapted by working very close to the lead TMA (usually within 50 to 100 ft downstream), which protects them from lateral intrusions but leaves them vulnerable if a large collision occurs with the TMA.
- An effective way of extending the work area length is adding an additional truck downstream from the work area in the lane just past the work crew. This “lead truck” can be a TMA, a work truck with an arrowboard, or a foreman’s pickup truck with strobe bar. In any case, the lead truck should be highly visible so that vehicles are able to see it as they are passing the lead TMA and understand that it is not yet safe to return to the closed lane. On I-90, tests were performed with and without a lead truck. In the case of no lead truck, no vehicles attempted to swerve into the closed lane when the work zone length was less than 150 ft. At 200 ft, vehicles began swerving into the work area, thinking they were beyond it. By placing a TMA downstream of the work area, no incursions were attempted for the 200-ft work area length. Swerving into the work area did not happen with the lead truck until the work area length reached 300 ft.
- At the rural test site on I-88, the practice of parking the supervisor’s pickup 300 ft downstream of the lead TMA and on the shoulder was effective in delaying the return of vehicles to the closed lane. Without the pickup, traffic began reentering the lane at 100 ft, with the majority of users cutting in at 150 to 450 ft. With the supervisor’s pickup, traffic delayed until 175 ft before reentering the lane, with the majority of vehicles cutting in at 250 to 600 ft downstream.

Truck Configurations and Taper Lengths

- The number and spacing of traffic control trucks varied greatly from one location to the other. All maintenance crews used a minimum of three trucks to close the lane and protect the work area, as well as an advance warning vehicle further upstream to warn motorists of what was ahead. However, the number and spacing of trucks was variable, and in some cases significantly different from the published standards. At the rural site, a series of four trucks were spaced at 500-ft intervals, forming a gradual 1500-ft taper to warn and guide motorists away from the closed lane. In urban areas, the trucks tend to space themselves closer together to prevent vehicles from intruding into the taper and work area. One maintenance yard routinely uses a three-truck taper with a total length of only 150 ft. This has been effective in preventing errant vehicles from passing between the trucks and into the work area, but it provides little transition area for traffic to change lanes.
- On the last night of testing on I-90, the traffic control truck configuration was modified by inserting a buffer truck in the convoy. The idea of the buffer truck is to provide additional distance between the work crew and the TMA taper in case a collision occurs with the TMAs, while still protecting against lateral intrusions. In this case, a channel truck with arrowboard was placed 100 ft in front of the lead TMA. The work crew placed themselves approximately 50 ft forward of the buffer truck. This configuration was tested in stationary and moving modes for approximately 2 hours with no attempted intrusions. At the end of the night, the workers gave positive feedback regarding the use of a buffer truck.

Advance Warning and Cut-Out Distance

- The advance warning area is the area upstream of the work zone where motorists are advised of what is ahead. Typically, a warning truck is placed on the shoulder from 0.25 to 0.5 mi in advance of the TMA taper. The truck is equipped with either orange warning signs or a portable changeable message system (PCMS). The PCMS can be either truck- or trailer-mounted. The purpose of the advance warning truck is to promote traffic to reduce speed and vacate the soon-to-be closed lane. The distance upstream at which vehicles vacate the lane is defined as cut-out. In general, cut-out distances in rural areas were longer than in urban settings under free flow traffic conditions. In this study, 94.4 percent of drivers vacated the lane at least 500 ft before the TMA taper at the rural test site, compared to 86.8 percent in the urban area. The number of vehicles approaching the work zone closely (within 500 ft) was 4.8 and 12.2 percent in the rural and urban areas, respectively. In both cases, a small percentage of drivers entered the TMA taper before changing lanes (0.8 and 1.1 percent for the rural and urban areas, respectively). In general, vehicles waiting until the TMA taper represent a hazardous situation.
- Driver behavior in the advance warning area under congested conditions is much different than when traffic is free flowing. In general, congestion occurs on heavily trafficked roads when a lane is closed. This results in reduced vehicle speeds and increased saturation of the lanes upstream of the work zone. Typically, traffic approaches the work zone much closer before merging into the open lane. In the case of our field tests, traffic speeds dropped from approximately 55 mph to anywhere between 40 and 15 mph, depending on traffic volumes and the number of open lanes available. In the case of the I-90 test site, congestion caused the number of vehicles approaching the TMA taper closely (within 500 ft) to increase to 22.8 percent. The percentage of vehicles changing lanes within the TMA taper increased to 6.2 percent. At

the Eisenhower Expressway test site, the most common location for vehicles to change lanes was 20 ft behind the TMA blocking the lane, meaning the queue of vehicles in the congested upstream lane drove as far forward as they could before merging to the open lane. Many times these vehicles had to come to a complete stop directly behind the TMA and wait for an opening to merge out of the lane.

- Various PCMS messages were tested on the advance warning truck for the rural site on I-88 to see their effect on driver's speeds at the work area. The base case of a single message—"Right Lane Closed"—produced average speeds of about 62 mph (the posted speed limit was 65 mph), as did the alternating messages "Right Lane Closed. Reduce Speed." The alternating message "Right Lane Closed. Reduce Speed 45 MPH" produced an approximately 5 mph speed reduction (57 mph); however, this meant that traffic still was traveling significantly faster than the suggested work zone speed limit.

Nighttime Operations

- Due to traffic congestion caused by daytime lane closures, many work activities in urban areas are performed at night. While this benefits the highway users, it poses unique risks to workers, such as increased exposure to impaired drivers (intoxicated and fatigued), higher vehicle speeds, and less visibility. During our nighttime testing on I-90, three near-misses occurred in the first hour, all of them involving vehicles that approached the work zone in the closed lane, changing lanes very close to the TMAs.
- Traffic control procedures at night are very similar to daytime operations. The main changes at night were the use of additional high-visibility clothing by personnel and balloon lighting of the work area.
- Cut-in distances for nighttime motorists were similar to those for daytime traffic. The main difference is that traffic volumes are lower and travel speeds are higher. For the I-90 tests, vehicles began reentering the lane at 50 ft, with a peak cut-in distance of 100 ft. Traffic approached the work zone at average speeds of 60 to 65 mph, decreasing to 50 to 55 mph at the work zone.
- A concern with nighttime closures is drivers' ability to correctly interpret the warning messages and arrowboards that guide them to the open lane. Because they are traveling at higher speeds, they do not have as much time to make corrections. It was noticed during the first night of testing a two-lane closure on I-90 (i.e., two of three lanes were closed) that many vehicles approached the work zone closely before changing to the open lane, in spite of there being plenty of space to do so earlier. A supervisor's pickup with strobe bar was placed 500 ft upstream of the TMAs on the shoulder, and this had a positive effect on encouraging traffic to change lanes sooner. With the supervisor's pickup, the percentage of vehicles that approached the work zone closely (within 500 ft) decreased from 18.1 to 3.6.

Police Presence

- Police presence had a significant effect in all cases where it was evaluated. In the case of I-90 daytime testing, a single lane closure (i.e., one of three lanes were closed) was set up with and without police presence. Without police, traffic was free flowing and traveling from 50 to 60 mph. With a lit squad car placed at the work zone, speeds

decreased by about 10 to 15 mph immediately, very quickly backing up traffic, eventually resulting in heavy congestion moving at 15 to 20 mph.

- Experiments also were conducted on I-88 with and without police in the advance warning area. In this case, police had the effect of reducing traffic speeds and moving vehicles to the open lane sooner. Vehicle speeds at the work zone decreased from 62 to 51 mph with a lit Illinois State Police squad car on the shoulder. Also, the percentage of vehicles that approached the work zone closely (within 500 ft) decreased from 5.6 to 0.7. No vehicles entered the TMA taper when police were present.

Other Related Issues

The following reoccurring and/or pertinent issues were noted during interviews and discussions with IDOT, ISTHA, and Illinois State Police (ISP) personnel involved with traffic control operations and supervision.

- The policies on when moving lane closures can be used and for what duration varied between maintenance yards. In rural areas, moving lane closures are permitted about any time of day and may stay at a single location up to 30 min. On I-90 moving lane closures are generally allowed during the daytime (except for incident response) due to congestion. Therefore, work activities are scheduled for nighttime closures, and work crews are allowed to stay at a given location for up to 20 min. On the Eisenhower Expressway, traffic is so heavy that moving lane closures are generally scheduled for between 10 am and 2 pm, and some activities are scheduled for night work. During the day, moving lane closures are permitted for only 15 min at a single location. Work requiring a longer duration is generally performed under stationary lane closures. In the case of the Eisenhower Expressway, both daytime moving and stationary closures will cause significant congestion; however, the feeling is that under stationary closures that workers are less likely to be confronted with “uninformed motorists,” due to the additional traffic control devices.
- A reoccurring topic is the desire of field crews to be allowed to use moving closures more often and for longer durations. The alternative to a moving closure is a stationary lane closure using signs, barricades, stationary arrowboards, cones, and so on. As stated above, stationary closures provide the advantage of using more traffic control devices, which increases the likelihood that motorists are safely guided through the work zone. The disadvantage of stationary closures is the inherent danger of setting up and taking down devices, as well as the length of time required to do so. Typical devices such as barrels, barricades, and cones require workers to be outside of the trucks, physically exposing themselves to traffic, and the length of time required to place the devices increases their length of exposure. A particularly hazardous moment of setup is when the very first devices are placed on the roadway, and likewise, when the very last devices are removed at the end of the day. There is sentiment among the field crews that the length of time and exposure to traffic required to setup a stationary closure is not practical in some cases, where the duration of setting up the closure is longer than the duration of the work activity itself.
- Another frequent comment was that mobile work zones do not have the same public perception as traditional construction work zones; therefore, highway users do not respond with the appropriate level of care. For example, much publicity and public education is done to encourage drivers to slow down in construction zones and make

them aware of the fines and penalties that exist for breaking work zone speed limits. However, motorists generally do not view the same rules applying to moving closures. They are correct in the sense that speed limit reductions posted for moving closures (on PCMS and/or orange signs) are suggested only and are not enforceable. On the other hand, Illinois' Scott's law (the "move over" law) is a very beneficial regulation that can prevent accidents with maintenance crews and also be used to ticket motorists that drive unsafely through moving closures.

- Not only is the balance between safety and mobility a major policy issue at the national level, but the effects can be seen at the local level, too. For example, maintenance crews prefer working in congestion due to low traffic speeds. Obviously, this is not acceptable to the driving public. To accommodate motorists, many maintenance activities are performed at night, exposing workers to hazardous conditions such as impaired drivers operating at high speeds.
- When asked what could be done to make moving lane closures safer, universally traffic control crews stated, "more trucks and more police." The benefits of both of these resources are confirmed by the results of this study; however, their availability is highly dependent on agency funding.

RECOMMENDATIONS FOR FUTURE RESEARCH

Based on feedback from the technical review panel, the investigators recommend continuing this research through a second phase designed to gain broader agency input and to develop a list of recommendations to incorporate into revisions of the traffic control standards governing moving lane closures. The scope of work would include:

- A series of large group meetings held throughout the state to present the results of the phase I study, gain feedback from a diverse group of people involved with moving closures, and develop specific recommendations for revisions to current traffic control standards. We envision a series of three meetings (Chicago area, central Illinois, and downstate) attended by supervisors from IDOT maintenance yards, district operations personnel, the Bureau of Safety Engineering, private traffic control providers, and state law enforcement.
- An expert panel meeting with professionals from throughout the U.S. involved with moving lane closures. This may include officials from other state highway agencies, the Federal Highway Administration (FHWA), researchers, and, academia. The half-day panel discussion would provide the opportunity to collaborate with experts in this field, learn from their experiences, and receive their feedback regarding proposed changes to IDOT and ISTHA traffic control standards based on this study.
- The product of phase II would be specific recommendations for changes to existing traffic control standards to increase safety for highway users and workers.

Table of Contents

ACKNOWLEDGEMENT	I
DISCLAIMER.....	II
EXECUTIVE SUMMARY	III
<i>PROJECT GOALS AND APPROACH</i>	<i>III</i>
<i>FINDINGS AND RECOMMENDATIONS</i>	<i>III</i>
Hazard Identification	iii
Rollahead Distance	iii
Findings from the Field Tests.....	iv
Other Related Issues	vii
<i>RECOMMENDATIONS FOR FUTURE RESEARCH.....</i>	<i>VIII</i>
INTRODUCTION	1
<i>BACKGROUND</i>	<i>1</i>
<i>PROJECT GOALS</i>	<i>1</i>
<i>RESEARCH APPROACH</i>	<i>1</i>
DEFINITION OF TERMS	3
<i>WORK ZONE COMPONENTS</i>	<i>3</i>
<i>VEHICLES AND EQUIPMENT.....</i>	<i>4</i>
<i>CONVENTIONS</i>	<i>8</i>
<i>VEHICLE CATEGORIES.....</i>	<i>8</i>
IDENTIFICATION OF HAZARDS.....	9
<i>GENERAL HAZARDS.....</i>	<i>9</i>
Individual Driver Characteristics	9
Driving Habits.....	9
Roadway Characteristics	9
Day vs. Night.....	10
Weather	10
<i>SPECIFIC SAFETY CHALLENGES OF MOVING LANE CLOSURES</i>	<i>10</i>
ROLLAHEAD DISTANCE ANALYSIS.....	12
EXPERIMENT DESIGN	14
SITE 1 – I-90 AT MEACHAM ROAD, SCHAUMBURG	16
<i>SITE DESCRIPTION— URBAN EXPRESSWAY, DAYTIME TRAFFIC</i>	<i>16</i>
<i>TRAFFIC CONTROL SETUP</i>	<i>16</i>
<i>CUT-IN DISTANCE AND EFFECT OF WORK AREA LENGTH</i>	<i>17</i>
<i>THE USE OF A LEAD TRUCK.....</i>	<i>21</i>
<i>ADVANCE WARNING AREA – WITH AND WITHOUT POLICE PRESENCE</i>	<i>22</i>
<i>VEHICLE SPEED DATA</i>	<i>24</i>
<i>SUMMARY OF KEY FINDINGS—URBAN EXPRESSWAY, DAYTIME TRAFFIC</i>	<i>26</i>
SITE 2 – I-88 AT SOMONAUK ROAD, DEKALB	28

<i>SITE DESCRIPTION—RURAL INTERSTATE, LOW TRAFFIC VOLUMES</i>	28
<i>TRAFFIC CONTROL SETUP</i>	28
<i>BUFFER AREA AND LEAD TRUCK TESTS</i>	29
<i>EFFECT OF POLICE PRESENCE IN THE ADVANCE WARNING AREA</i>	31
<i>EFFECT OF VARIOUS MESSAGES ON VEHICLE SPEEDS</i>	33
<i>SUMMARY OF KEY FINDINGS—RURAL INTERSTATE, LOW TRAFFIC VOLUMES</i>	33
SITE 3 – I-290 AT LARAMIE AVENUE, CHICAGO	35
<i>SITE DESCRIPTION—HIGH-VOLUME, URBAN EXPRESSWAY WITH RAMPS</i>	35
<i>TRAFFIC CONTROL SETUP</i>	36
<i>CUT-IN DISTANCE IN FRONT OF THE LEAD TMA</i>	36
<i>INCURSIONS BETWEEN TMAS</i>	37
<i>CUT-OUT DISTANCES IN THE ADVANCE WARNING AREA</i>	37
<i>VEHICLE SPEED DATA</i>	38
<i>SUMMARY OF KEY FINDINGS—HIGH-VOLUME, URBAN EXPRESSWAY WITH RAMPS</i>	41
SITE 4 – I-90 AT BARRINGTON ROAD, HOFFMAN ESTATES	42
<i>SITE DESCRIPTION—URBAN EXPRESSWAY, NIGHTTIME OPERATIONS</i>	42
<i>TRAFFIC CONTROL SETUP</i>	42
<i>CUT-IN DISTANCE</i>	43
<i>ADVANCE WARNING AREA</i>	43
<i>VEHICLE SPEEDS</i>	45
<i>BUFFER TRUCK ADDITION TO THE CONVOY</i>	45
<i>SUMMARY OF KEY FINDINGS—URBAN EXPRESSWAY, NIGHTTIME OPERATIONS</i>	47
OTHER RELATED ISSUES	48
APPENDIX A – LITERATURE REVIEW	50
<i>APPLICABLE TRAFFIC CONTROL STANDARDS</i>	1
Manual on Uniform Traffic Control Devices	1
FHWA Manual on Traffic Control for Nighttime Operations	2
Illinois Department of Transportation	2
Illinois Tollway	3
<i>OUTSIDE AGENCY STANDARDS/BEST PRACTICES</i>	4
Wisconsin DOT	4
North Carolina	4
Missouri DOT	4
<i>RELATED RESEARCH AND TRAFFIC CONTROL DEVICES</i>	4
Speed Reduction Methodologies—Illinois DOT	4
You/Me Speed Display Boards—Wisconsin DOT	5
Driver Opinions of Traffic Control Devices for Mobile Work Zones	5
<i>REFERENCES</i>	7
<i>FIGURES</i>	9

INTRODUCTION

BACKGROUND

Aging highway infrastructure in the U.S. requires more and more maintenance each year. Combined with an ever-increasing number of users, it is each time more difficult to close traffic lanes for maintenance and rehabilitation activities. To minimize the duration of lane closures for maintenance and repair operations, rolling closures consisting of a convoy of large, highly visible work trucks with signs and arrowboards are used. These moving operations allow maintenance crews to enter the traffic stream, divert traffic out of the closed lane, and protect motorists and work crews from the hazards associated with performing work on in-service roadways.

Unfortunately, performing work on open roads is an inherently dangerous activity. Of the over 400,000 traffic accidents in Illinois each year, approximately 2 percent occur in highway work zones. In 2006, this amounted to 8,326 work zone crashes, resulting in property damage, injuries, and fatalities. Moving lane closures are especially vulnerable to accidents, as many drivers fail to recognize them as highway work zones and do not respond with appropriate care.

PROJECT GOALS

To study the hazards involved with moving lane closures and identify possible improvements to increase the safety of maintenance crews, workers, and the traveling public, the investigators performed this research on actual moving lane closures. The lane closures were conducted at multiple locations and covered a broad range of traffic and environmental conditions, with the ultimate goal of improving the safety of moving lane closures through influencing drivers to:

- Slow down when approaching and passing work convoys
- Vacate the closed lane at a safe distance upstream of the work zone
- Remain in the open lane while passing the work convoy and until safely beyond

The scope of the current project focused on moving lane closures on multilane, divided highways in both urban and rural settings. The research is intended to be applicable to both the Illinois Department of Transportation (IDOT) and the Illinois State Toll Highway Authority (ISTHA) applications.

RESEARCH APPROACH

The main focus of this research was studying driver behavior in and near moving lane closures through a series of field tests performed specifically for this study. The project team videotaped vehicle maneuvers from cameras mounted on bridges near the lane closures and in the work vehicles. In addition, the Illinois State Police (ISP) monitored traffic speeds approaching and passing the work zones from an unmarked vehicle placed in the work convoy. Lane closures were provided by IDOT and ISTHA at a total of four locations for two to three days of testing at each site.

The complete scope of work included:

- Project meetings with the technical review panel to provide guidance, input, and review of completed work
- A literature review to identify current traffic control standards, innovative traffic control devices, and recent research performed on the topic throughout the U.S.

- An analysis of rollahead distance of traffic control vehicles when impacted by moving traffic
- Identification of hazards through interviews with field and office personnel involved with traffic control operations
- Field tests at four locations to record driver behavior approaching, at, and beyond lane closures
- Analysis of video and speed data to quantify driver behavior and identify possible alternatives to improve the safety of moving lane closures
- A written report with a summary of findings and recommendations

The following sections describe the results of the work performed and our findings and recommendations.



Figure 1. Driver behavior was studied by videotaping lane closures provided by IDOT and ISTHA maintenance personnel.

DEFINITION OF TERMS

The following terms, used throughout this report, are defined here for clarity.

WORK ZONE COMPONENTS

A moving lane closure has the same basic components as a typical stationary lane closure, as shown by figure 2 taken from the 2003 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD, figure 6C-1). They include:

Advance Warning Area: Area where traffic is alerted as to what is ahead.

Transition Zone: Zone where vehicles are moved out of the soon-to-be closed lane.

Buffer Area: A clear zone between the initiation of the lane closure and workers.

Work Area: Area where workers and equipment are performing work activities.

Terminal Area: Zone where traffic is permitted to return to the previously closed lane.

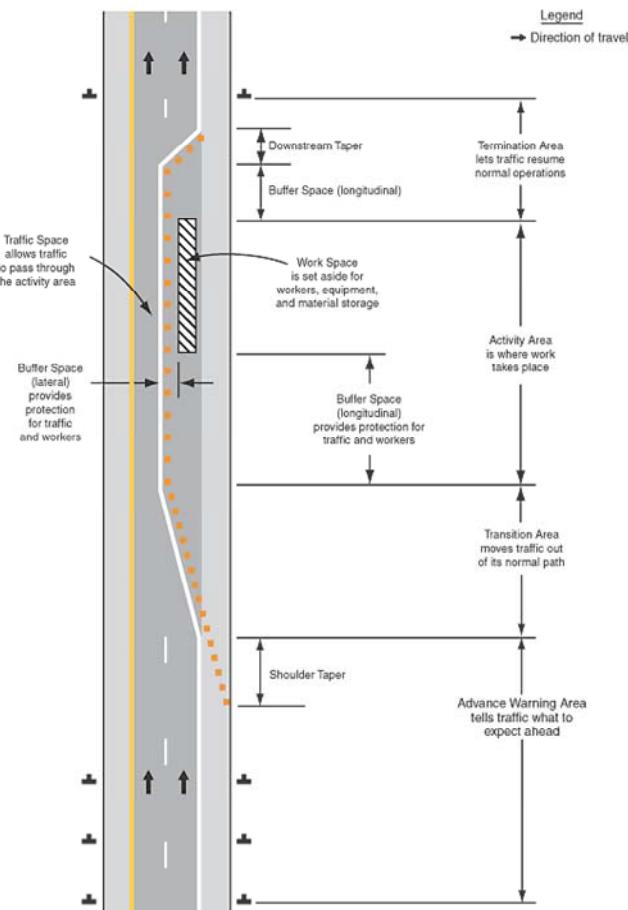


Figure 2. Component parts of a typical stationary lane closure.

VEHICLES AND EQUIPMENT

Rolling, Moving, and Mobile Lane Closures: All terms used synonymously to describe traffic control operations that move along the road either intermittently or continuously. They typically utilize trucks equipped with signs, arrowboards, and/or attenuators to alert motorists and direct them around the closed lane.

Truck (or Trailer) Mounted Attenuator (TMA): An attenuator is a large shock-absorbing device mounted to the rear of traffic control vehicles to reduce the impact of rear end collisions from errant vehicles. The term TMA commonly refers to a truck equipped with an attenuator.

Lead TMA (or TMA1): As defined for this study, the lead TMA is the truck positioned in the traffic lane directly upstream of the work area. It is sometimes referred to as TMA1 in the field tests.

Shoulder TMA: A TMA placed on the shoulder several hundred feet upstream of the lead TMA. In a two-truck operation, it and the lead TMA are the only two trucks used to warn traffic and close the lane.

Straddler: Typically used in a three-truck operation and placed midway between the lead and shoulder TMAs, such that it straddles the longitudinal lane-to-shoulder joint. The combination of the three TMAs forms a taper, indicating to motorists to change lanes, and closing the lane gradually, instead of all at once.

Advance Warning Truck: A truck typically placed 500 to 1500 ft upstream of the TMA taper on the shoulder and containing signs or a message board to alert motorists of what is ahead. The advance warning truck is usually a pickup or utility truck and usually is not equipped with an attenuator.



Figure 3. A typical truck-mounted attenuator and arrowboard used for moving lane closures.



Figure 4. Trailer-mounted attenuators are becoming a popular replacement to the older truck-mounted types, due to increased energy absorption, mobility, and ease of installation.



Figure 5. A typical three-truck taper used to close a single lane.

Portable Changeable Message System (PCMS): A PCMS is a programmable message board that displays lit messages to roadway users. They usually are larger, more visible, and more customizable than traditional warning signs. They can be either trailer- or truck-mounted.

Lead Truck: An additional truck sometimes used just downstream of the work area. It is used to provide additional visibility to the work area and prevent passing vehicles from reentering the closed lane too early. The lead truck may be a TMA or other truck.

Bomber: A term used by IDOT's Eisenhower Maintenance Yard (District 1) for a large truck placed on the shoulder adjacent to the closed lane to prevent vehicles from passing the work area on the shoulder.

Work Truck: Any vehicles included in the moving operation solely for the purpose of carrying equipment and workers specific to the work activities being performed. Not used specifically for traffic safety protection, but work trucks usually are equipped with strobes and lightbars, increasing visibility.

Light Detection and Ranging (LIDAR): As applied to highway operations, it refers to the handheld laser-based device used to measure vehicle speeds. Effectively, it is an improved version of radar.



Figure 6. A trailer-mounted PCMS in transport mode.



Figure 7. A truck-mounted PCMS has a smaller letter size but is more mobile.



Figure 8. The bomber is used to block shoulder traffic in urban areas.

CONVENTIONS

Upstream: Convention used to define the location of vehicles relative to the work zone. Upstream vehicles were defined as those approaching the lane closure.

Downstream: Downstream vehicles are those that have passed and are proceeding away from the work zone.

Cut-in Distance: Term defined specifically for this study. It refers to the distance downstream of the lane closure at which vehicles return to the previously closed lane. In this study, the cut-in distance was determined at the point where the vehicle's first front tire crossed back into the lane.

Cut-out Distance: The distance upstream of the lane closure at which vehicles vacate the soon-to-be closed lane. Determined at the point where the vehicle's last rear tire exited the lane.

VEHICLE CATEGORIES

This study defined three vehicular categories for characterizing traffic:

Cars: Passenger cars, minivans, pickup trucks, and sport-utility vehicles.

Single-Units (SU): Delivery trucks, single unit box and flatbed trucks, and dump trucks.

Multiple-Units (MU): Tractor-trailer combinations, and cars or SUs pulling a trailer.

IDENTIFICATION OF HAZARDS

The researchers interviewed IDOT and ISTHA personnel involved with providing traffic control to learn from their experiences. This included maintenance workers and foremen from the maintenance garages that provided traffic protection for the field tests, as well as supervisors from IDOT District 1 headquarters and the ISTHA main office. With respect to the traffic, environmental, and human factors that make working in temporary maintenance work zones inherently dangerous, the personnel identified the following items as specific hazards to themselves, their co-workers, and the traveling public.

GENERAL HAZARDS

Individual Driver Characteristics

The characteristics of individual drivers were commonly cited reasons for unsafe driving habits, including:

- Impaired (due to drugs or alcohol)
- Fatigued
- Distracted (for example, due to cell phones or other people in the vehicle)
- Impatient
- Inattentive (especially with respect to reading signs and messages)
- Angry (road rage and verbally abusive actions and gestures towards highway workers)

Driving Habits

Individual and group driving habits are common sources of accidents and near-misses, specifically:

- Speeding
- Tailgating
- Driving in platoons
- Abrupt lane changes just before a lane closure when there is another vehicle following closely behind
- Not paying attention to or obeying the advance warning and instruction given by temporary traffic control devices approaching and at the work zone
- Aggressive driving, especially in urban areas

Roadway Characteristics

Certain roadway characteristics were mentioned frequently as being exceptionally hazardous for setting up temporary lane closures:

- Horizontal and vertical curves that limit lines of visibility to the work zone
- Number and width of traffic lanes and shoulders
- Traffic volume, composition (trucks vs. cars), and travel speed (note: workers prefer to work under congested traffic conditions because of the slow vehicle speeds, although obviously this is not the preference of motorists)
- On and off ramps
- Surface characteristics and roughness

- Presence of guard rail or safety cable in the median not allowing message boards to be used on the inner shoulder

Day vs. Night

In many urban areas, moving lane closures are scheduled for nighttime work due to congestion caused by taking away a lane during the day. This presents increased hazards, including:

- Higher speed traffic, as vehicles are not restricted by congestion
- Higher percentage of impaired drivers (due to intoxication and fatigue)
- Decreased visibility of the roadway and surroundings

Weather

Inclement conditions such as rain, fog, and snow create hazardous driving conditions and decrease visibility. Generally, moving lane closures are not permitted under these conditions, but they may be necessary due to special circumstances, such as incident response.

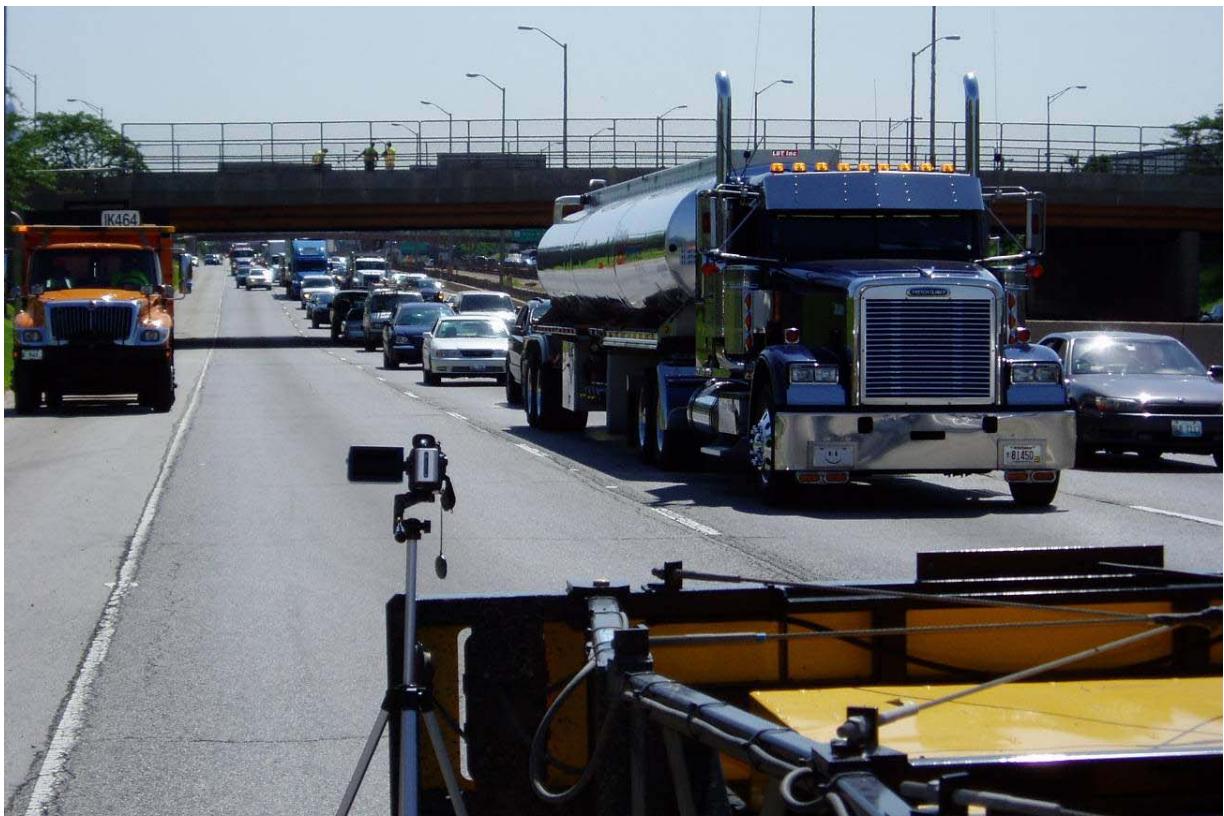


Figure 9. Moving lane closures are particularly susceptible to accidents because motorists do not perceive them as work zones, but rather as inconveniences.

SPECIFIC SAFETY CHALLENGES OF MOVING LANE CLOSURES

Moving lane closures are presented with the same basic challenges as stationary work zones, including:

- Adequate advance warning to motorists

- Decreasing driver speeds and heightening motorist awareness approaching the work zone
- Getting drivers to change lanes at a safe distance upstream of the work zone
- Maintaining traffic in the open lane until a safe distance beyond the work area

Moreover, moving lane closures typically must accomplish the above with far fewer traffic control devices and over much shorter distances than stationary work zones. Specifically, the following crash types occur with moving lane closures, resulting in personal injuries and fatalities to motorists and workers:

- Errant vehicles striking traffic control vehicles parked on the shoulder, straddling the shoulder, or placed in the lane
- Vehicles intruding into the taper and passing the work area on the shoulder
- Lateral intrusions into the work area by vehicles that reenter that closed lane too soon
- Intrusions into the work area by traffic control trucks or equipment rear-impacted from errant vehicles

Figure 10 demonstrates one of the greatest challenges with moving lane closures—defining the location and boundaries of the work area in front of the lead TMA. As workers increase their distance away from the traffic control trucks, they increasingly become exposed to traffic returning to the closed lane. By working closer to the lead TMA, the likelihood of being impacted by a lateral intrusion decreases, but vulnerability due to rear impacts to the traffic control trucks increases.

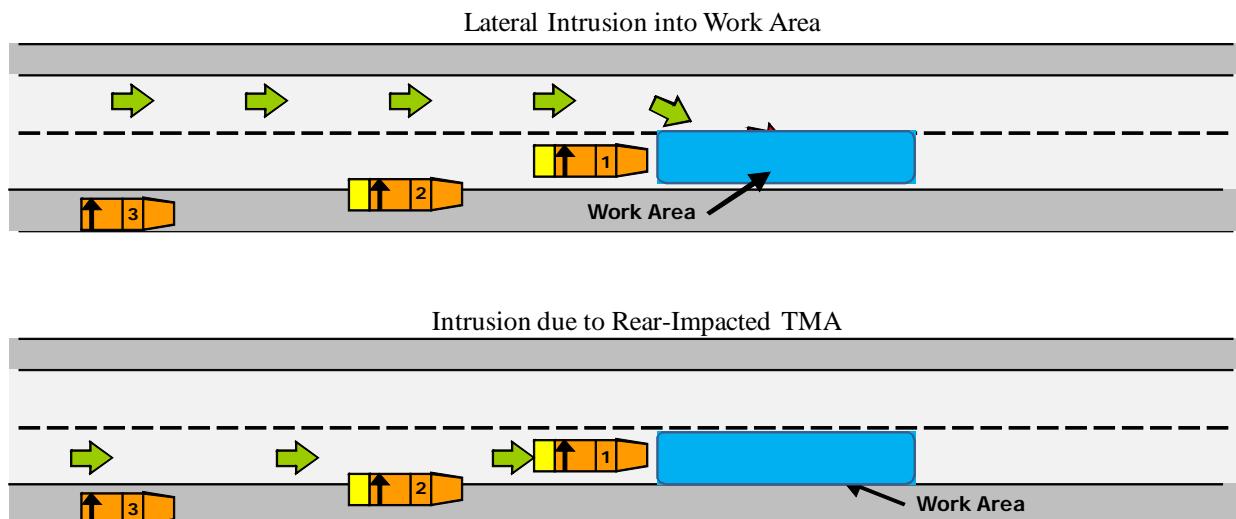


Figure 10. The work area is inherently dangerous due to the potential for lateral intrusions (above) and impacts to the lead TMA.

ROLLAHEAD DISTANCE ANALYSIS

Rollahead is the distance a traffic protection vehicle moves forward when impacted from the rear by another vehicle. It is an important parameter to take into account when designing a moving closure truck configuration, as even traffic control trucks equipped with modern impact absorbing attenuators can move forward significantly if impacted by heavy or fast-moving vehicles. At particular risk are workers on foot that may be located in front of a TMA truck struck from behind.

The energy absorption equations based on the conservation of momentum for an inelastic collision describe what happens when two objects collide and kinematic energy is not conserved (i.e., a good attenuator). The distance the impacted vehicle moves forward is a function of its weight, the weight and speed of the impacting vehicle, the coefficient of friction between the impacted vehicle and road surface, and the acceleration due to gravity. The equation for an inelastic collision between two objects is:

$$m_1 v_1 = (m_1 + m_2) \times v_2 \quad (\text{equation 1})$$

where;

m_1 = mass of the moving vehicle

v_1 = speed of the moving vehicle on impact, ft/s

m_2 = mass of the TMA truck

v_2 = speed of both vehicles immediately after impact, ft/s

The deceleration of the moving vehicle is described by the following:

$$\frac{1}{2} \times (m_1 + m_2) \times v_2^2 = m_2 g f d \quad (\text{equation 2})$$

where;

g = acceleration due to gravity = 32.2 ft/s²

f = coefficient of friction between the tires and road = 0.6

d = distance travel until coming to rest (i.e., rollahead distance)

Through combination of the above equations, rollahead distances for various vehicle weights and impact speeds can be determined. Figure 11 presents the relationships for vehicles of various weights impacting a TMA weighing 30,000 lb at 45 and 62 mph. These speeds are used to determine National Cooperative Highway Research Program (NCHRP) 350 Test Level (TL) ratings. TL-2 and TL-3 ratings correspond to vehicles traveling 45 and 62 mph, respectively.

The results show that smaller vehicles such as cars, pickups, and sport-utility vehicles generally result in TMA rollahead distances less than 25 ft. However, as vehicle size increases, the consequences also increase. A heavy single unit truck, such as a fully loaded dump truck, can push a TMA forward up to 150 ft, depending on its speed at impact. Worse yet is the case of multiple unit trucks, especially when loaded and traveling at high speeds. Almost all multiple unit truck collisions at speeds greater than 45 mph are expected to produce rollahead distances in excess of 100 ft, ranging up to 400 ft in extreme cases.

The results demonstrate the extreme danger to workers and equipment in front of the lead TMA if impacted by a large vehicle traveling at high speeds, as typical buffer distances between TMAs and work crews are in the range of 100 ft or less.

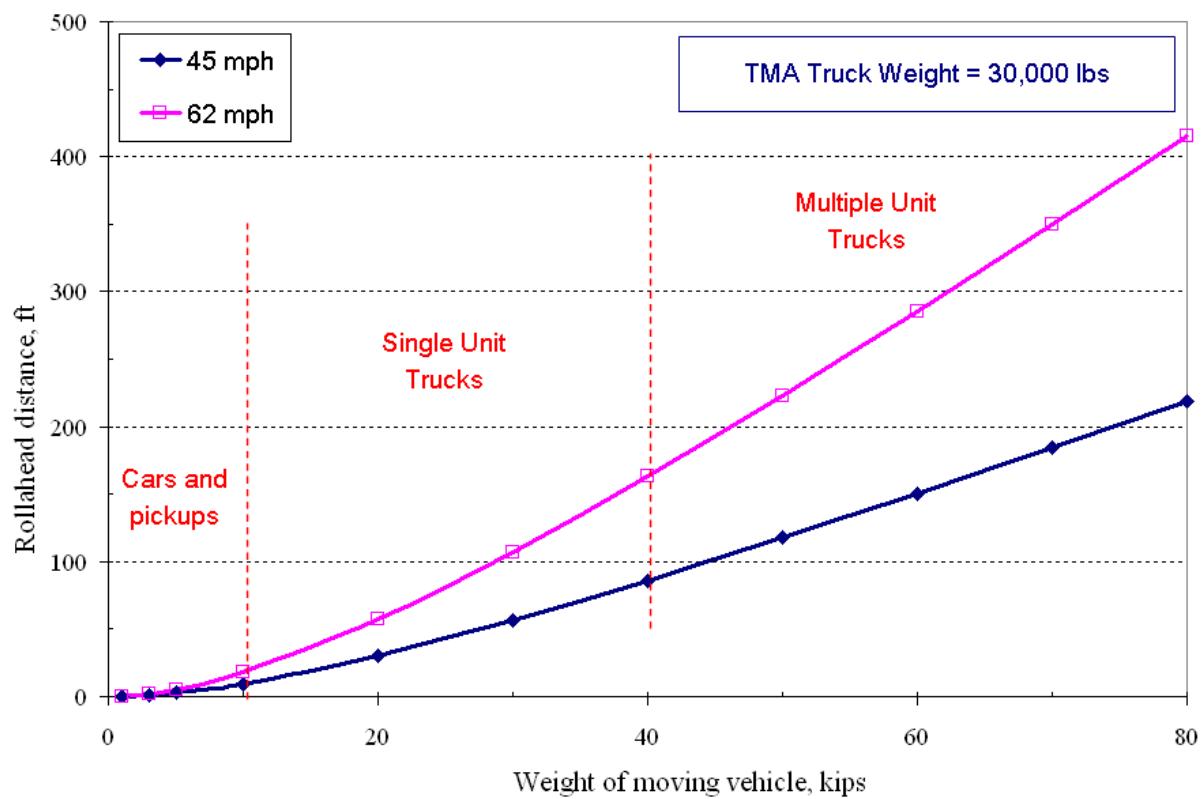


Figure 11. Estimated rollahead distance for a TMA truck struck by a moving vehicle.

EXPERIMENT DESIGN

The focus of this research was a series of full-scale field tests to study driver behavior around moving lane closures under a range of conditions. The technical review panel selected four sites with distinct roadway and traffic conditions, as summarized in table 1. At each site, the investigators met with maintenance personnel to discuss the project objectives and videotaped driver behavior around lane closures set up using the local maintenance yard's usual equipment, personnel, and procedures. Once sufficient data had been collected to establish a baseline, the traffic control setups were modified in various ways to assess the influence on traffic patterns of factors such as:

- Number and spacing of traffic control trucks
- Work zone length
- The effect of a lead truck on reducing attempted incursions into the work area
- Alternate advance warning messages
- An additional flashing vehicle on the shoulder during night testing
- Police presence

The lane closures were located near bridge overpasses and were stationary during videotaping. This made it feasible for the data collection team to view the study area from a vantage point without having to relocate cameras continuously. At the same time, the traveling public's perspective of the lane closure was the same as if the operation had actually been in motion.

The research team operated two video cameras at each site and collected two to three days of data for each location. The ISP monitored traffic speeds approaching and at the work area using LIDAR placed in an unmarked police vehicle.



Figure 12. ISP monitoring traffic speeds at the lead TMA with LIDAR.

Table 1. Experiment Design Summary

Site No.	Location	Test Days	Facility Type and Conditions	Vehicles Per Day	Lane(s) Closed	Experiment Types
1	I-90 at Meacham Road, Schaumburg	3	Urban expressway, High traffic, Daytime testing	90,000	Eastbound (lane 4 of 4) Westbound (lane 4 of 4)	Buffer space Lead truck Police presence
2	I-88 at Somonauk Road, Dekalb	2	Rural Interstate, Low traffic, Daytime testing	13,500	Eastbound (lane 2 of 2) Westbound (lane 2 of 2)	Buffer space Lead truck Alternative Messages Police presence
3	I-290 at Laramie Avenue, Chicago	2	Urban expressway, Very high traffic, Many on/off ramps, Daytime testing	180,000	Westbound (lane 4 of 4)	Buffer space Taper length
4	I-90 at Barrington Road, Hoffman Estates	2	Urban expressway, Nighttime operations	80,000	Eastbound (lanes 1 and 2 of 3) Westbound (lanes 1 and 2 of 3)	Buffer space Shoulder truck Buffer truck

SITE 1 – I-90 AT MEACHAM ROAD, SCHAUMBURG

SITE DESCRIPTION— URBAN EXPRESSWAY, DAYTIME TRAFFIC

The first field tests took place on I-90 at the Meacham Road Bridge near Schaumburg on May 20-22, 2008 (figure 13). At this location, I-90 consists of four lanes in each direction with a one-way average daily traffic (ADT) of approximately 90,000 vehicles per day, including heavy truck traffic. The main purpose of field tests at this site was to evaluate driver behavior just as vehicles come around the lane closure, as well as motorist habits in the advance warning area. Specifically, tests were performed to determine cut-in distance with and without a lead truck, cut-out distance, and the effect of police presence.

Tests were performed during the daytime with clear weather and good visibility. Traffic speeds were relatively low for the majority of testing, as the lane closure typically produced congestion. Normally, daytime lane closures would not be scheduled at this location for this reason, and most maintenance work is performed at night.

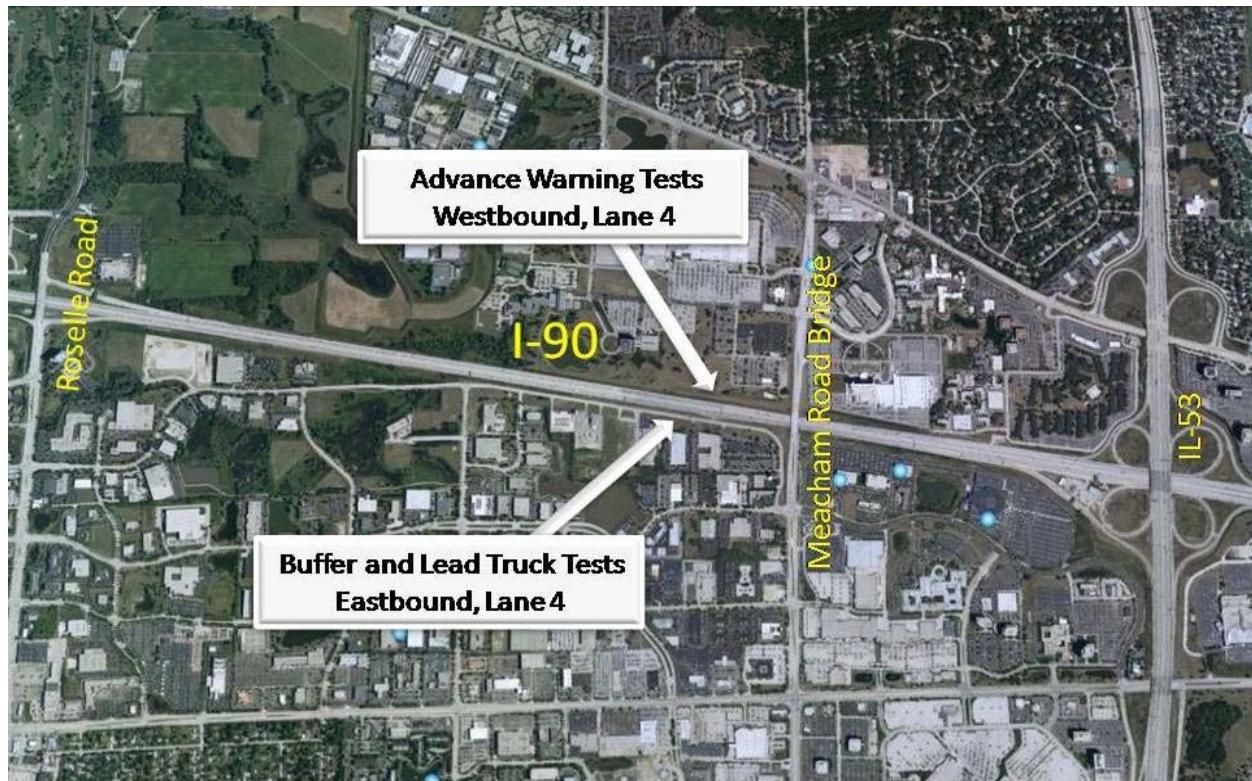


Figure 13. Aerial view of the I-90 test site at Meacham Road.

TRAFFIC CONTROL SETUP

Traffic control was provided by ISTHA Maintenance Yard 5 (M-5) using the setup shown in figure 14. The setup consisted of three TMAs to close the lane and a trailer-mounted message board placed approximately 0.25 to 0.50 miles upstream of the work zone. The three TMAs form a taper by placing one TMA on the shoulder, a second TMA straddling the lane-shoulder joint, and a third TMA completely in the closed lane. Typical nighttime operations in this area involve the closure of two lanes at a time, plus additional trucks, personnel, and safety equipment (such as balloon lighting). However, for our

purposes, a single lane was closed to minimize traffic congestion. To simulate workers on foot, a traffic barrel was used in place of actual workers.

An important characteristic of M-5's traffic control setup is the spacing between trucks. ISTHA standards for moving lane closures (operations proceeding continuously between 5 and 30 mph) show spacing between TMAs ranging from 500 to 750 ft. In the case of a three-truck taper, this results in a transition length of 1000 to 1500 ft. Based on their experience, M-5 traffic control providers typically use a much tighter truck spacing to prevent lateral intrusions in the taper and between the lead TMA and work crew. In the case of our tests, the total distance between the three TMAs was approximately 150 ft. Also, ISTHA personnel informed us that they typically use a very short distance between the work crew and lead TMA (less than 50 ft) for the same reason.

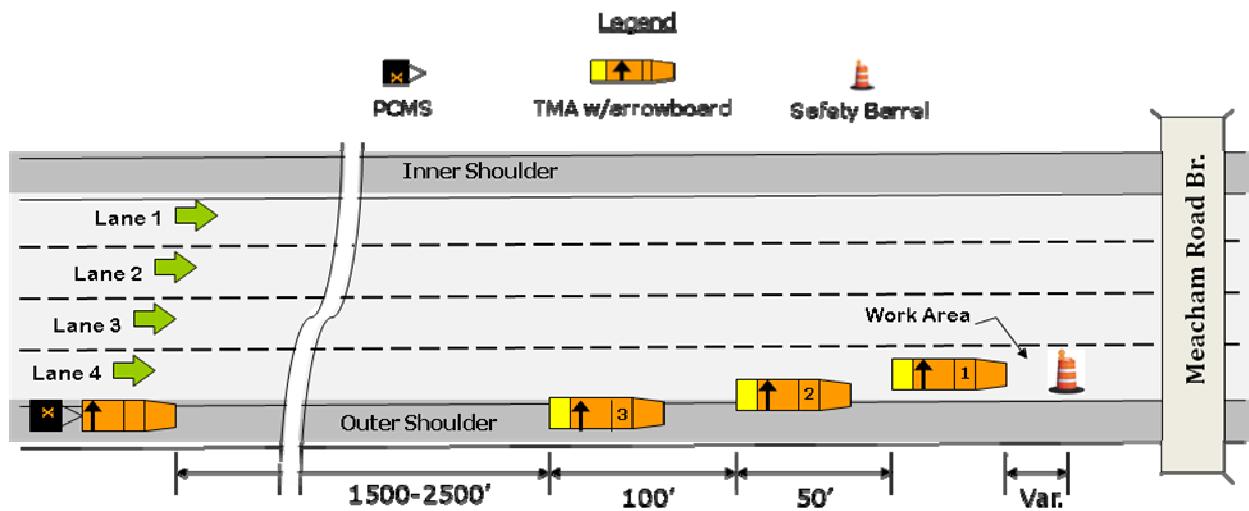


Figure 14. Traffic control setup used by M-5 for the field tests.

CUT-IN DISTANCE AND EFFECT OF WORK AREA LENGTH

The first tests were conducted in the I-90 eastbound lanes just west of the Meacham Road Bridge using a closure of the outer lane 4. At this location, lane 4 is actually an auxiliary lane beginning at Roselle Road and terminating as a ramp to IL-53 southbound. Therefore, drivers were motivated to reenter lane 4 following the lane closure to make their exit onto IL-53.

Cut-in distance was tested by placing a traffic barrel at variable distances in front of the lead TMA. Figures 15 to 19 show the results for five scenarios:

- No traffic barrel
- Barrels at 50, 100, 150, and 200 ft

The first vehicles typically entered at 50 ft, with a peak at 100 ft. Beyond 100 ft, traffic reentering the lane was significant but decreasing with distance from the work area. Figure 20 shows the distribution of cut-in distances was similar for all five scenarios, meaning it was independent of the length of the work area. Cut-in distances were similar for cars, SUVs, and MUVs, as shown in figure 21.

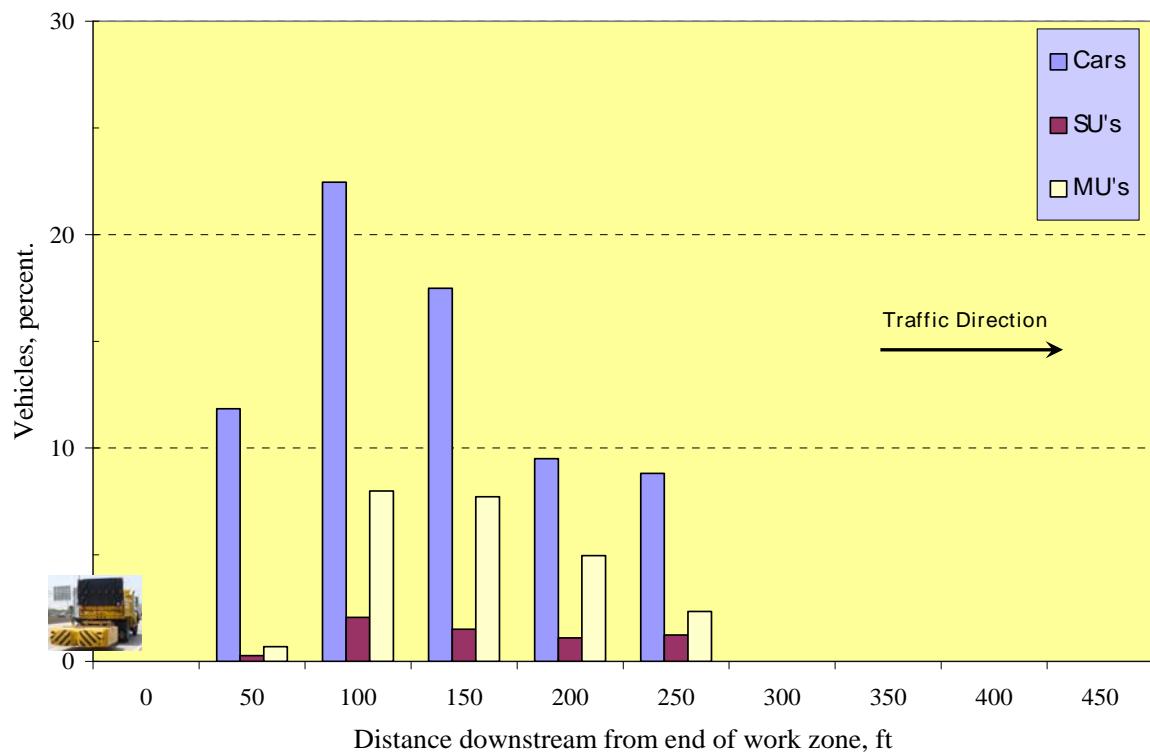


Figure 15. Cut-in distance with no work zone.

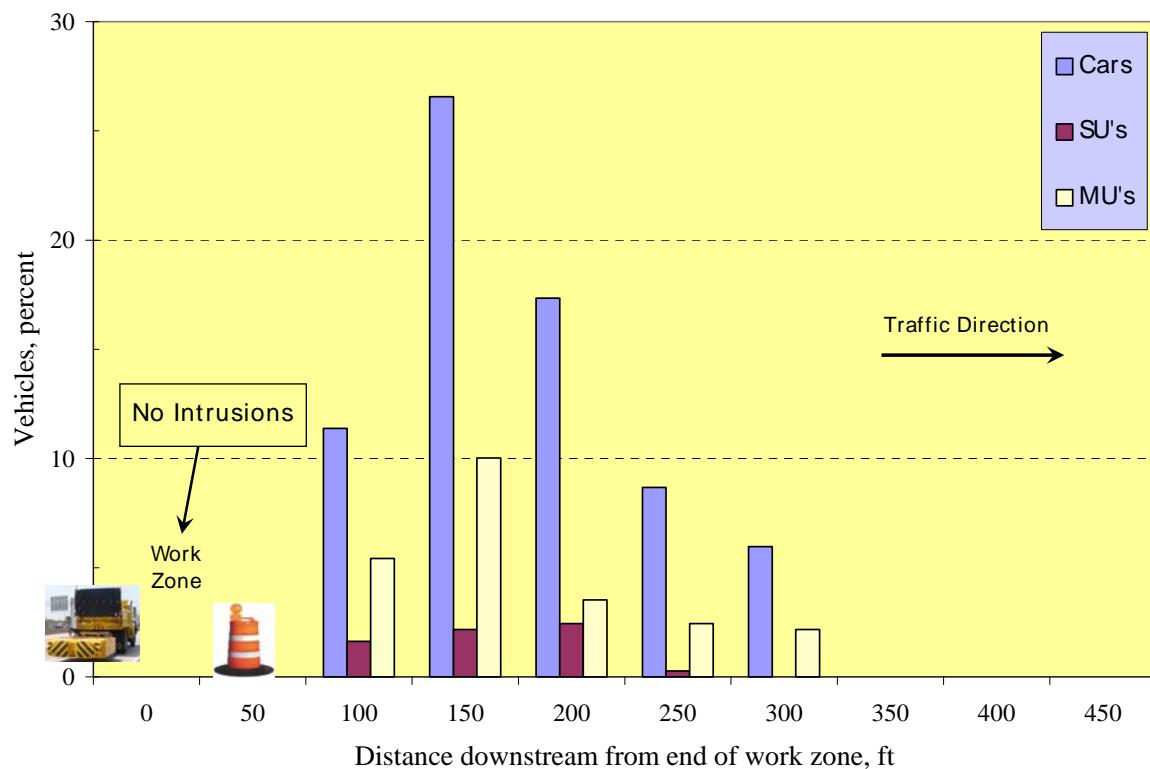


Figure 16. Cut-in distance with a 50-ft work zone.

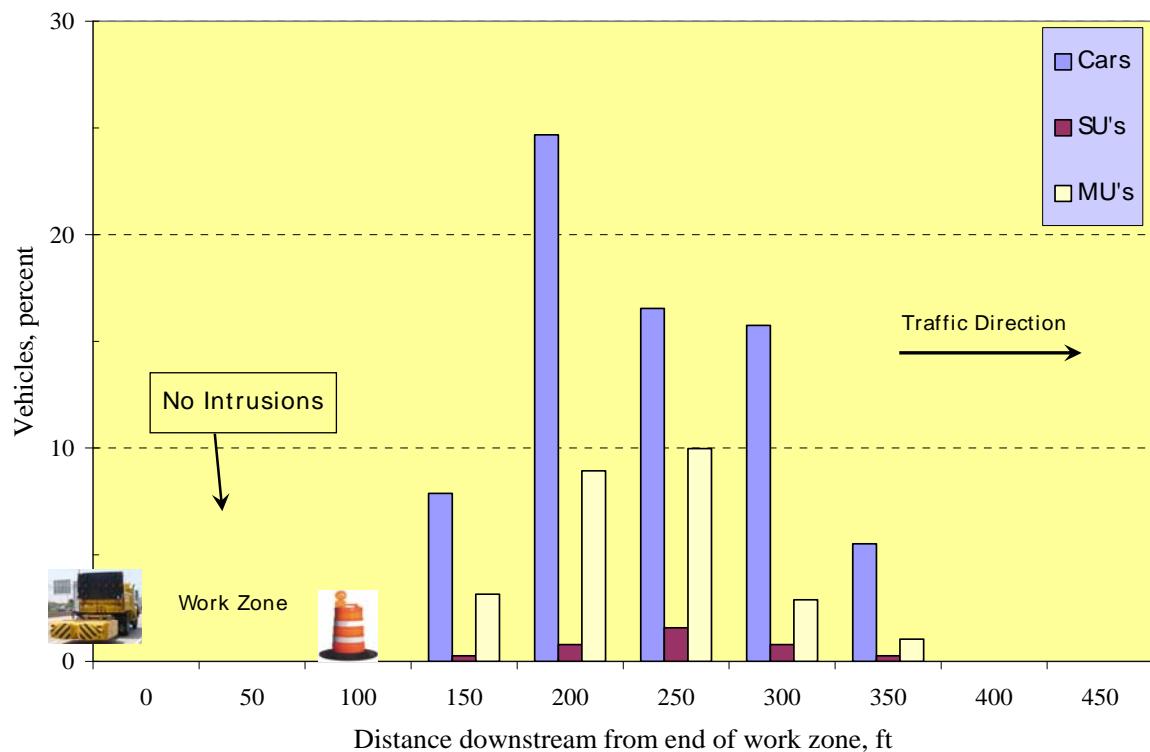


Figure 17. Cut-in distance with a 100-ft work zone.

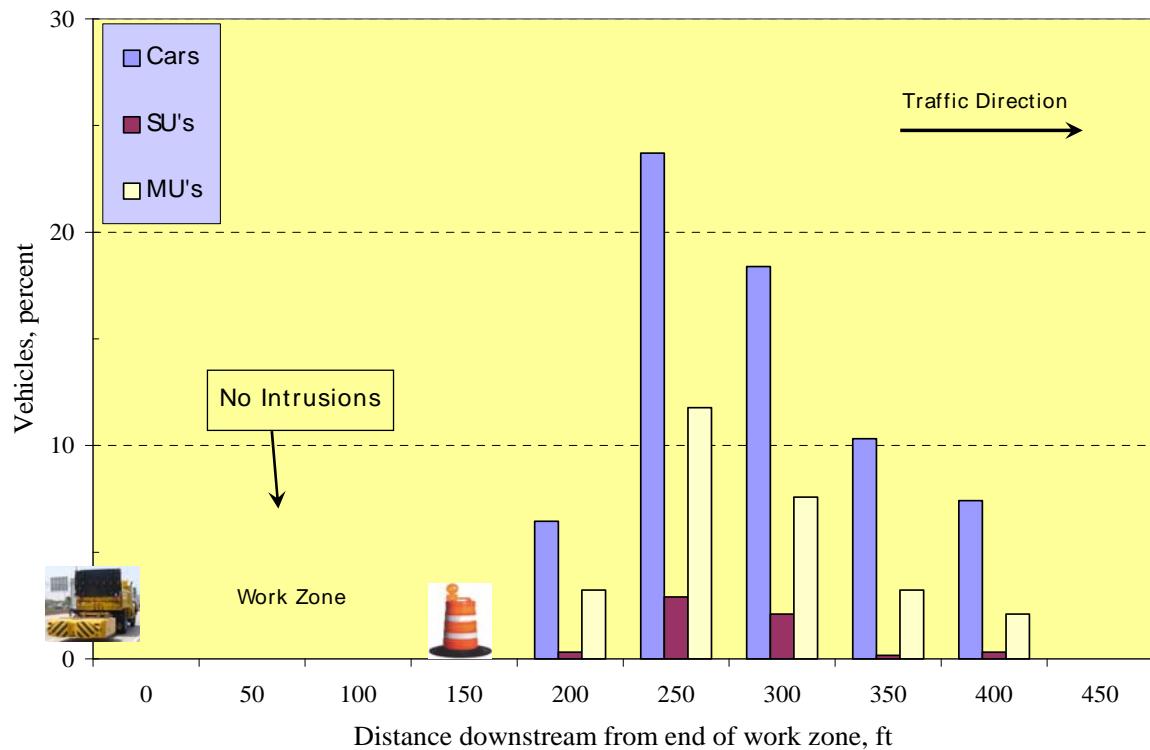


Figure 18. Cut-in distance with a 150-ft work zone.

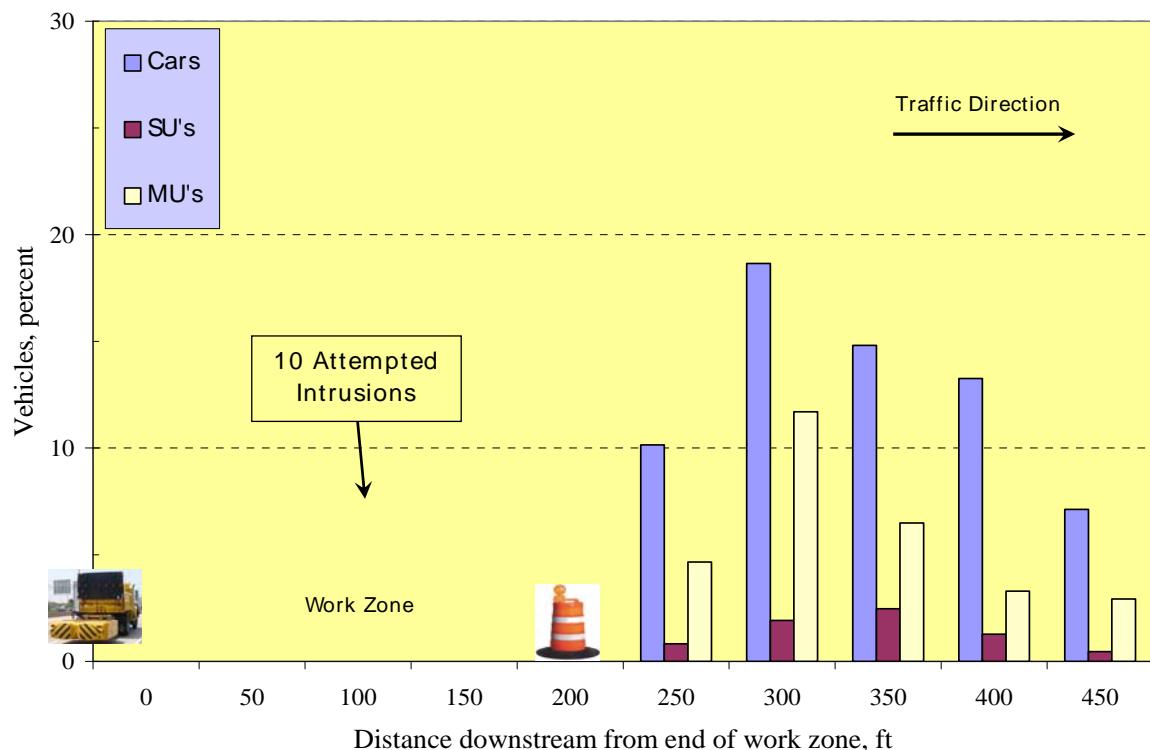


Figure 19. Cut-in distance with a 200-ft work zone.

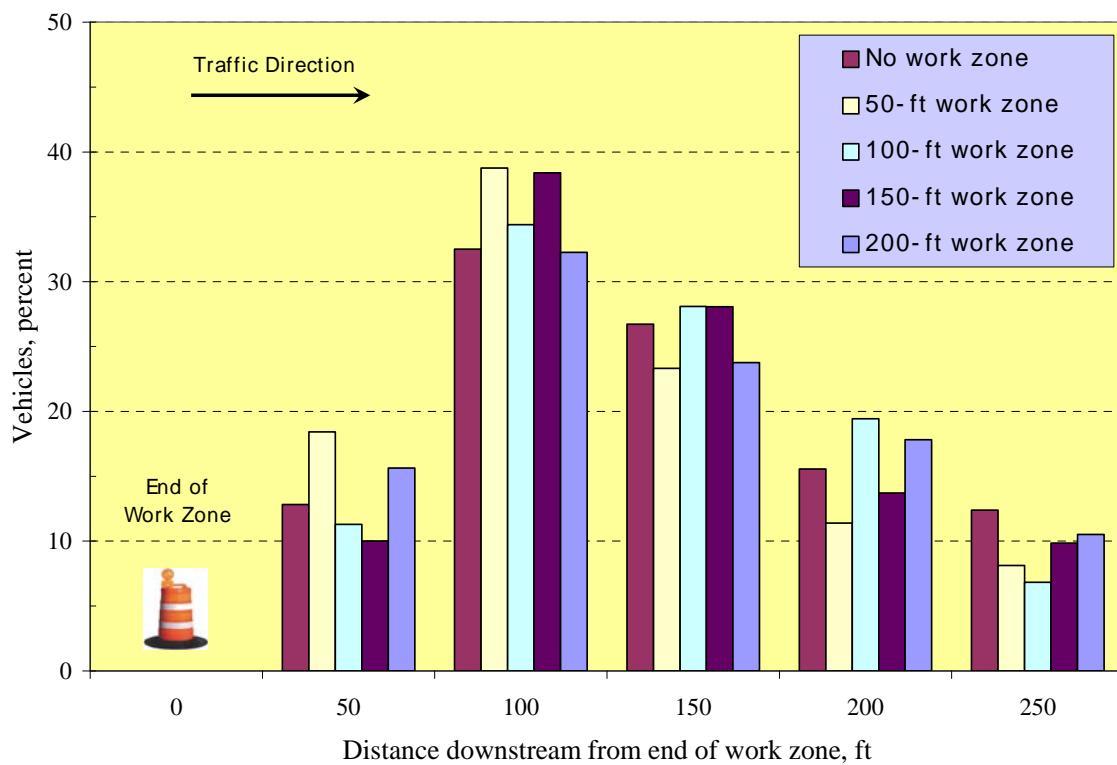


Figure 20. Cut-in distance for all vehicles—five scenarios.

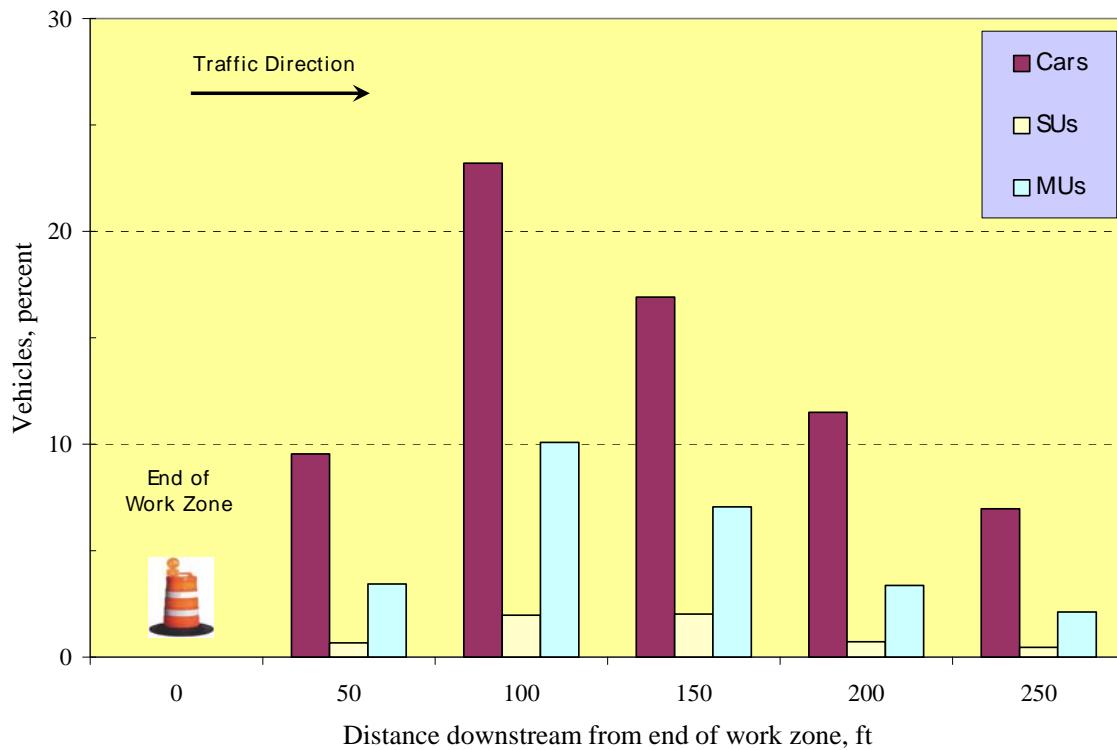


Figure 21. Mean cut-in distance for all scenarios by vehicle type.

The researchers also monitored the effect of work area length on lateral intrusions, or attempted lateral intrusions, into the work zone. Table 2 summarizes the results. As expected, for short work areas (50 to 150 ft), traffic did not attempt to reenter the closed lane prior to clearing the work area. However, at 200 ft drivers began swerving into the work area, believing that they had already cleared the work zone. In this case, 10 lateral intrusions (or attempted intrusions) were observed over a 48-min duration.

Table 2. Effect of Work Area Length on Lateral Intrusions—No Lead Truck.

Work Area Length, ft	Number of Lateral Intrusions
50	0
100	0
150	0
200	10 (swerves)

THE USE OF A LEAD TRUCK

The effect of placing a lead truck in front of the lead TMA in the closed lane was studied in much the same way as the buffer space experiment. The purpose of the lead truck is to increase the visibility of the work area to traffic as it passes the lead TMA, thereby reducing the possibility that motorists reenter the closed lane prior to clearing the work crew. In this experiment, a TMA was used as the lead truck and the following tests were performed:

- Work area length = 100 ft with a barrel placed at 50 ft

- Work area length = 200 ft with a barrel placed at 100 ft
- Work area length = 200 ft with no barrel
- Work area length = 300 ft with a barrel placed at 150 ft

As shown in Table 3, the lead truck scenario produced positive results for work area lengths up to 200 ft, even when no barrels were placed between it and the lead TMA. At 300 ft, traffic began reentering the lane prior to clearing the lead truck. In this case, four attempted intrusions were observed over a 16-min duration.

Table 3. Effect of work zone length on lateral intrusions—lead truck scenario.

Work Area Length, ft	Number of Lateral Intrusions
100	0
200	0
200 (no barrel)	0
300	4 (swerves)

ADVANCE WARNING AREA – WITH AND WITHOUT POLICE PRESENCE

The advance warning area was studied in the I-90 westbound lanes just west of the Meacham Road Bridge. The research team positioned cameras to monitor traffic patterns as vehicles approached the work zone. Specifically, they looked to see at what distance upstream traffic vacated the closed lane. Tests were conducted with and without police presence.

Figure 22 shows the cut-out results for the case of no police. Most vehicles changed lanes between 500 and 1200 ft upstream of the work zone, while the remaining vehicles merged from 100 to 500 ft upstream. Typically, vehicles took longer to change lanes if they approached the work zone in platoons. Interestingly, closure of the outer lane 4 did not cause congestion, and traffic was free flowing for the case of a lane closure with no police.

The effect having an ISP squad car on scene with lights activated was dramatic. Vehicle speeds decreased instantly, and within a few minutes traffic was backed up. This produced slow speeds both approaching and at the work zone, as well as more vehicles in lane 4 as motorists began saturating the lane upstream of the closure. Figure 23 shows the increase in traffic in lane 4 and the increase in vehicles approaching the work zone at a close distance, although at slow speeds.

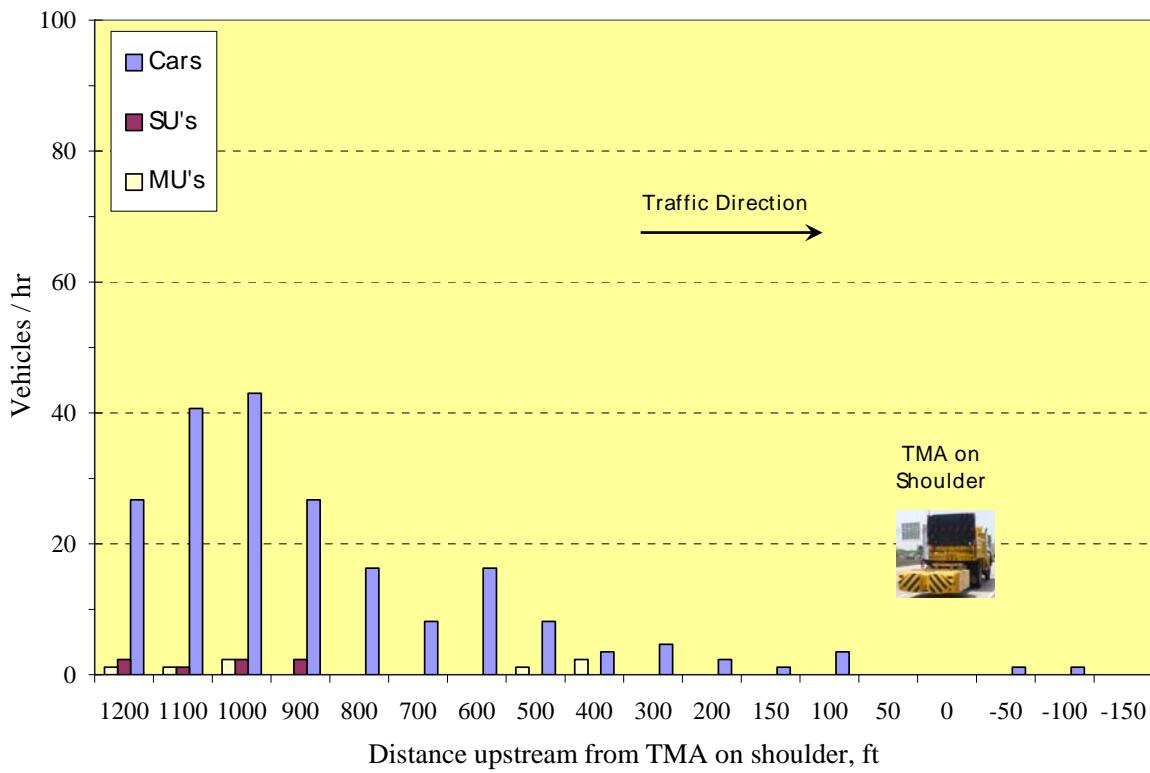


Figure 22. Cut-out distance—no police and free flowing traffic.

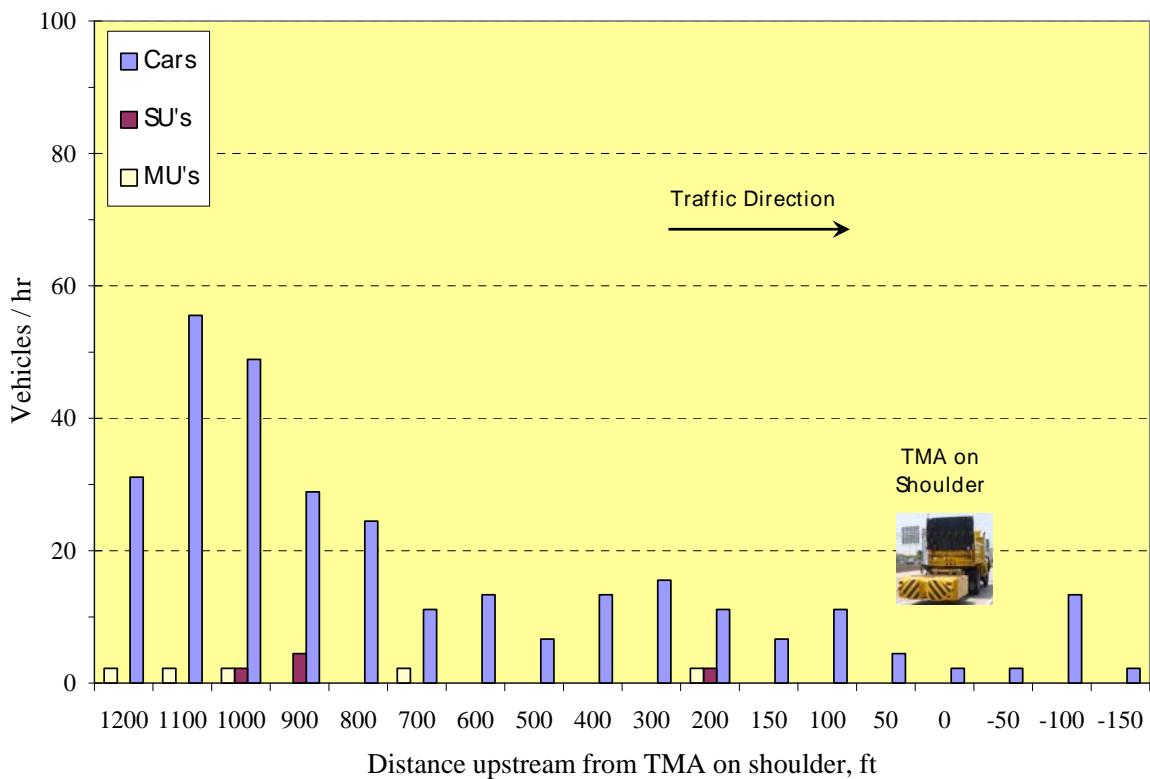


Figure 23. Cut-out distance—police and congested traffic.

VEHICLE SPEED DATA

An ISP trooper monitored vehicle speeds from an unmarked vehicle on the shoulder using LIDAR. Cars, SUs, and MUs were sampled in all the open lanes (1, 2, and 3). Speeds were recorded for the same vehicle at two locations—approaching the lane closure (approximately 1000 ft upstream) and at the work zone.

Figure 24 shows vehicle speeds for the cut-in distance tests conducted with congested traffic. Overall, speed averaged 30 mph for all vehicles in all lanes until congestion began to lift towards the end of the test period. Figure 25 shows that cars were typically 5 to 10 mph faster than trucks, and figure 26 illustrates that traffic in lane 3 adjacent to the lane closure was slowest, while lane 1 carried the fastest traffic. Traffic speeds between lanes 1 and 3 varied by as much as 30 mph. The posted speed limit for I-90 at this location is 55 mph.

Figure 27 contains the speed results for the advance warning tests performed with and without police. The dramatic effect of having police on the scene is obvious, as traffic conditions converted from free flowing to congested.

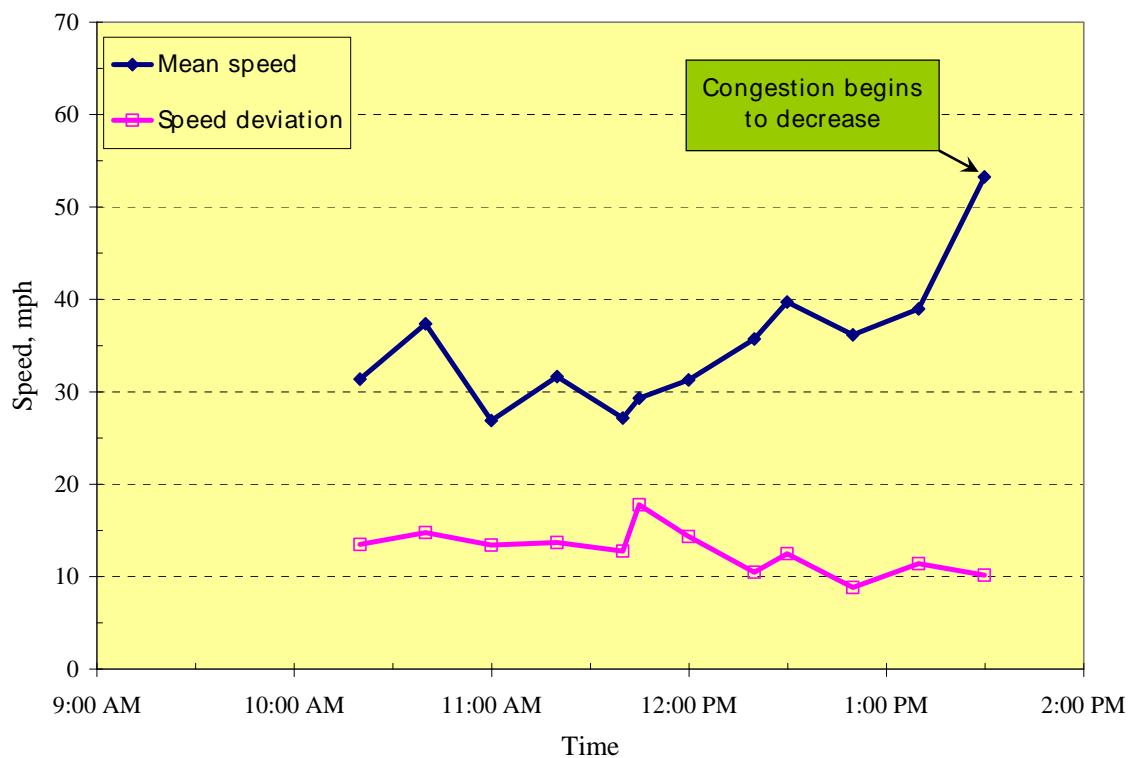


Figure 24. Traffic speed and deviation for all vehicles during the cut-in tests—congestion.

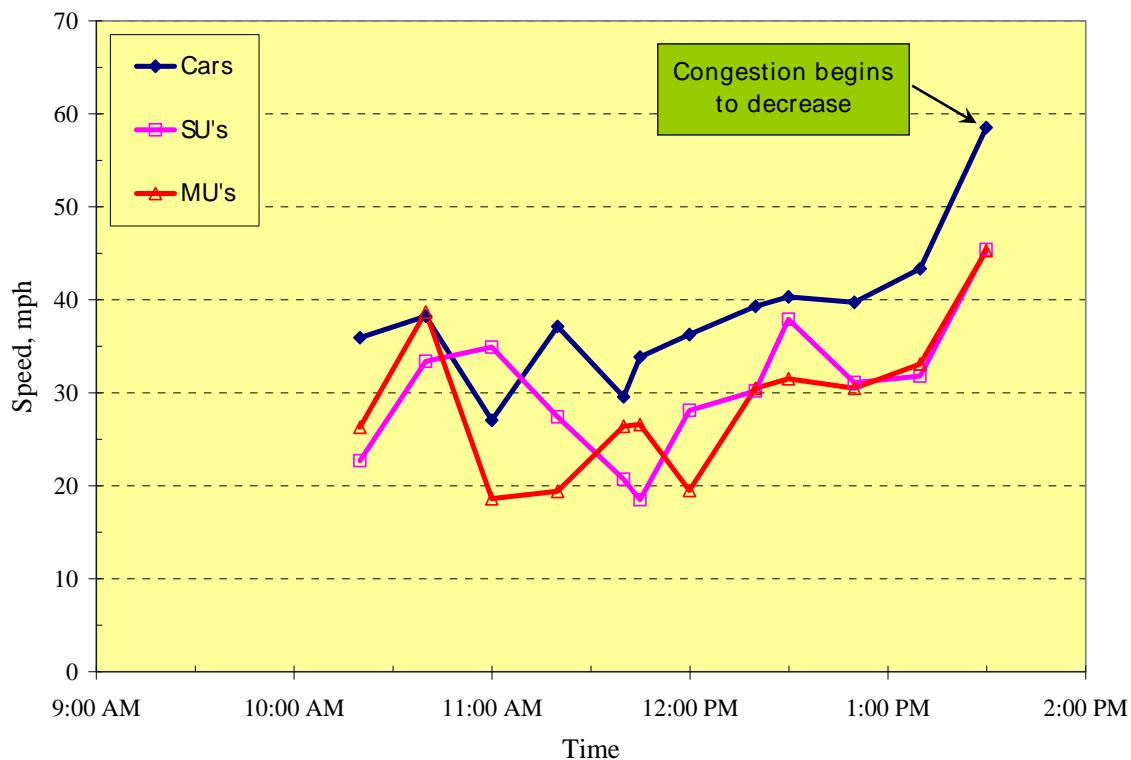


Figure 25. Speed by vehicle type.

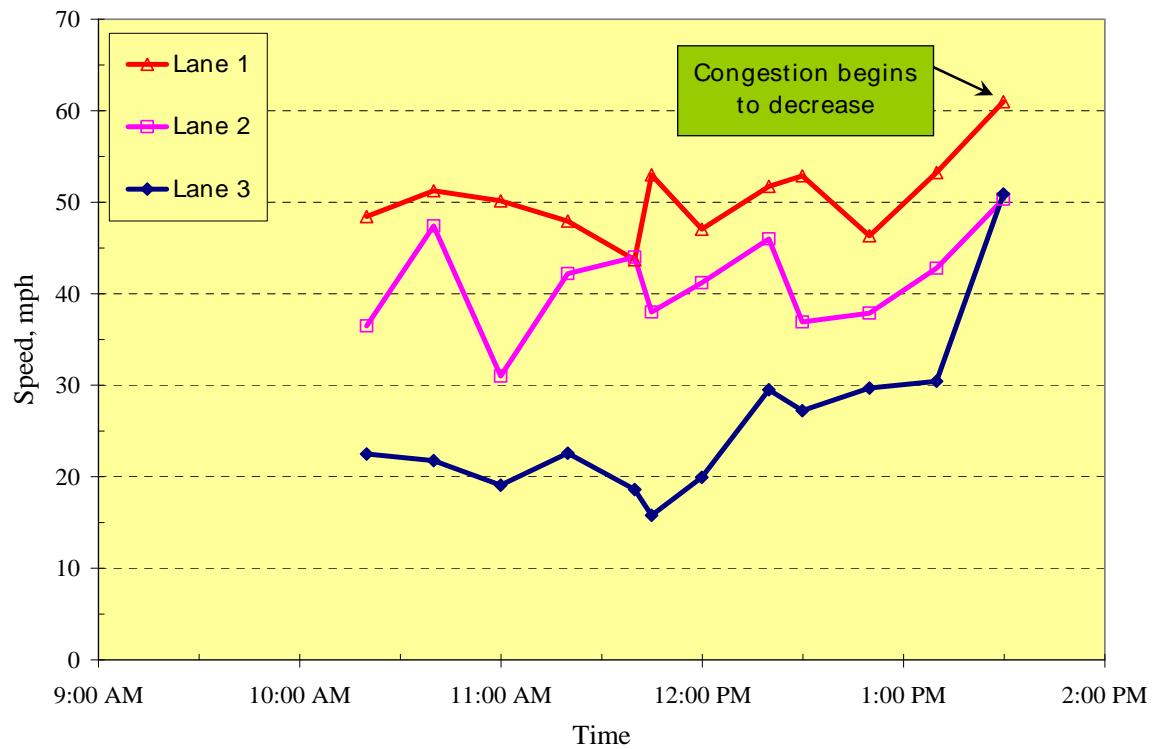


Figure 26. Speed by lane.

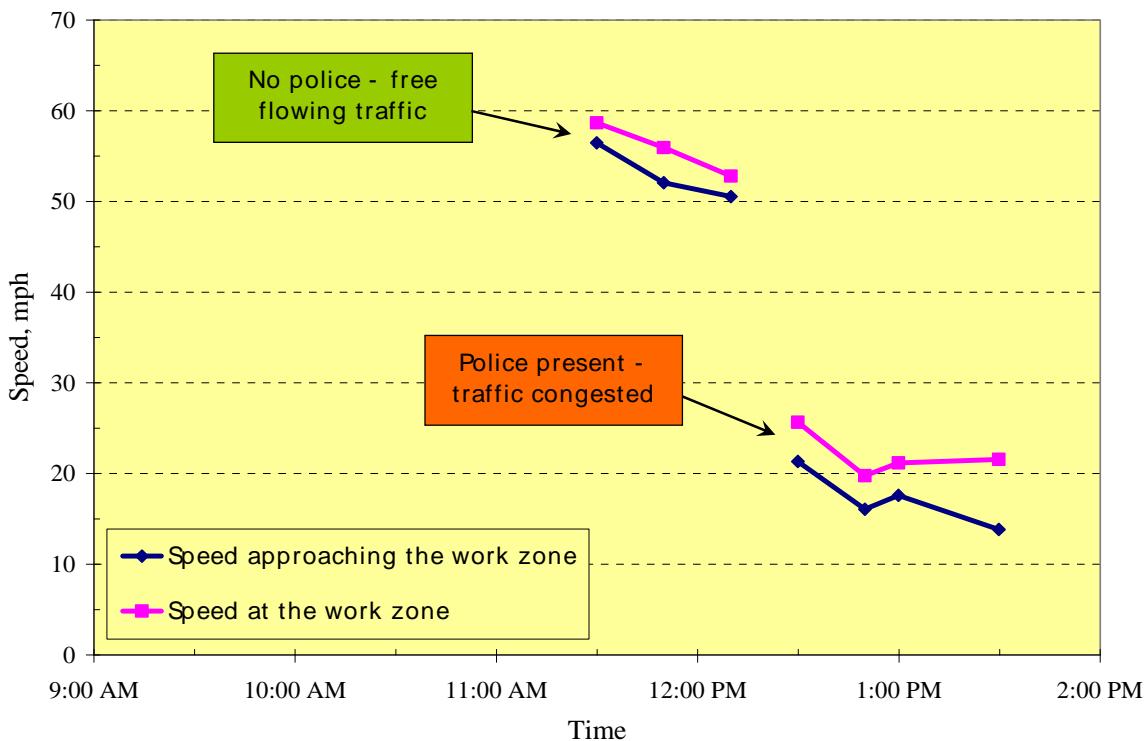


Figure 27. Effect of police presence on traffic speed—free flowing and congestion.

SUMMARY OF KEY FINDINGS—URBAN EXPRESSWAY, DAYTIME TRAFFIC

- **TMA truck spacing in urban areas is very tight, as is the distance from lead TMA to work crew.** ISTHA standards call for TMA spacing between 500 and 750 ft for moving operations. In our study, the transition length for all three TMAs totaled 150 ft. Short spacing between TMAs has evolved as a countermeasure to aggressive urban drivers who pose the risk of incursions if too much space is used between trucks. The same situation exists between the lead TMA and work crew, which typically work less than 50 ft apart.
- **Cut-in distances are short.** Under congested conditions and low speeds, traffic begins to reenter the closed lane approximately 50 ft after the work area. The peak reentry distance for both cars and trucks is 100 ft.
- **Lateral intrusions began when the work area length exceeded 150 ft.** When the distance between the lead TMA and traffic barrel ranged from 50 to 150 ft, no lateral intrusions occurred. At a spacing of 200 ft, vehicles began swerving into the work area prematurely.
- **Visibility and safety of workers is increased by use of a lead truck.** By placing an additional TMA in front of the work area (i.e., use of a lead truck in front of the workers), the work area length was increased to 200 ft without any lateral intrusions. At 300 ft, traffic began swerving in prematurely. The lead truck adds visibility and reduces the likelihood of errant vehicles entering the work area.
- **Under free flowing traffic conditions, the majority of vehicles vacated the closed lane from 500 to 1200 ft upstream.** Those that changed lanes at less than 500 ft typically approached the work zone in platoons and had difficulty merging with

traffic in the open lane. A few drivers dangerously waited until the TMA taper before changing lanes.

- **Police presence has a dramatic effect.** Traffic reduced speed immediately when an ISP squad car with lights activated was positioned at the work zone. Eventually, the slower speeds caused congestion, and average free flow speeds of 55 mph were reduced to 20 mph. The peak cut-out distance still occurred 500 to 1200 ft upstream; however, more vehicles occupied lane 4, and more vehicles closely approached the work zone closely (22.8 percent came within 500 ft), and 6.2 percent entered the TMA taper before changing lanes.
- **Traffic in lanes further away from the closed lane moves faster.** Traffic in lanes 1 and 2 moved up to 30 and 20 mph faster than lane 3, when lane 4 was closed. As congestion decreased, lane 3 speeds increased, approaching those of lane 2. Cars averaged 5 to 10 mph faster than trucks.

SITE 2 – I-88 AT SOMONAUK ROAD, DEKALB

SITE DESCRIPTION— RURAL INTERSTATE, LOW TRAFFIC VOLUMES

The research team conducted field tests on I-88 at the Somonauk Road Bridge near Dekalb on June 3-5, 2008, (figure 28) to provide a contrast between rural and urban traffic patterns. The main items investigated were cut-in distance, cut-out distance, the effect of various messages on vehicle speed, and police presence. At this location, I-88 consists of four lanes in each direction with a one-way ADT of approximately 13,500 vehicles per day, including a high percentage of truck traffic.

Weather conditions for the I-88 testing were highly variable, ranging from rain to fog to clear. No testing was performed during the rain or when visibility was less than a mile. All testing was done during the day. According to ISTHA personnel, most maintenance and repair operations are carried out during the daytime at this location and involve either blocking of a shoulder or a single-lane closure. Closing of the inner lane 1 to repair the safety cable system is very common.

Traffic at this location is generally free flowing and fluctuates seasonally and daily due to commuter traffic traveling to the university at Dekalb. ISP monitored traffic speeds using LIDAR, similar to the I-90 study.

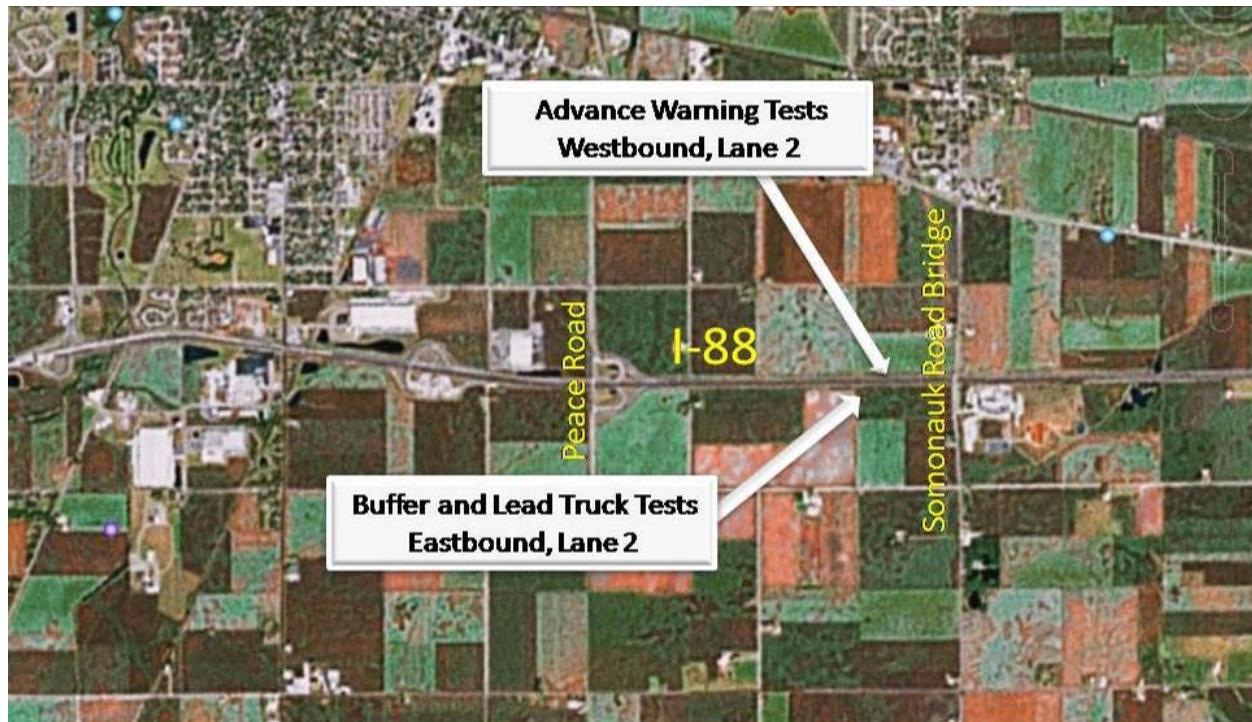


Figure 28. Aerial view of the I-88 test site at Somonauk Road, Dekalb.

TRAFFIC CONTROL SETUP

Traffic control was provided by ISTHA Maintenance Yard 11 (M-11) using the setup shown in figure 29. This consists of four TMAs and a pickup truck-mounted message board placed approximately 0.25-0.50 mi upstream of the work zone. Frequently, the supervisor's pickup will accompany the work crew and serve as a lead truck.

In contrast to the tight truck spacing used in the urban areas in M-5, the rural environment and driver habits of M-11 permit greater spacing between trucks. In this case, the four trucks were spaced at intervals of 500 ft, resulting in a transition length of 1500 ft. Also, with four TMAs at their disposal, the traffic control crew is able to form a much longer, gradual taper, as each truck closes just a third of the lane at a time.

The portable truck-mounted message board used in M-11 is smaller than the trailer-mounted type used in M-5. This has the advantage of making the message board more maneuverable, but it is less visible due to the smaller letters. The typical message used in M-11 is "Right (or Left) Lane Closed."

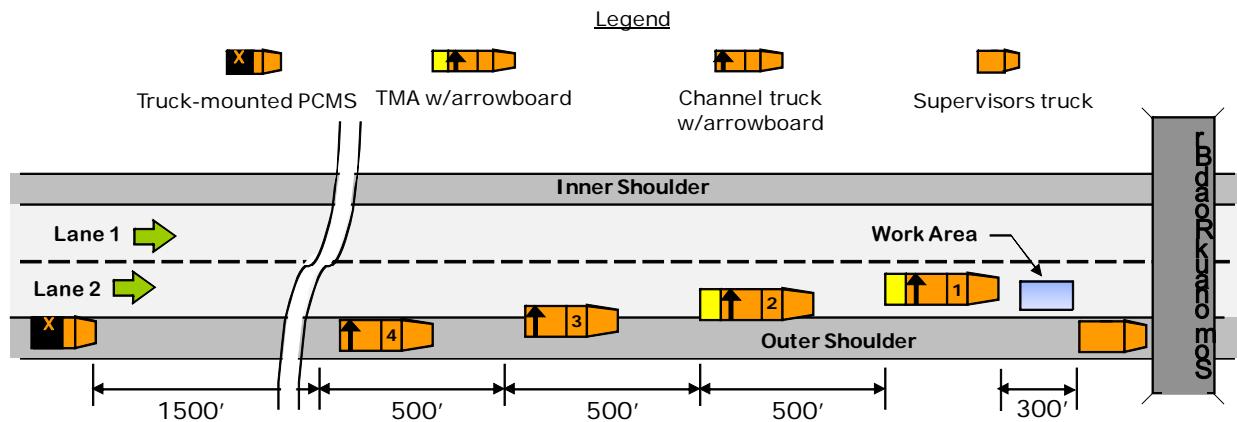


Figure 29. Typical ISTHA M-11 traffic control setup.

BUFFER AREA AND LEAD TRUCK TESTS

The traffic coming around the lead TMA in the work area on June 3-4 between 9 a.m. and 2 p.m. was studied, as weather permitted. The first tests were conducted with reference cones placed along the outside shoulder and median for use as distance reference in video data analysis. However, preliminary field observations suggested that the presence of cones in a rural setting may influence some drivers' decisions on when to pull back into the closed lane, so the cones were removed for the second day of testing. Tests were conducted in the I-88 eastbound lanes just west of the Somonauk Road Bridge using a single lane closure in the outer lane 2. There are no ramps or other obstructions in this area.

Figures 30 and 31 present the cut-in results with and without the foreman's truck on the shoulder. The data show that with no lead truck in front of TMA1, vehicles typically began reentering the lane at 100 ft past the TMA. The majority of traffic returned to the lane 150 to 450 feet beyond the TMA. As seen in figure 31, placing the supervisor's pickup on the shoulder 300 ft in front of TMA1 had a positive effect. Traffic delayed reentering the lane until 175 ft beyond the TMA, and the majority of traffic entered from 250 to 600 ft downstream.

Traffic was free flowing and averaged approximately 55 mph. As seen in figure 32, according to LIDAR measurements, approaching speeds were very similar to speeds at the work zone. Given that traffic passed the work area at speeds less than the posted limit of 65 mph, this may indicate that traffic reduced speed prior to coming into our LIDAR's range.

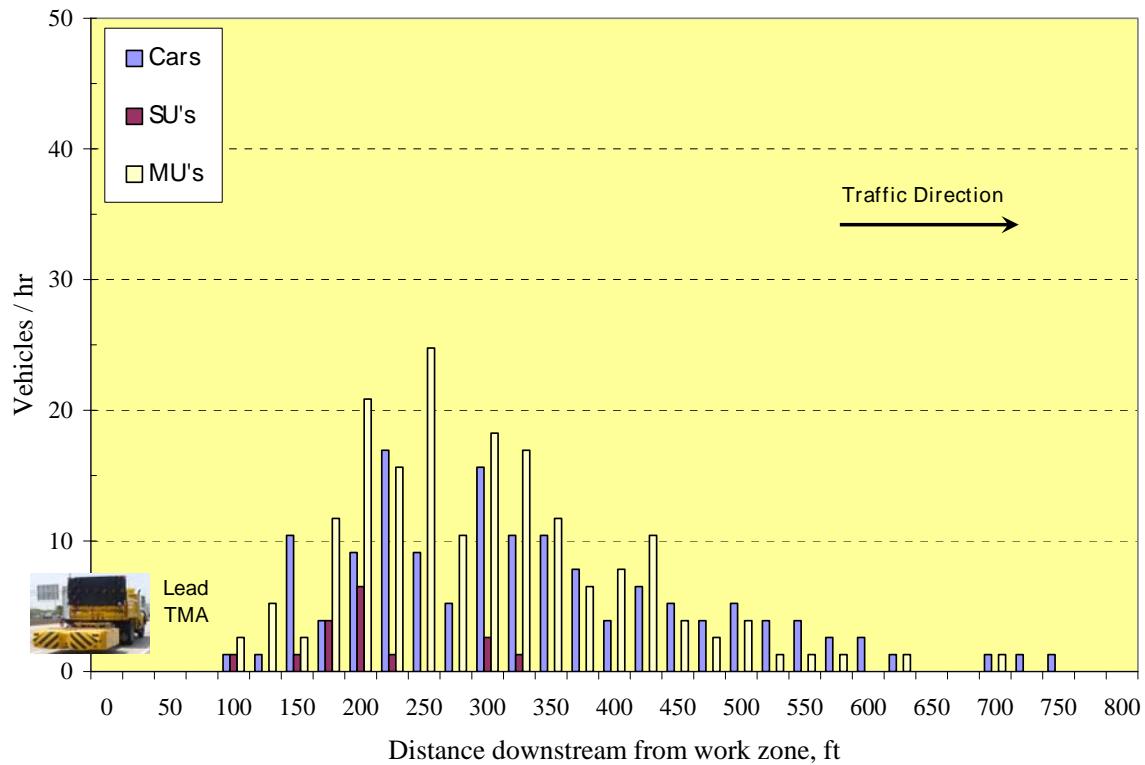


Figure 30. Cut-in distance without the supervisor's truck.

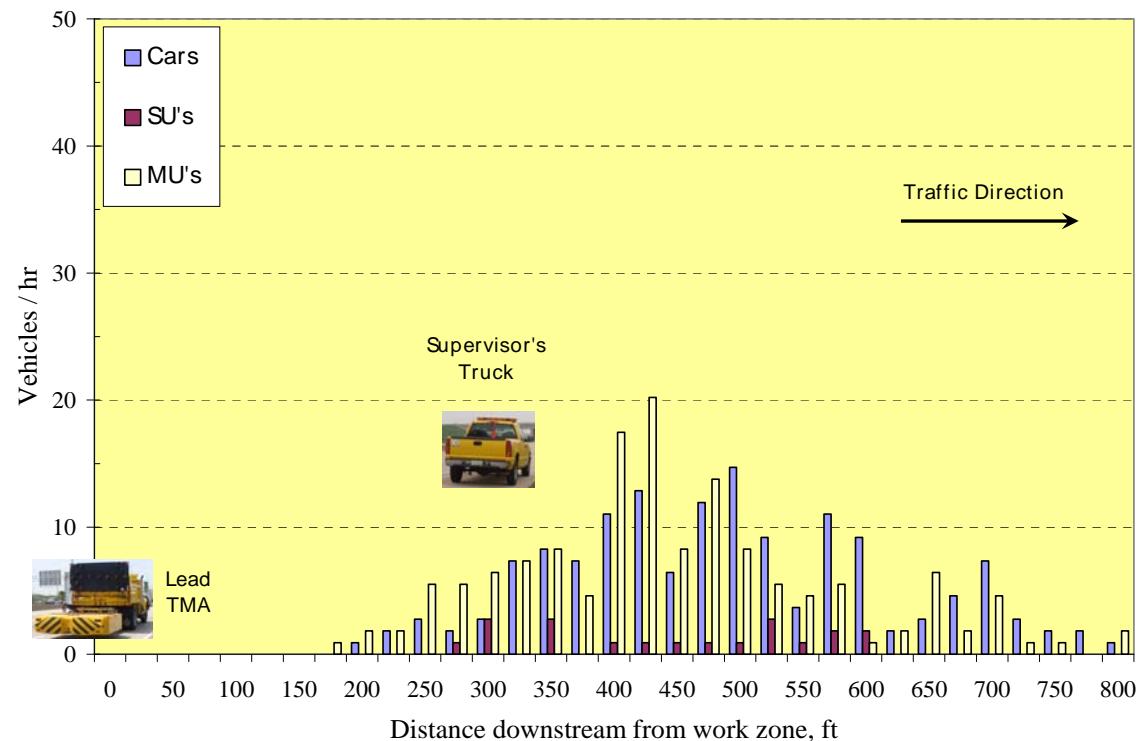


Figure 31. Cut-in distance with supervisor's truck parked at 300 ft on shoulder.

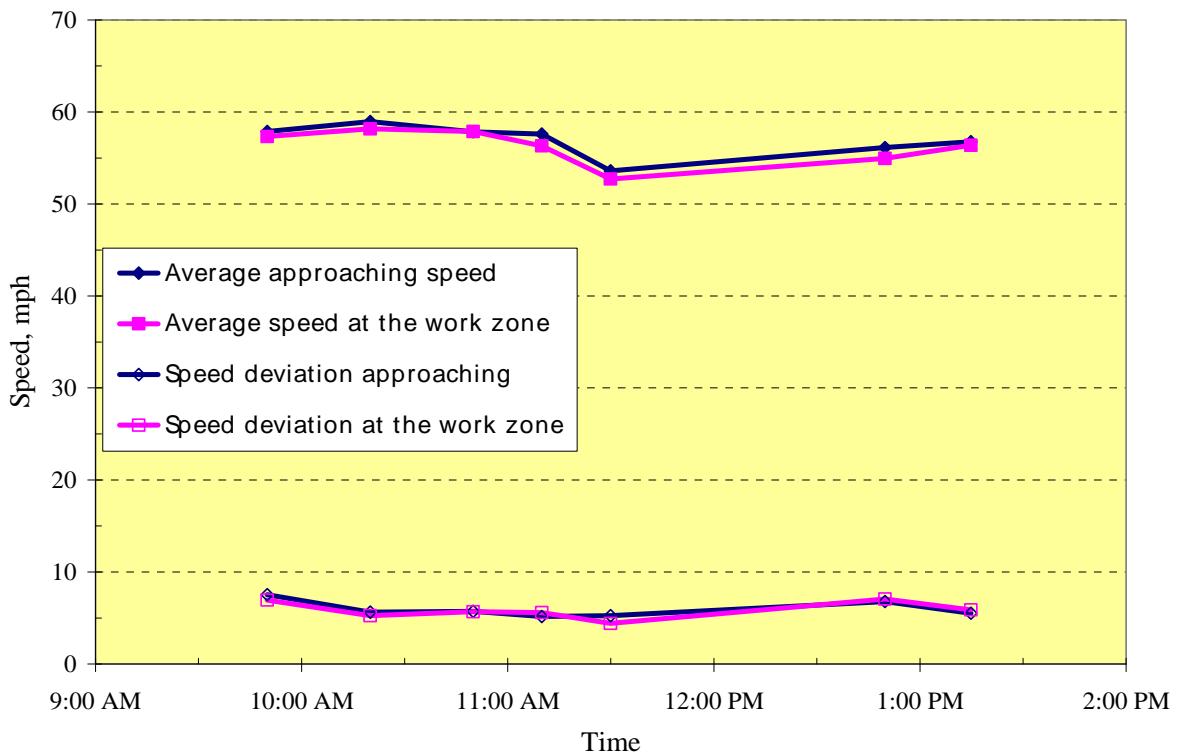


Figure 32. Traffic speed and deviation during the buffer tests—free flow conditions.

EFFECT OF POLICE PRESENCE IN THE ADVANCE WARNING AREA

The advance warning area was studied in the I-88 westbound lanes just west of the Somonauk Road Bridge. Cameras were positioned to monitor traffic patterns as vehicles approached the work zone. Specifically, the researchers were looking to see at what distance upstream traffic vacated the closed lane. Figure 33 shows the traffic control setup.

Figure 34 presents the cut-out distances with and without police presence. The figure shows the percentage of vehicles that vacate the closed lane at five distances relative to the first truck in the TMA taper (i.e., the shoulder TMA):

- > 3000 ft Prior to reaching the observation zone
- 3000 to 2200 ft The start of observation zone to the truck-mounted PCMS
- 2200 to 400 ft The PCMS to the ISP squad car
- 400 to 0 ft The ISP squad car to the shoulder TMA
- < 0 ft Downstream of the shoulder TMA

The results show that fewer vehicles approached the work zone in the closed lane at less than 500 ft when the police car was present with lights activated. For example, with no police present, 5.6 percent of all traffic came within 500 ft of the work zone prior to merging, whereas just 0.7 percent of traffic came within 500 ft of the work zone with the ISP car on site.



Figure 33. Overview of the advance warning setup on I-88, no police.

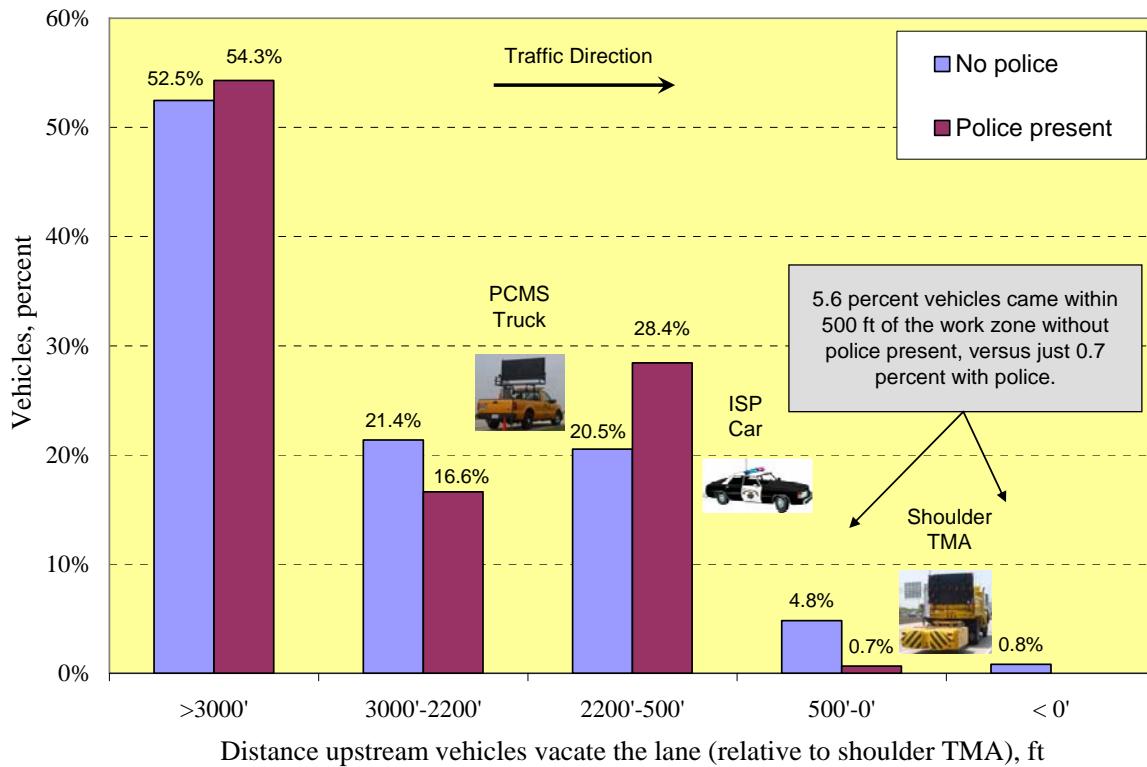


Figure 34. Cut-out distance with and without police present.

EFFECT OF VARIOUS MESSAGES ON VEHICLE SPEEDS

Figure 35 presents the speed results for various messages programmed on the PCMS. Three different messages were used:

- Right Lane Closed
- Alternating Messages: Right Lane Closed. Reduce Speed
- Alternating Messages: Right Lane Closed. Reduce Speed 45 MPH

In addition, an ISP squad car with lights activated was placed on the shoulder approximately 600 feet upstream of the work zone. The “Right Lane Closed” message was displayed during the police presence.

Figure 35 shows the speed results for all four variations. There was little difference between the “Right Lane Closed” and the “Reduce Speed” variations, with traffic averaging about 63 mph in both cases. The “Reduce Speed 45 MPH” variation did show a speed decrease of about 5 mph, while the police presence had the greatest effect, decreasing traffic speeds by 10 mph. In all cases, the speed at the work zone was lower than the approach speed, showing that free flowing rural traffic slows down about 5 mph as it approaches the work zone.

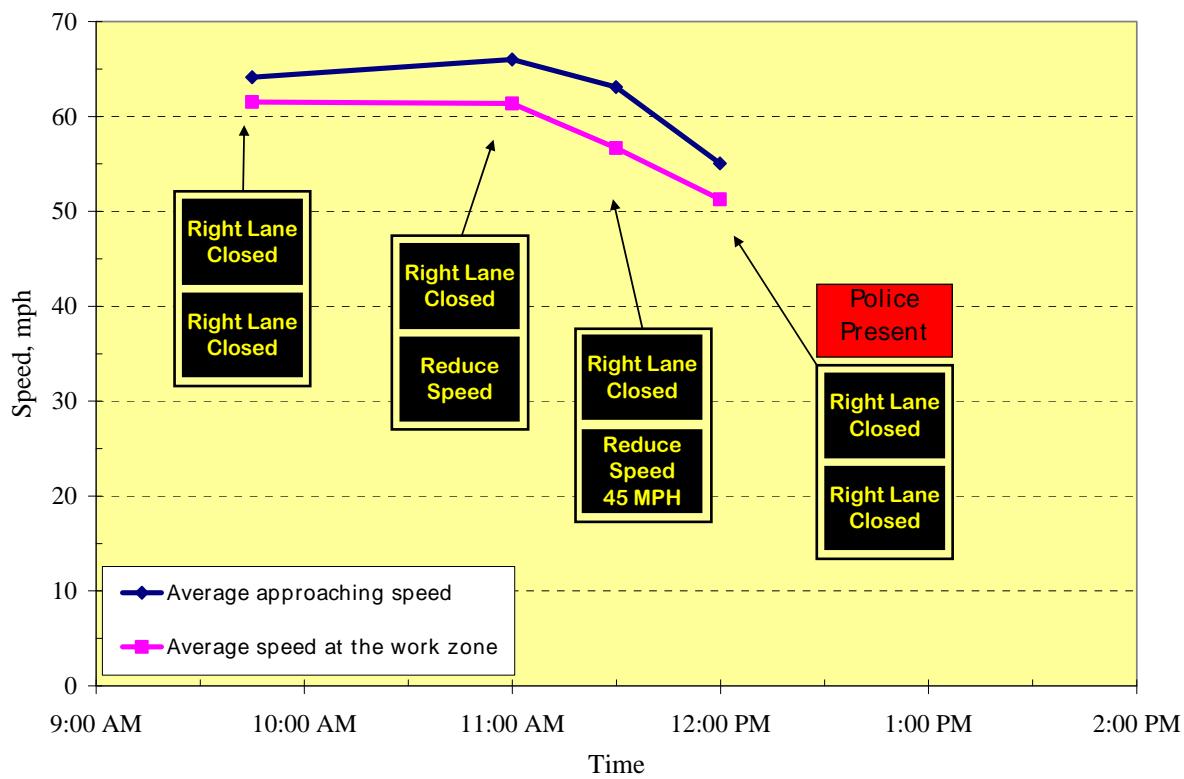


Figure 35. Effect of various messages and police presence on speed, I-88.

SUMMARY OF KEY FINDINGS—RURAL INTERSTATE, LOW TRAFFIC VOLUMES

- **Rural and urban conditions are very different; therefore, the techniques used by traffic control crews are different.** The M-11 garage typically uses four trucks spaced 500 ft apart each to close the lane. This is possible as the potential for

incursions is less than in an urban environment. Longer spacing between trucks provides a longer transition zone and more time for drivers to change lanes upstream of the work area. The one disadvantage of rural highways is the higher speed limit (65 mph).

- **Rural traffic leaves the lane sooner and waits longer to come back in, relative to urban drivers.** The earliest cut-in distance for traffic on I-88 was 100 ft, and the majority entered at 150 to 450 ft beyond the work zone. The advance warning tests showed that 73.9 percent of the traffic had vacated the closed lane by the time it reached the PCMS located 1800 ft upstream of the TMA taper.
- **Traffic responds to flashing vehicles on the shoulder.** With the supervisor's truck placed on the shoulder 300 ft in front of the lead TMA, traffic delayed returning to the lane until 175 ft, with the majority of vehicles reentering between 250 and 600 ft. This simple technique made a large improvement to the safety conditions in the work area.
- **Alternative PCMS messages made minor reductions to vehicle speed.** Alternating the message "Reduce Speed 45 MPH" with the standard "Right Lane Closed" message showed a speed reduction of about 5 mph. While this may not seem a large improvement, it does show that sign wording can have an effect in rural areas. A trailer-mounted PCMS with larger letters may have more effect.
- **The presence of the PCMS itself may influence motorists more than the message.** It was observed that many motorists changed lanes far upstream of the PCMS, even before they could read the message. Also, many times once the vehicles were beyond the PCMS they returned to the closed lane, in spite of the text warning. This indicates that motorists are responding to the presence of a flashing vehicle on the shoulder (i.e., Scott's law), rather than reading the message itself. This is a concern during lane 1 closures, because the PCMS actually is located on the outer shoulder due to width restrictions on the median side. In this case, the PCMS could be pushing traffic into the closed lane unintentionally.
- **Police had a positive effect on both cut-out distance and vehicle speeds.** Placing an ISP squad car with lights activated near the work zone reduced the number of vehicles approaching the TMA taper in the closed lane from 5.6 to 0.7 percent. Vehicles speeds were reduced by 10 mph.

SITE 3 – I-290 AT LARAMIE AVENUE, CHICAGO

SITE DESCRIPTION— HIGH-VOLUME, URBAN EXPRESSWAY WITH RAMPS

The third set of field tests were conducted on I-290, the Eisenhower Expressway, at the Laramie Avenue Bridge, Chicago (figure 36). Tests were performed during the hours of 10 a.m. to noon on May 17-18, 2008. At this location, I-290 consists of four lanes in each direction with a one-way ADT of approximately 180,000 vehicles per day. Testing was conducted in the westbound outer lane 4 east and west of the bridge. East of the bridge there is an auxiliary fifth lane that runs between the Cicero Road on ramp and the Laramie Avenue off ramp. The section tested was a tangent; however, a reverse curve just upstream of the site limited visibility leading up to the test section.

This site was selected to represent IDOT's high-volume, urban expressways. Specifically, this section contains closely spaced on and off ramps that present a unique challenge for moving lane closures due to weaving traffic at the ramps. The main aspects studied at the I-290 site were cut-in distance, traffic conflicts in the advance warning area due to ramps, and spacing between TMAs.

The weather was clear during the I-290 testing and did not pose a hindrance to the traveling public or work crew. In general, the high-volume traffic was free flowing until the traffic control trucks entered the highway and closed the lane. Several times throughout the test periods the lane closure was removed to allow congestion to clear out. According to IDOT personnel, at this location most maintenance and repair operations are carried out during the daytime. Moving lane closures typically are limited to 15-min durations to avoid excessive congestion. Programmed activities requiring more than 15 min are performed under stationary lane closures using advance warning signs and barricades. The posted speed limit is 55 mph.



Figure 36. Aerial view of the I-290 test site at Laramie Avenue, Chicago.

TRAFFIC CONTROL SETUP

IDOT's Eisenhower maintenance yard provided traffic control using the setup shown in figure 37. The setup consists of three TMAs—two to close the lane and one lead TMA to close the lane—and an advance warning truck. For our testing only, an additional trailer-mounted message board was placed approximately 0.5 mi upstream of the work zone. Typically, a large dump truck, referred to as a “bomber,” is placed on the shoulder to prevent traffic from passing on the shoulder.

The truck configuration used on I-290 was unique from the other test sites in two ways: it used only two trucks to close the lane (one TMA on the shoulder and the next TMA fully in the closed lane), and it used a lead TMA several hundred feet in front of the first TMA blocking the lane. This was the only traffic control setup we studied that did not use a straddler TMA, resulting in a very abrupt lane closure. IDOT's experience is that a straddler truck does not function well with aggressive, urban motorists. The TMA lead truck is beneficial in case a collision occurs at the first TMA blocking the lane, as it provides more distance between the work crew and the point of impact.

For the testing, the spacing between all three TMAs ranged from 400 to 500 ft, significantly less than the 1000-ft recommendations in the IDOT manual for moving lane closures. The distances specified in the manual typically are too generous for urban conditions, where aggressive drivers are prone to weaving in and out of traffic control vehicles if the spacing is too great.

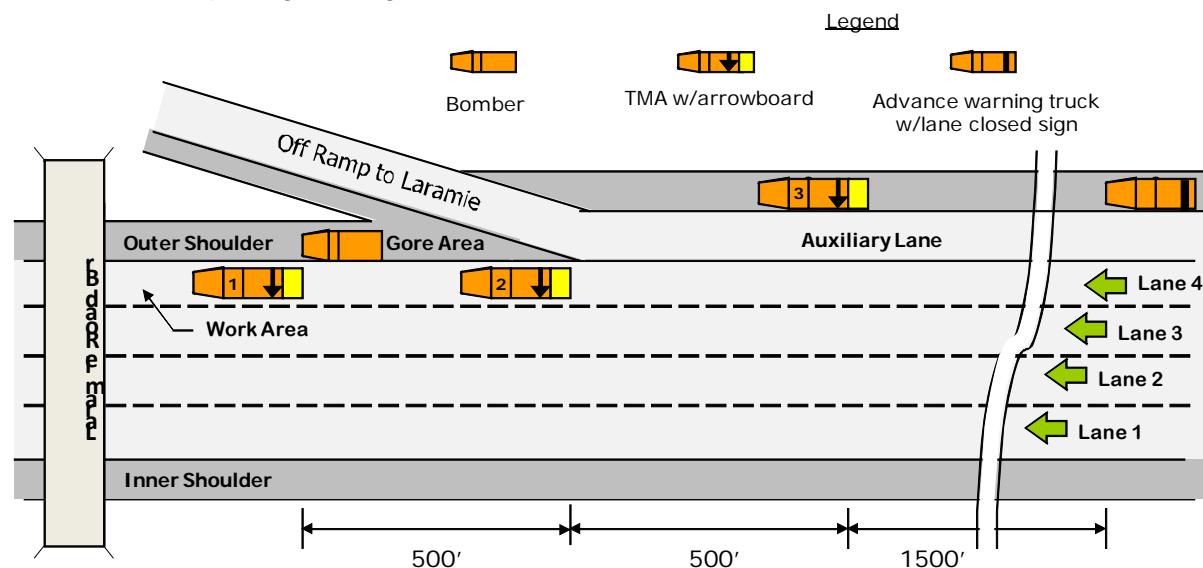


Figure 37. Traffic control setup used by IDOT District 1 personnel during the field tests.

CUT-IN DISTANCE IN FRONT OF THE LEAD TMA

The first day of testing took place just east of the Laramie Avenue Bridge in the outer lane 4. This placed the shoulder TMA on the shoulder of the auxiliary lane leading to the Laramie Avenue off ramp. TMA2—the first truck blocking the lane—was adjacent the gore area. Many traffic conflicts occurred around TMA2, typical of work performed in ramp areas. Figure 38 shows the cut-in distances. Vehicles reentered the lane as early as 20 ft beyond the lead TMA. The majority of traffic returned to the closed lane between 40 and 160 ft beyond the lead TMA.

INCURSIONS BETWEEN TMAS

A camera placed in TMA2 monitored the buffer space between it and the lead TMA. Table 4 summarizes the type and number of conflicts occurring in this area in a 30-minute period.

Table 4. Summary of traffic conflicts between TMA2 and the lead TMA.

Type of Conflict	Number of Conflicts
Traffic in the open lane 3 swerving in and out of the closed lane between the two TMAs	7 (all cars)
Vehicles on the Laramie Avenue off ramp crossing the gore area between the two TMAs to reach lane 3	13 (12 cars and 1 SU)
Traffic moving from lane 3 across the gore area between the two TMAs to reach the Laramie Avenue off ramp.	1 (car)

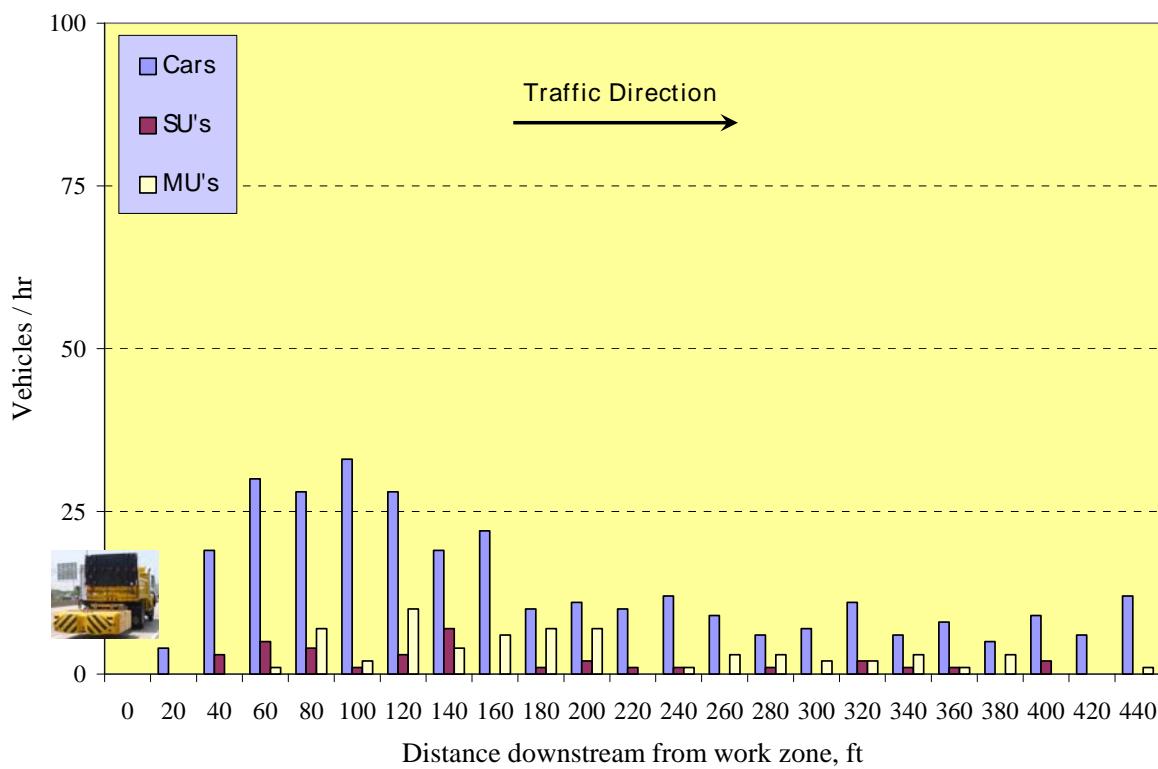


Figure 38. Cut-in distance—congested traffic.

As seen, working next to a ramp is inherently conflictive. Many vehicles were observed using the off ramp as a bypass of the work zone, intending to use the frontage road instead of staying on I-290, but cutting back across the gore area as they realized it was a short work area.

CUT-OUT DISTANCES IN THE ADVANCE WARNING AREA

The advance warning area was studied by positioning the convoy of trucks just west of the Laramie Avenue Bridge, such that the shoulder TMA was just west of the bridge and

TMA2 was 200 ft ahead. This placed the lead TMA near the exit ramp to Central Avenue. The advance warning vehicle and trailer-mounted message board were positioned upstream, as in previous scenarios. Traffic was free flowing prior to the lane closure but soon became congested.

Figure 39 shows the cut-out distances. The distribution of lane changes is fairly even from 100 to 320 ft, with a minor peak just before the shoulder TMA at 240 ft and a large peak just before TMA2 at 20 ft. Many vehicles were blocked from merging earlier by heavy traffic in the adjacent lane 3. Several vehicles came to a stop just behind TMA2 until they were able to change lanes. Congested traffic was moving slowly at 20 mph.

TMA2 was moved forward 100 ft to see if the additional space between it and the shoulder TMA allowed traffic to change lanes without approaching it so closely from behind; however, as seen in figure 40, traffic followed the same pattern.

At 11:40 a.m., the traffic control trucks drove off site to allow congestion to relieve. Vehicle speeds increased, and the trucks returned to the lane closure at 11:50 a.m. Figure 40 shows cut-out distances very similar to before, but with a slight decrease in the large number of vehicles that waited until the last second to change lanes. The trend is similar to the previous two experiments, with a slight decrease in the number of vehicles that changed lanes just before TMA2. This seems to indicate that traffic may have an easier time merging when speeds are higher and there is less congestion.

The high number of vehicles that closely approach the TMA in the lane is a concern. Although traffic was moving slowly (20 to 35 mph), it would be easy for an accident to occur with so many vehicles approaching TMA2 closely.

VEHICLE SPEED DATA

IDOT's Traffic Division provided a radar unit to monitor traffic speeds during the advance warning experiment on June 18. The operator collected data in a similar manner as ISP, sampling car and truck speeds approaching and at the work zone. Figure 41 presents the average traffic speeds for each sample unit. Speeds were slow due to congestion, ranging from 17 to 43 mph. The higher speeds occurred after the trucks drove off site for several minutes to allow congestion to lift. Although these speeds are low, they are typical of daytime lane closures on IDOT's expressways.

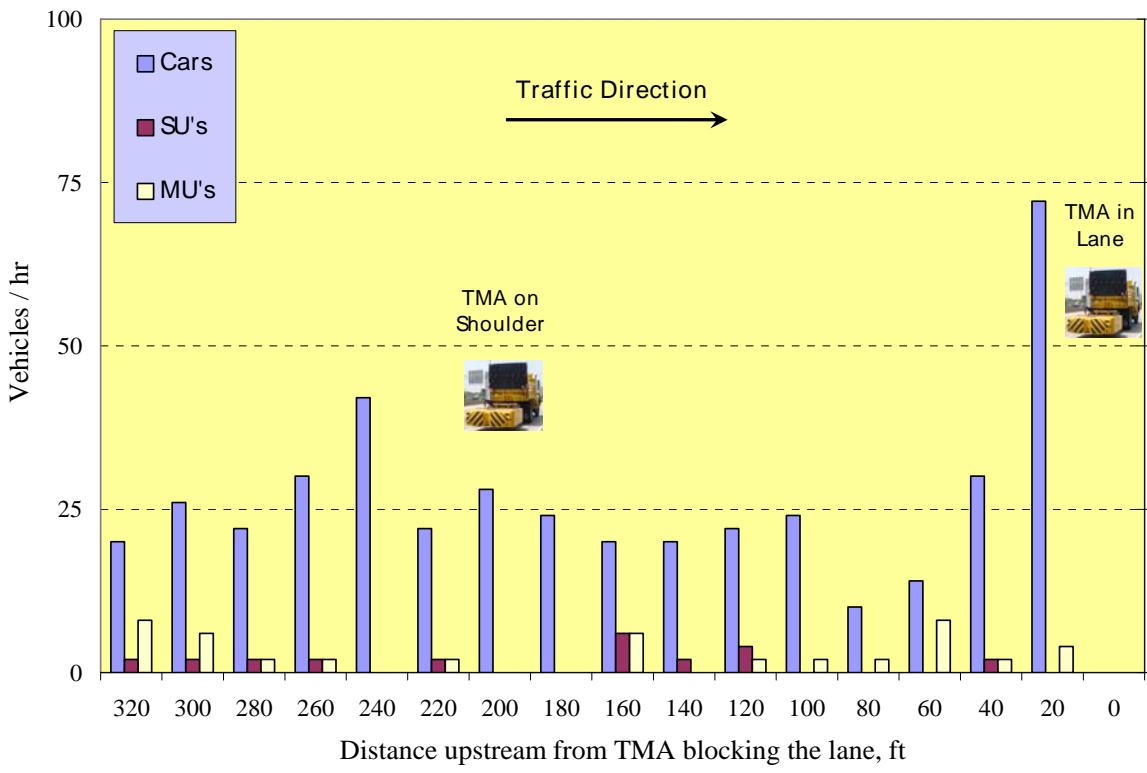


Figure 39. Cut-out distance—200-ft transition area.

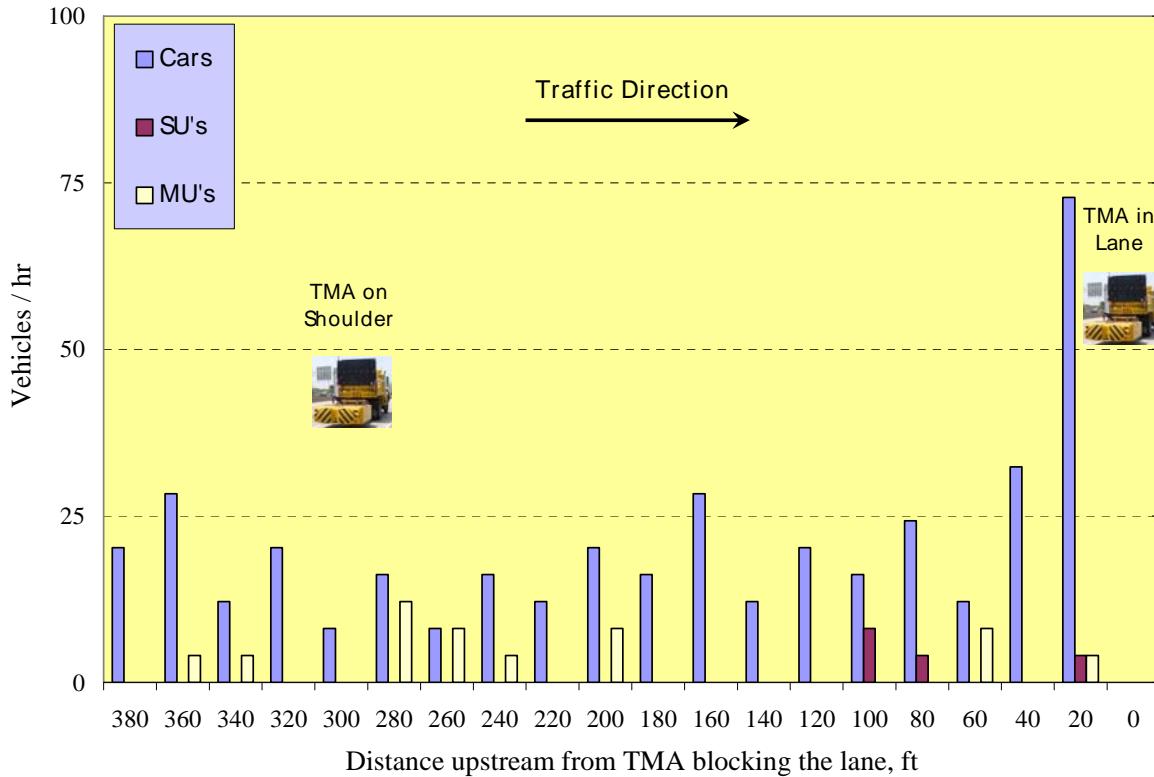


Figure 40. Cut-out distance—300-ft transition area.

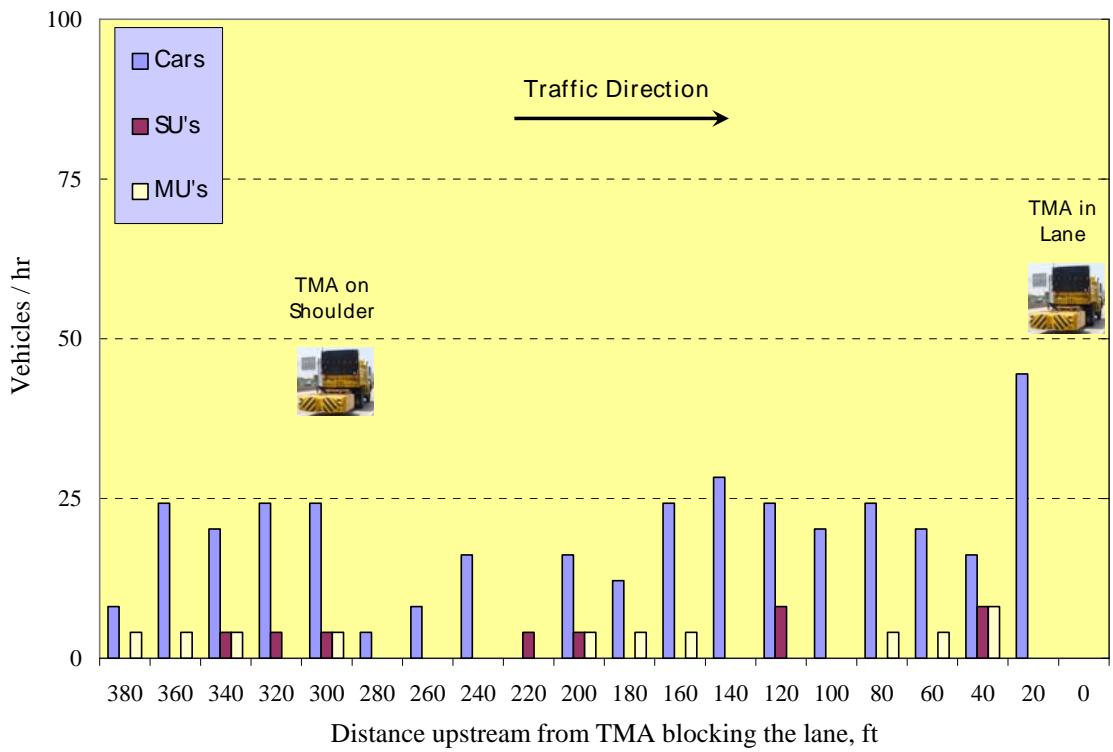


Figure 41. Cut-out distance—300-ft transition area and less congested traffic.

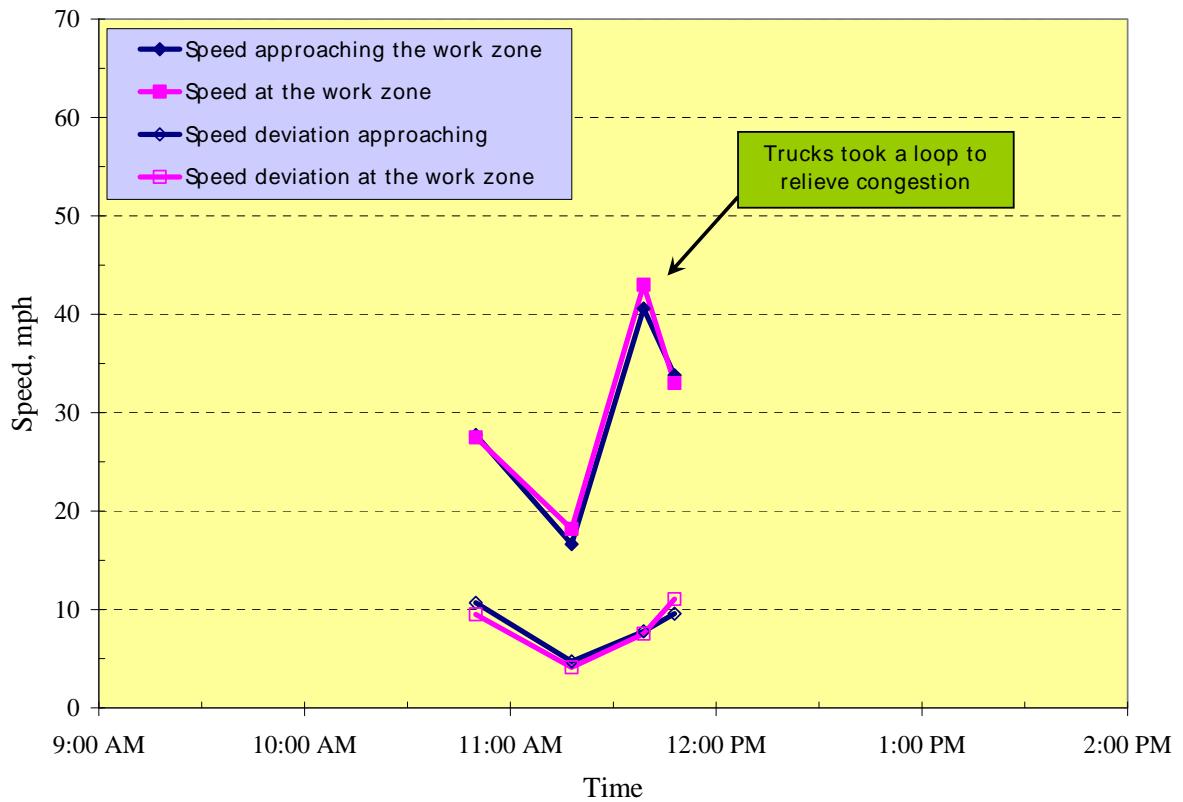


Figure 42. Traffic speed and deviation during the advance warning tests.

SUMMARY OF KEY FINDINGS— HIGH-VOLUME, URBAN EXPRESSWAY WITH RAMPS

- **IDOT's expressways are characteristically extremely high-volume, have many ramps, and backup quickly when lanes are closed during the day.** Most expressways carry a minimum of 100,000 vehicles per day. Average daily traffic on the section of I-290 tested is approximately 180,000 vehicles. On and off ramps are frequent and cause many conflicts. For congestion and safety reasons, intermittent daytime closures are permitted for only 15 min at a time.
- **Traffic at ramps is conflictive and unpredictable.** During a 30-min period, 14 potentially dangerous merges were observed due to traffic either trying to get to the ramp or enter the traffic stream from the ramp. Many drivers began exiting the expressway to avoid the lane closure, but then changed their minds at the last moment and cut across the gore area and between the TMAs. Based on discussions with field crews, vehicles would not hesitate to use the shoulder for passing if allowed to do so, hence the use of the bomber truck blocking the shoulder.
- **Truck spacing is complicated in urban areas, especially with many ramps.** The Eisenhower maintenance crew uses a two-TMA taper to close the lane, resulting in a very abrupt lane closure. A straddler TMA inserted between the two TMAs would provide a more gradual transition, but their experience is that this causes other problems. They do have two TMAs blocking the lane, which is beneficial in the case that a collision occurs; however, when spaced several hundred feet apart, traffic begins to swerve in between them. Seven swerves into the space between TMAs 1 and 2 were observed in a 30-min period.
- **Traffic cuts-in very close to the work area.** Our tests showed traffic reentering the lane as early as 20 ft, with the majority coming in between 40 and 160 ft.
- **Many vehicles wait until just before the TMAs to vacate the lane.** Under congested conditions, the most common location for vehicles to change lanes was 20 ft behind the TMA blocking the lane, meaning the queue of vehicles in the congested upstream lane drove as far forward as they could before exiting the closed lane. Many times these vehicles had to come to a complete stop directly behind the TMA and wait for an opening to merge out of the lane. This was due to congestion and the absence of a TMA taper to gradually move traffic over.
- **For a two-TMA taper, changing truck spacing did not alleviate the problem behind TMA2.** We experimented with both 200- and 300-ft spacing between the shoulder TMA and TMA2; however, a high percentage of traffic continued to approach within 20 ft of TMA2.
- **Advance warning vehicles and message boards were used effectively for the given roadway geometry.** The section tested is situated just after a set of reverse curves that limited visibility of the lane closure. An advance warning truck and a trailer-mounted PCMS were positioned in and before the curves at distances of about 0.25 and 0.5 mi upstream to warn traffic of the lane closure ahead.

SITE 4 – I-90 AT BARRINGTON ROAD, HOFFMAN ESTATES

SITE DESCRIPTION—URBAN EXPRESSWAY, NIGHTTIME OPERATIONS

The final round of field tests took place on I-90 between mileposts 14 and 18, which includes the Barrington Road Bridge (figure 43). This round of testing was a combination of observing ISTHA's maintenance crew replacing plowable markers, as well as experimenting with modified configurations in the advance warning and buffer areas. Testing was performed during the nights of June 18 and 19, 2008. This section of I-90 has three traffic lanes per direction and a one-way ADT of approximately 82,000 vehicles per day. Nighttime testing was studied because of the dangerous conditions that exist when low traffic volumes are moving at high speed at night—the time many maintenance and repair operations take place. Impaired or fatigued drivers are an additional nighttime hazard.

TRAFFIC CONTROL SETUP

Traffic control was provided by M-5 using the setup shown in figure 44. This consists of three closely spaced TMAs to close the lane, a trailer-mounted message board placed approximately 0.25-0.50 mi upstream of the work zone, a work truck with arrowboard and equipment for the workers located in the closed lane about 50 ft in front of the lead TMA, and the supervisor's pickup truck in front of the workers. A balloon light was mounted in the bed of the work truck to provide lighting and for the workers and visibility.

Lanes 1 and 2 were closed to allow replacement of the plowable markers along the longitudinal joint between the lanes. The convoy proceeded forward at walking speed, as workers on foot removed and replaced the marker lenses. Based on information from M-5 personnel, typically two lanes are closed for nighttime operations, as congestion is not a concern and it provides additional safety for the workers.

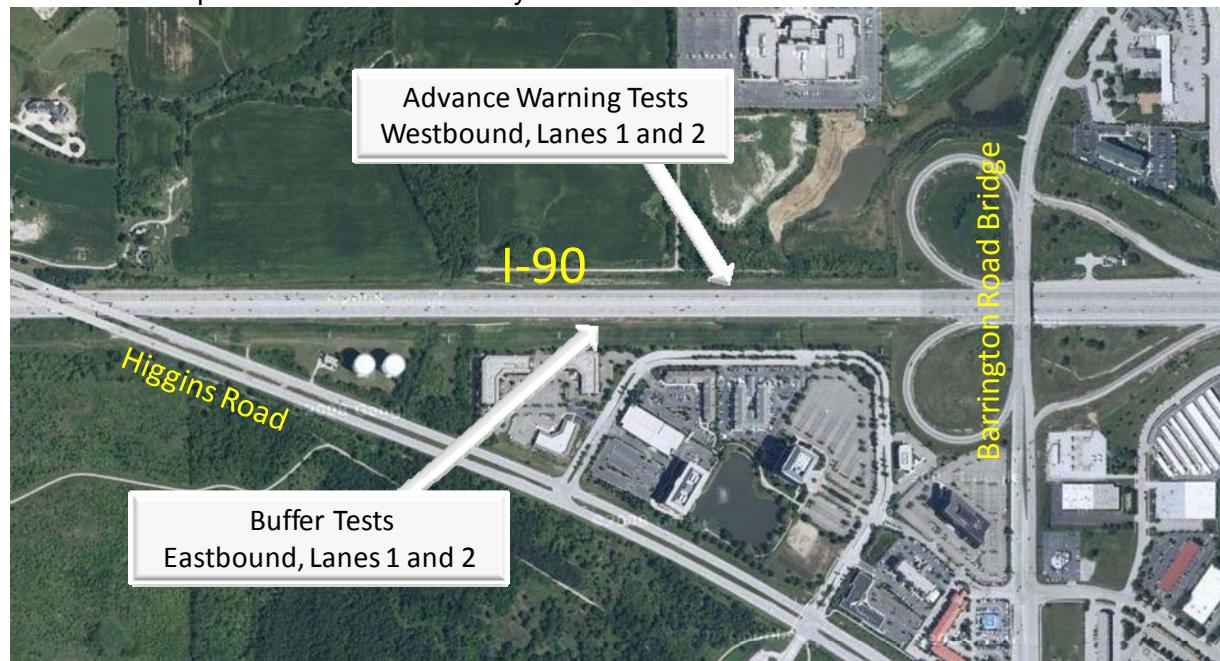


Figure 43. Aerial view of the I-90 test site at Barrington Road, Hoffman Estates.

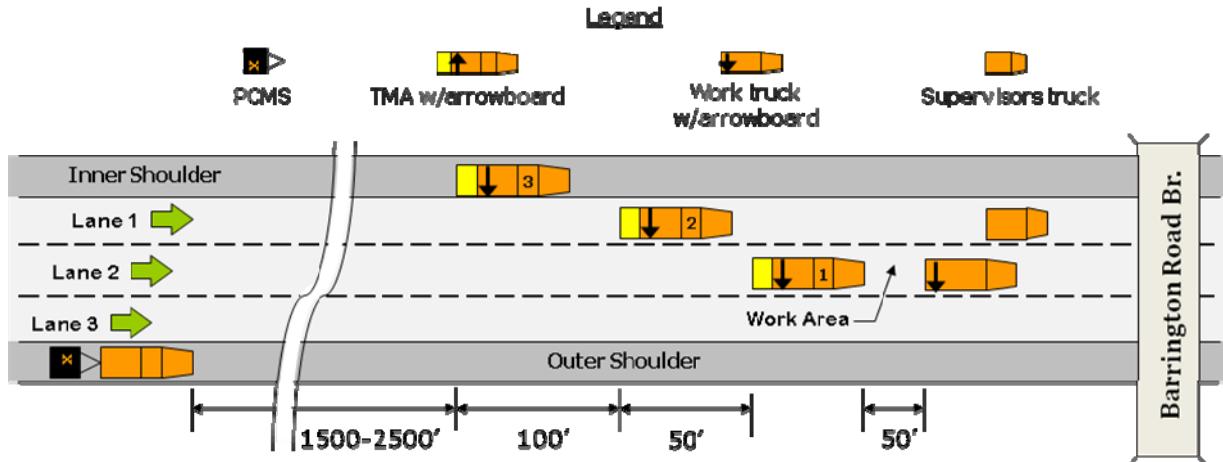


Figure 44. Two-lane closure used by M-5 personnel to replace plowable markers.

CUT-IN DISTANCE

At the onset of the first night's testing, the convoy remained stationary in the eastbound lanes just west of the Barrington Road Bridge to allow the research team to film traffic patterns moving around the work zone.

Figure 45 displays the cut-in distances for traffic reentering the closed lanes 1 and 2. Cars reentered the lanes as early as 50 ft beyond the lead truck, with the majority of traffic entering between 100 and 250 ft. The remainder of the night the convoy proceeded forward with marker replacement, while the traffic maneuvers were videotaped from a camera mounted in the supervisor's truck. This information confirmed a similar trend for reentering traffic when the convoy was in motion.

ADVANCE WARNING AREA

The first night, several near-misses occurred in the advance warning area due to traffic that came close to impacting the TMAs from behind. In each case, vehicles at high speed waited until very late to change lanes. Therefore, the second night we evaluated the effect of placing the supervisor's pickup in the advance warning area to improve traffic patterns upstream of the TMAs. Two scenarios were evaluated:

- Supervisors pickup placed 500 ft upstream of the work zone on the inner shoulder
- Same lane closure without the supervisor's pickup

Figure 46 summarizes the results. In the figure, "close" was defined as vehicles that came within 500 ft of the work zone before merging to the open lane. The supervisor's truck made a significant improvement, as 18.1 percent of the vehicles approached the convoy closely when it was not present, compared to only 3.6 percent when it was. This shows that additional advance warning, even something as simple as the supervisor's pickup on the shoulder, can have a positive influence on approaching traffic.

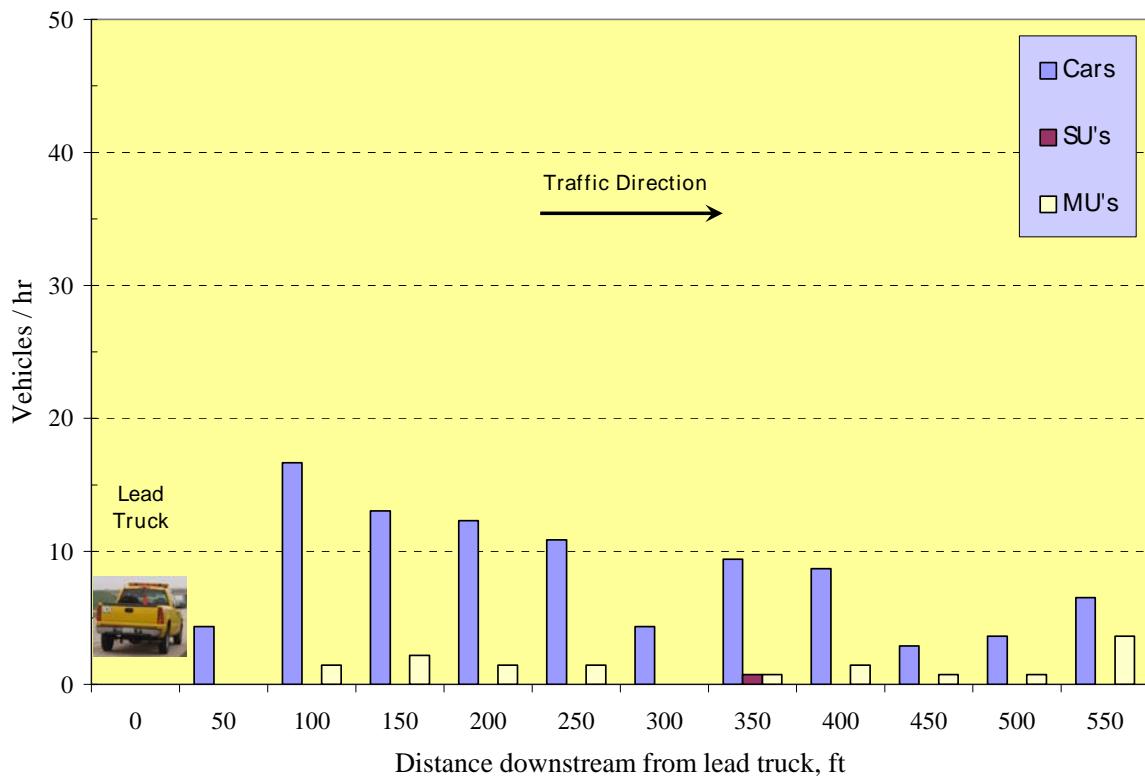


Figure 45. Cut-in distance for nighttime work—free flowing traffic.

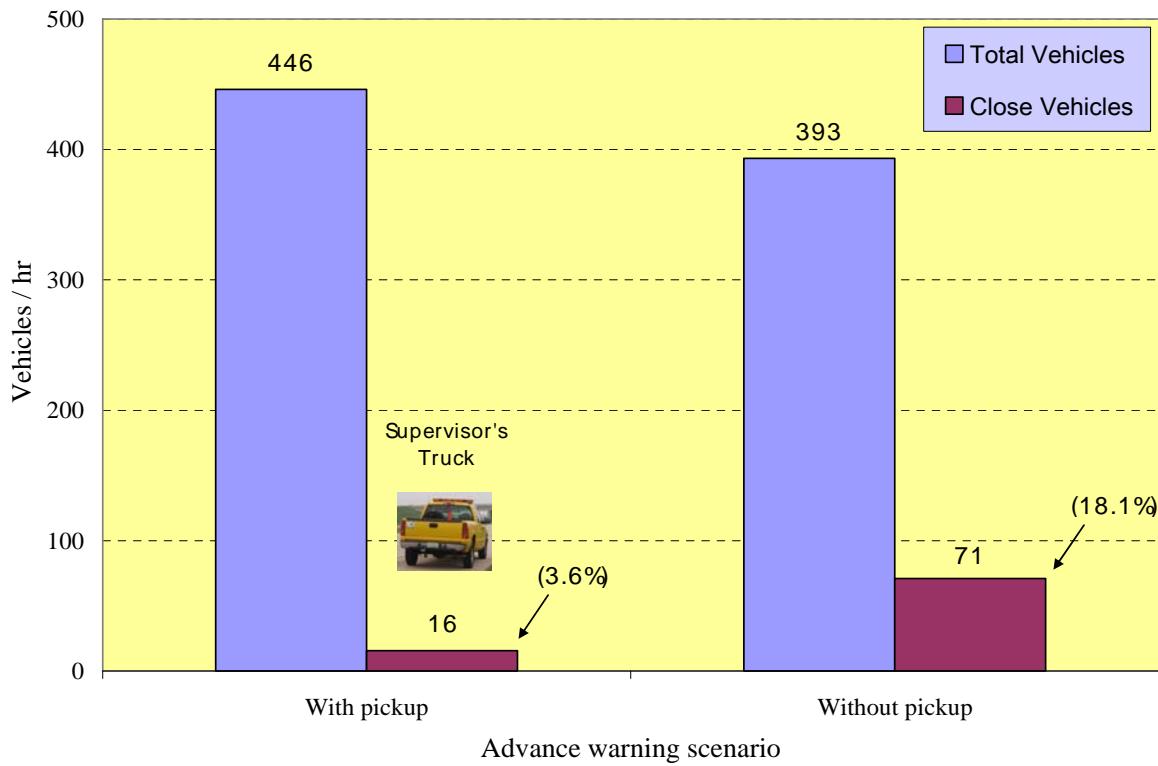


Figure 46. The effect of the supervisor's truck in the advance warning area.

VEHICLE SPEEDS

Vehicle speeds were monitored by ISP using LIDAR mounted in one of the TMAs on both nights. As expected, average traffic speeds were much higher at night than during the day, as lower traffic volumes allow vehicles to operate at their desired speed. Mean traffic speeds were very similar both nights, ranging from approximately 50 to 60 mph, as seen in figures 47 and 48. Interestingly, vehicles slowed down 5 to 10 mph as they passed the work zone.

BUFFER TRUCK ADDITION TO THE CONVOY

Near the end of the second night, the traffic control crew experimented with the addition of a buffer truck in the convoy. The idea of the buffer truck is to provide additional distance between the work crew and the TMA taper in case a collision occurs with the TMAs, while still protecting against lateral intrusions. In this case, a channel truck with arrowboard was placed 100 ft in front of the TMA in lane 2. The work crew placed themselves approximately 50 ft forward of the buffer truck, as seen in figure 49. Previous testing at the Meacham Road site showed that no intrusion had occurred when the truck-to-truck spacing was 200 ft or less.

The work crew remained stationary at the Barrington Road Bridge for approximately 30 min while we videotaped traffic proceeding around the modified setup, and then continued replacing plowable markers with the same configuration for the remainder of the night. Feedback from the workers at the end of the night regarding the use of a buffer truck was positive.

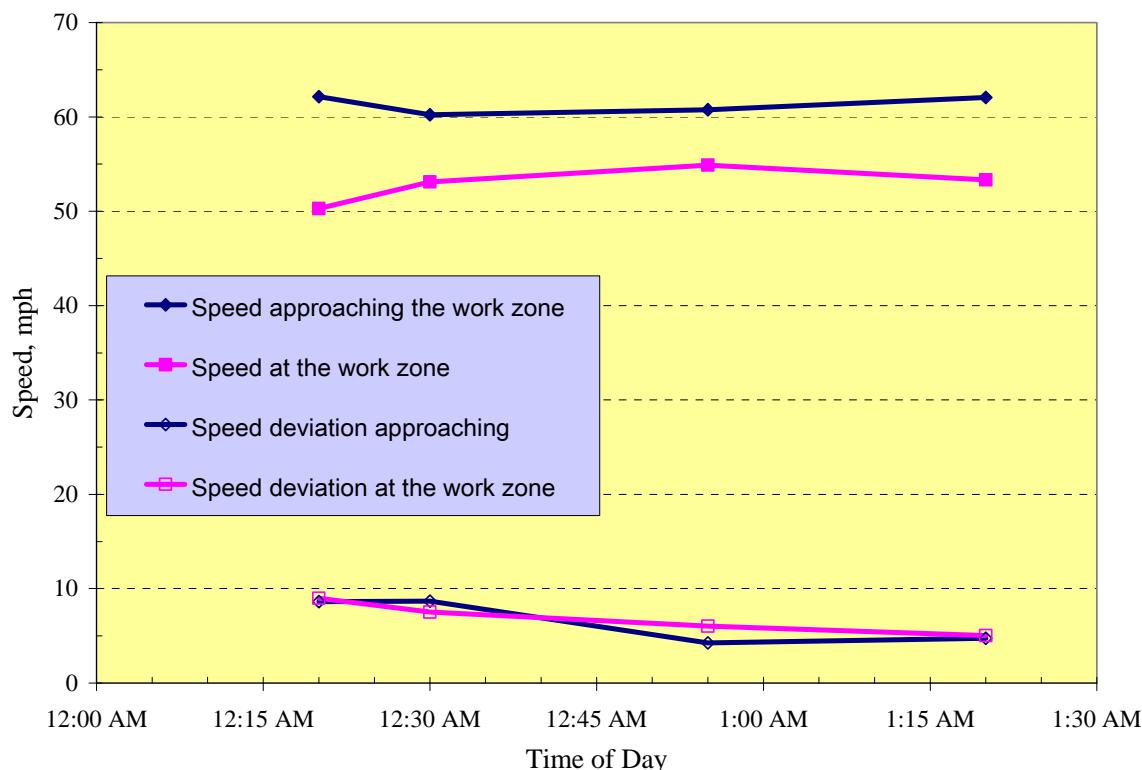


Figure 47. Traffic speed and deviation for all vehicles—night of June 18, 2008.

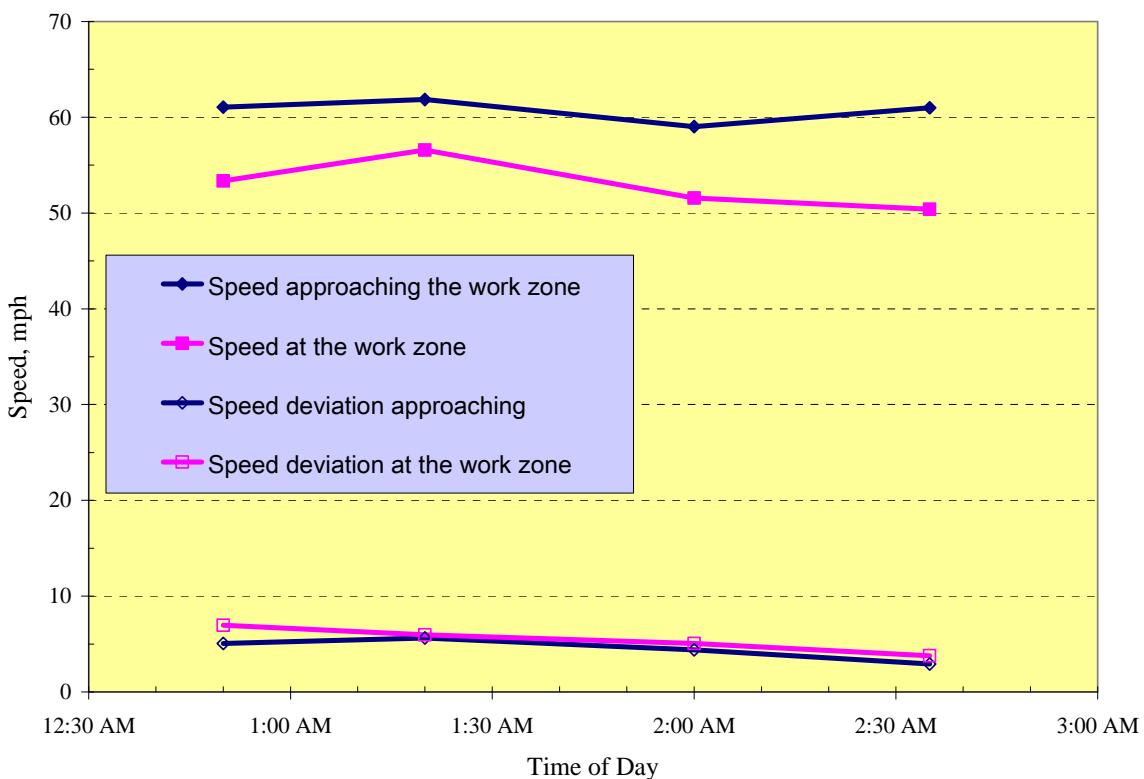


Figure 48. Traffic speed and deviation for all vehicles—night of June 19, 2008.

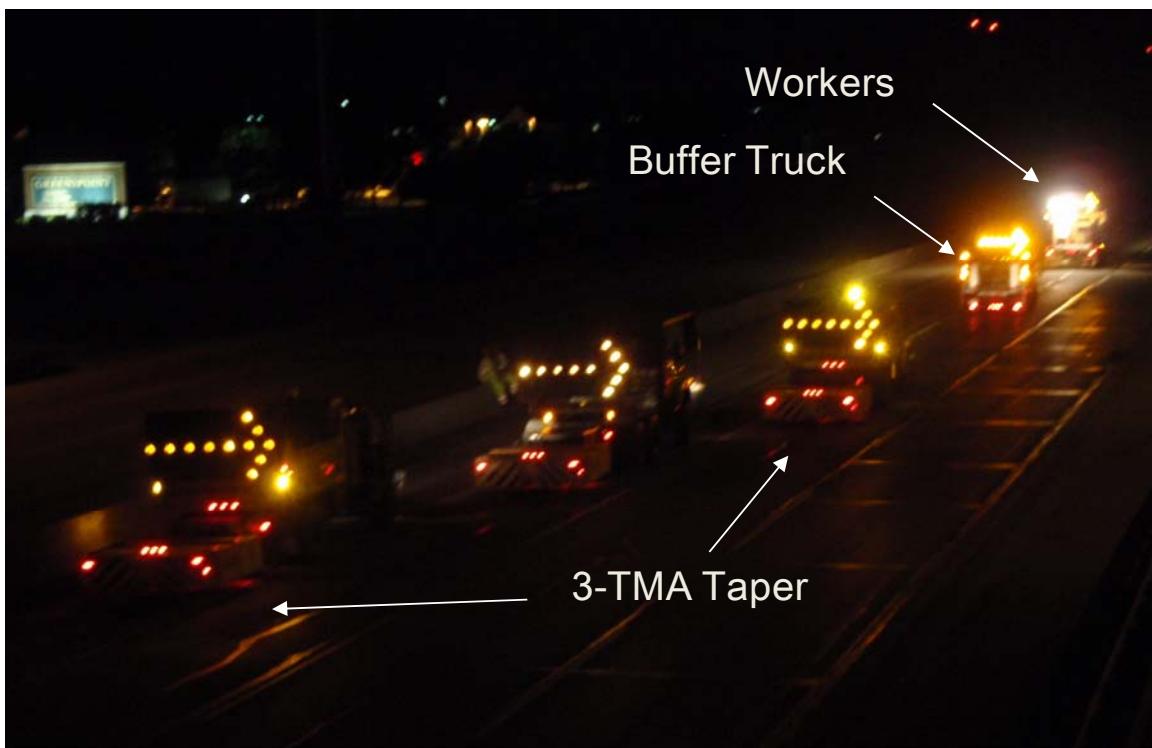


Figure 49. A buffer truck added to the convoy provides additional distance between the workers and TMAs in the event of a rear impact.

SUMMARY OF KEY FINDINGS—URBAN EXPRESSWAY, NIGHTTIME OPERATIONS

- **Nighttime testing poses unique hazards and is considered by many to represent the most dangerous conditions for moving closures.** Nighttime traffic speeds are higher due to lower volumes. Higher speeds and reduced visibility due to darkness give vehicles less reaction time to avoid accidents. A higher percentage of impaired drivers (either intoxicated or fatigued) are on the roads at night, as well as a high truck percentage.
- **Cut-in distances at night are similar to daytime.** The first vehicles began reentering the lane at 50 ft, similar to daytime conditions. Most traffic reentered the lane between 100 and 250 ft.
- **The advance warning area can be precarious at night, due to reduced driver awareness and understanding of instructions from traffic control vehicles.** Within the first hour of nighttime testing three near-misses occurred from vehicles that approached the work area too close.
- **Placing a flashing vehicle on the shoulder in the advance warning area made a significant improvement.** Tests were conducted with and without the foreman's truck placed on the shoulder 500 ft upstream of the work zone to increase advance warning to oncoming traffic. The number of vehicles that approached the TMAs within 500 ft before changing lanes was reduced from 18.1 to 3.6 percent.
- **The addition of a buffer truck to the convoy was tested and received positive feedback.** A channel truck with arrowboard was added to the convoy to provide more space between the work crew and the TMA blocking the lane. The buffer truck was placed 100 ft in front of the TMA, and the work crew placed themselves another 50 ft in front of it. The buffer truck has the potential to reduce injuries to the work crew in the event that a collision takes place with the TMAs, while still protecting the work area from lateral intrusions. Initial response from the field crew was positive.

OTHER RELATED ISSUES

The investigators noted the following reoccurring and/or pertinent issues during interviews and discussions with IDOT, ISTHA, and ISP personnel involved with traffic control operations and supervision.

- **Urban vs. rural roadways and their effects on traffic control setups and standards.** The research documented the distinct differences between urban and rural settings, including traffic volumes, speeds, driver behavior, and conflicts such as ramps. Maintenance yards have adopted practices tailored towards their specific conditions, but this is not always reflected in the agency's standards. For example, in urban areas, traffic control crews space their TMAs closely together to prevent intrusions, but this is contrary to the published standards. It seems appropriate to have multiple standards that take traffic volume or setting into account.

IDOT District 1 emphasized that the published standards are only a minimum guideline, and that maintenance yards should and do apply additional resources as the conditions require. This is true; however, it seems that having standards applicable to hazardous high-volume, urban conditions would provide maintenance yards with guidance and promote uniformity between crews. The following statement was heard often: "every maintenance yard [or foreman] has a different way of doing things."

- **Public perception of maintenance operations as inconveniences, instead of work zones.** Although construction zones have their own hazards, in general, the public treats them with a higher degree of respect than maintenance operations. For example, much publicity and public education is done to encourage drivers to slow down in construction zones and make them aware of the fines and penalties that exist for breaking work zone speed limits. However, fewer motorists seem to believe that the same rules apply to moving lane closures. The investigators discussed the issue of work zone speed limits with ISP and ISTHA, and ISP confirmed that speed limit reductions for moving closures are not enforceable by law and can be posted only as suggestions. On the other hand, Scott's law is a very beneficial regulation that can prevent accidents with maintenance crews and also be used to ticket motorists that drive unsafely through moving closures.
- **Policy on the time duration allowed for intermittent operations.** The policy on how long a moving lane closure can be used at one place varied from 15 to 20 to 30 min, depending on agency and maintenance yard. Almost universally, maintenance yards would like to be allowed to perform closures with trucks for longer durations. The alternative to a moving closure is a stationary closure using signs, barricades, and cones. These take longer to set up, expose workers more to traffic, and result in increased user delays. IDOT's District 1 Maintenance Office presented a different perspective, stating that once stationary closures are in place, workers are less likely to be confronted with uninformed motorists, due to the increased traffic control devices used.
- **Balance between safety and mobility.** Not only is this a major policy issue at the national level, but the effects can be seen at the local level, too. Maintenance crews

prefer working in congestion due to low traffic speeds; however, this is not acceptable to the driving public. To accommodate motorists, many maintenance activities are performed at night, exposing workers to hazardous conditions such as impaired drivers operating at high speeds.

- **When asked what could be done to make moving lane closures more safe, universally traffic control crews stated, “more trucks and more police”.** The benefits of both of these resources are evident in our field data; however, their availability is highly dependent on agency funding.

APPENDIX A – LITERATURE REVIEW

A basic literature review was undertaken to understand local, state, regional, and national mobile traffic control standards, review innovative traffic control devices, and examine recent research on topics relating to mobile lane closures.

APPLICABLE TRAFFIC CONTROL STANDARDS

Traffic control standards in force in Illinois come from several sources. Federal Highway Administration (FHWA) standards are the basis for local standards developed by the Illinois Department of Transportation (IDOT) and the Illinois Tollway. Documents from all of these organizations were reviewed and are discussed below.

Manual on Uniform Traffic Control Devices

The Manual on Uniform Traffic Control Devices (MUTCD) is recognized as the prevailing traffic control standard (FHWA, 1993; FHWA, 2007). The MUTCD provides definitions and minimum traffic control standards and equipment that are used by agencies throughout the U.S., including the IDOT and the Illinois Tollway. The MUTCD notes that, for short duration and mobile operations, it is important to balance the hazards for the crew involved in setting up and taking down traffic controls with the amount of time required to perform the actual work task; therefore, simplified control procedures may be warranted (FHWA, 1993). The shortcomings of these simplified procedures may be offset by the use of dominant vehicles with special lighting, signing, and safety devices.

It is recognized that there is a difference between urban and rural settings and that the traffic control standards must be consistent with the characteristics of the roadway. In general, expressways and freeways are designed for uninterrupted traffic flow, and the traveling public has become accustomed to this free flow. Therefore, it is important in these situations to extend the distance on the advance warning signs as far as 0.5 mile or more (FHWA, 2007). Further, recognizing that rural highways generally are characterized by higher traffic speeds, the effective placement of the first warning signs should be longer.

Given the nature of mobile lane closures, it may be necessary to modify or elaborate on safety devices to enhance the safety of the work zone. These enhancements may include, but are not limited to, the following:

- Additional signs
- Larger signs
- Flashing arrow displays
- More channelizing devices at closer spacing
- High-level warning devices
- Portable changeable message signs
- Portable barriers
- Impact attenuators
- Longer advance warning area
- Temporary roadway lighting
- Flashing lights

Regardless of the safety devices, methods, and standards employed, the uniformity of the devices and their applications is extremely important (FHWA, 1993).

The MUTCD provides a “typical application” diagram to show the minimum safety requirements for mobile operations on a multi-lane roadway (FHWA, 2007). The standard shows the situation where a single lane closure is provided on the inner lane of a four-lane (i.e., two lanes per direction) roadway. Two advance warning trucks are provided, one on the shoulder and the other in the traffic lane. Both of these vehicles are shown to have a flashing

arrow directing the traffic in the transition area. The vehicle in the traffic lane must be equipped with a truck mounted attenuator (TMA), and the advance vehicle on the shoulder and the work vehicle may have TMAs. There is no specific spacing requirement between any of the vehicles, no defined taper distance, and no mention of a buffer space. The standard states that for high-speed roadways, a third shadow vehicle should be added. In this case the vehicles should be configured such that the first shadow vehicle is completely in the lane, the second straddles the edge line, and the third is completely on the shoulder.

FHWA Manual on Traffic Control for Nighttime Operations

In 2003, the FHWA published the *Traffic Control Handbook for Mobile Operations at Night: Guidelines for Construction, Maintenance, and Utility Operations* (FHWA, 2003). This report is a synthesis of practices of mobile operations at night. It was based on work zone manuals from a selection of state and local highway agencies, discussions with highway officials, and field observations of a select number of nighttime highway mobile work zone operations.

Mobile night operations pose an increased risk to the roadway users and workers because of reduced visibility and its effect on driver behavior at night. To overcome the reduced visibility, adequate illumination is essential to enhance worker safety. This illumination should be provided using methods that do not cause glare to the oncoming vehicles. Lights such as balloon lights are designed and recommended for nighttime traffic control operations (El-Rayes et al., 2008).

In establishing nighttime single-lane closures, straddling the lane is not suggested. Instead, TMAs should be fully in the lane or fully on the shoulder. This is consistent with the diagrams shown as typical applications in the MUTCD: single lane closure on multi-lane highway, single lane closure with narrow shoulders and restricted site distance, and interior lane closure of multi-lane highway. When closing a single lane, three shadow vehicles are required in advance of the work area, with the first being completely on the shoulder and the other two in the lane. In the case of an interior lane closure, four trucks are used in the closure with one in the interior lane, one straddling the interior lane and the exterior lane, one in the exterior lane, and the last on the shoulder.

The manual on nighttime mobile operations provides guidance on typical ranges of distance/spacing of vehicles in a mobile closure, but it is noted that the actual distance should be based on actual traffic conditions.

Illinois Department of Transportation

The overall goal of IDOT's work zone safety and mobility rule is to reduce and eliminate crashes and to mitigate congestion due to work zones (IDOT, 2007). Addressing safety, the goal is zero worker fatalities in work zones, with reductions in work zone crashes by 10% each year. Mobility goals dictate that delays near work zones should be minimal when compared to baseline travel without the work zone present.

IDOT has three manuals/standards that govern traffic control under mobile lane closures on multi-lane highways.

The "Work Site Protection Manual for Operations Activities and Emergency Callouts" (IDOT, 2005) is the primary document used by IDOT maintenance and operations staff in establishing mobile lane closures. This document provides work zone cases with specific traffic control and protection requirements. For mobile lane closures on multi-lane roadways, there are eight different work zone cases to choose from:

- WZ40 – All speeds multi-lane up to 60 minutes

- WZ46 – All speeds, intermittent/moving operation, no time limit, more than 4 mile per day
- WZ46A – All speeds, intermittent/moving operation, no time limit, more than 4 mile per day
- WZ47 – 45 MPH or less, intermittent/moving operation with curb and gutter, one lane closure
- WZ 48 – All speeds, intermittent/moving operation, no time limit, less than 4 mile per day
- WZ49 – Intermittent/moving operation, two lane closure
- WZ52 – All speeds, multi-lane moving operation
- WZ63 – Moving operation for work at entrance ramp (15 min. and less); used with WZ46 or 46A

Each of these cases presents the minimum recommended traffic control devices and spacing for mobile operations. The number of trucks, truck equipment (signs, arrow board, etc.), and truck spacing are prescribed. Distances generally are given in ranges or minimum or maximum distances but sometimes are prescribed as fixed distances. In general, a minimum distance of 100 ft is shown from the lead truck to the work area.

The “Supplement to the Work Site Protection Manual” (IDOT 2001) provides guidance for IDOT workers whose primary responsibilities are not highway maintenance. The document is a policy for the proper application of traffic control devices as a minimum requirement for work site protection. For mobile lane closures on multi-lane roadways, there are four different work zone cases to choose from:

- WZ40 – All speeds multi-lane up to 60 minutes
- WZ 48 – All speeds, intermittent/moving operation, no time limit, less than 4 mile per day
- WZ49 – Intermittent/moving operation, two lane closure
- WZ52 – All speeds, multi-lane moving operation

These work zone cases are essentially the same with only minor changes to the distances to advance warning signs.

When contractor or other non-IDOT personnel establish mobile lane closures to perform construction, maintenance, or engineering functions, the IDOT Standard 701426-02 (IDOT, 2005) provides guidance for the minimum traffic control requirements. This standard presents two details for intermittent or moving operations, one for a single-lane closure and one for a two-lane closure. Both are required to employ a flagger with a traffic control sign when workers are on the pavement. The distances for signs, trucks, and work zones are outlined clearly, with some adjustment provided via a +/- designation made with the distance call-out. The single-lane closure requires two shadow trucks and advance warning signs, while the two-lane closure requires three or four trucks depending on workers being on pavement or in trucks.

Illinois Tollway

The traffic control standards for the Illinois Tollway are taken from the “Illinois Tollway Roadway Traffic Control and Communications Guidelines” (ISTHA, 2005). This document provides two diagrams, one for a single-lane closure and one for a two-lane closure, both of which show a four-truck closure with prescribed signs/arrow boards and defined spacing between trucks.

The Illinois Tollway diagrams generally include specific information on the number, spacing, and equipment on each truck in the mobile closure. The mobile closure configurations differ in number of trucks, truck spacing, signage, and other areas from the IDOT work zone cases, as they are based on Tollway procedures, equipment, and practices.

OUTSIDE AGENCY STANDARDS/BEST PRACTICES

Wisconsin DOT

Many state agencies use the MUTCD exclusively for work zone safety guidance. Wisconsin DOT has developed its own handbook that provides guidance for its personnel, agencies, and contractors (Wisconsin LTAP, 2003). This handbook, similar to the guides in Illinois, is provided to give the practitioner some additional assistance in the determination of the appropriate safety procedures under various traffic control situations. Wisconsin's standard for mobile operation on a multi-lane road was reviewed and compared to the Illinois DOT, Tollway, and MUTCD standards. The notes accompanying this standard provide guidance and allow judgment to be exercised by the field crew to establish a safe mobile closure. These notes include:

- When adequate shoulder width is not available, the rear shadow vehicle may drive partially in the lane.
- Shadow vehicles should travel at a varying distance from the work operation so as to provide adequate sight distance for traffic approaching from the rear.
- Spacing between vehicles should be minimized to deter traffic from driving in between the convoy of vehicles.
- Stationary advance warning signs can be used to provide additional advance warning. These signs might include SLOW MOVING TRAFFIC AHEAD, ROAD WORK AHEAD, PAINT CREW AHEAD, etc. Consider using these signs and/or a changeable message sign where speeds and volumes are high, where sight distance is limited, or if shadow vehicle #2 is not used.
- Work normally should be done during off-peak hours.

North Carolina

The North Carolina DOT has established traffic control standards that are different for continuously moving and for mobile operations that stop periodically (FHWA, 2000). These standards are also different based on the volume and speed of the facility where the mobile closure is performed. "One size fits all" is not appropriate for mobile closure standards, and the outcome of this multiple-standard guidance has been a decrease in crashes in work zones with mobile closures.

Missouri DOT

The Missouri DOT's *Truck Mounted Attenuators—TMA Training* (Missouri DOT, 2006) is intended to serve as a training reference for operators of trucks equipped with TMAs, including when to use a TMA and proper operational procedures. It makes frequent reference to the topic of TMA rollahead distance and recommends that a distance of at least 150 feet be maintained between the TMA and the workers it is protecting. The manual goes into detail regarding the required characteristics of the TMA driver, specific equipment and safety concerns, and operational issues. Finally, typical applications for seven scenarios are presented.

RELATED RESEARCH AND TRAFFIC CONTROL DEVICES

Speed Reduction Methodologies—Illinois DOT

The Illinois DOT sponsored research to investigate methods to reduce speeds in work zones to improve safety (Benekohal, 1992). This report described many methods to reduce

vehicle speeds in and around work zones, including use of flaggers, police presence, changeable message signs, drone radar, radar activated feedback, and others. Several of these investigated items are relevant to this study.

Horn systems that are tied to vehicle speed were shown to have some speed reduction effect on the motorist; however, the noise could be an issue for the workers or the residents adjacent to the work zones. New technologies in directed sound energy could overcome the identified drawbacks as technology continues to improve.

A survey of drivers from rural work zones noted that the majority pay more attention to work zone signs than general roadside signs. Further, they paid more attention to work zone signs after entering the work zone. Respondents noted that they wanted information on the characteristics of the work zone.

The use of drone radar was investigated and was noted to be most effective in short periods of time when the drivers have not identified the radar. However, it was recommended that drone radar use should be combined with police enforcement so that drivers are kept off-balance as to when the radar is real and when it is drone.

The use of changeable message signs (CMS) in advance of the work zone that display the speed limit for the work zone reduced the speed of vehicles. This is an uncommon use for CMS in mobile work zones.

The use of police cars in work zones has a marked impact on the speed of vehicles in the work zone. However, after passing the work space, the vehicles increased their speeds. Given the short duration of mobile lane closures, this could be a good method of speed reduction.

You/Me Speed Display Boards—Wisconsin DOT

As part of research performed through the Smart Work Zone Deployment Initiative (SWZDI), a speed display device known as a You/Me board was tested on Wisconsin highways (Notbohm et al., 2001). This device is mounted on the back of a traffic control vehicle and has two large, numeric displays—one that displays the speed of the traffic control vehicle and another that displays the speed of oncoming traffic. The purpose of the boards is to alert drivers to their differential speed relative to slower moving, or stopped, work vehicles participating in activities such as paint striping.

Observations were made of traffic behavior around painting convoys that incorporated the use of a You/Me board. In addition, the device was tested on a work truck parked on the shoulder of a two-lane highway in two manners—with the You/Me board turned on, such that motorists were advised of their speed relative to that of the parked vehicle, and with the You/Me board covered, so that its display was not visible to the highway users. The study determined the average speed of passing vehicles was 3 mph lower when the board was visible to motorists. There was also anecdotal evidence from the work crew that drivers were driving slower, more carefully, and that traffic was calmer in the presence of the display during painting operations.

Driver Opinions of Traffic Control Devices for Mobile Work Zones

Two studies on driver behavior provide information that is directly relevant to this study. These studies, performed at different times and in different locations, have underlying themes that are consistent and indicate features of traffic control devices that drivers consider important. The first, a Kansas study published in 2008 (Schrock et al., 2008), contained the following results:

Seventy-eight percent of participants indicated that they preferred sequential displays over flashing displays. Reasons given were that the sequential

movement of these displays indicated a more important or critical situation compared to the flashing alternatives.

Participants were generally favorable of staggering work vehicles into the closed lane (Straddling the lane) indicating that this provided positive reinforcement of the lane closure message.

Participants liked the idea of including additional information in the form of static signing on the back of the shadow vehicles, but there was no agreement on the nature of the information. Some participants wanted to know more about the nature of the work being performed, while others were only interested in information on what they were being directed to do. Further research is needed to determine what would be a more effective static message(s) displayed on the rear of shadow vehicles.

The second study (Ullman et al., 2003) involved research into the hazards of mobile traffic control operations and countermeasures to improve their safety. The research was funded by the Texas DOT (TxDOT) and involved field evaluation of innovative traffic control devices, such as signs with alternative messages, portable changeable message systems (PCMS), and You/Me boards. A sampling of the results from the Texas studies (Ullman et al., 2003; Finley et al., 2004) is noted below:

The # VEHICLE CONVOY sign should be used instead of the WORK CONVOY sign. The number needs to be adjustable and easy to change. For example, users were more likely to understand the meaning of a sign stating “3 VEHICLE CONVOY,” rather than the more general “WORK CONVOY” sign.

A PCMS can be substituted for the LANE BLOCKED sign on divided highways with three or less lanes in each direction. TxDOT should require the use of the PCMS messages and a minimum letter height of 12 inches.

The underlying themes from these studies is that the surveyed drivers appear to want to know what they can expect to encounter in a given work zone and what they should do.

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Schrock, Steven D., Chen Fei See, and Thomas E. Mulinazzi, "Public Opinion and Understanding of Advance Warning Arrow Displays Used in Short-Term, Mobile, and Moving Work Zones," University of Kansas, Report No. 45110-1, March, 2008.

Ullman, B.R., M.D. Finley, and N.D. Trout. *Identification of Hazards Associated with Mobile and Short Duration Work Zones*. Report 4174-1. Texas Transportation Institute, College Station, Texas, September, 2003.

Wisconsin LTAP. *Work Zone Safety: Guidelines for Construction, Maintenance and Utility Operations*, Transportation Information Center – LTAP, University of Wisconsin-Madison, 2003.

FIGURES

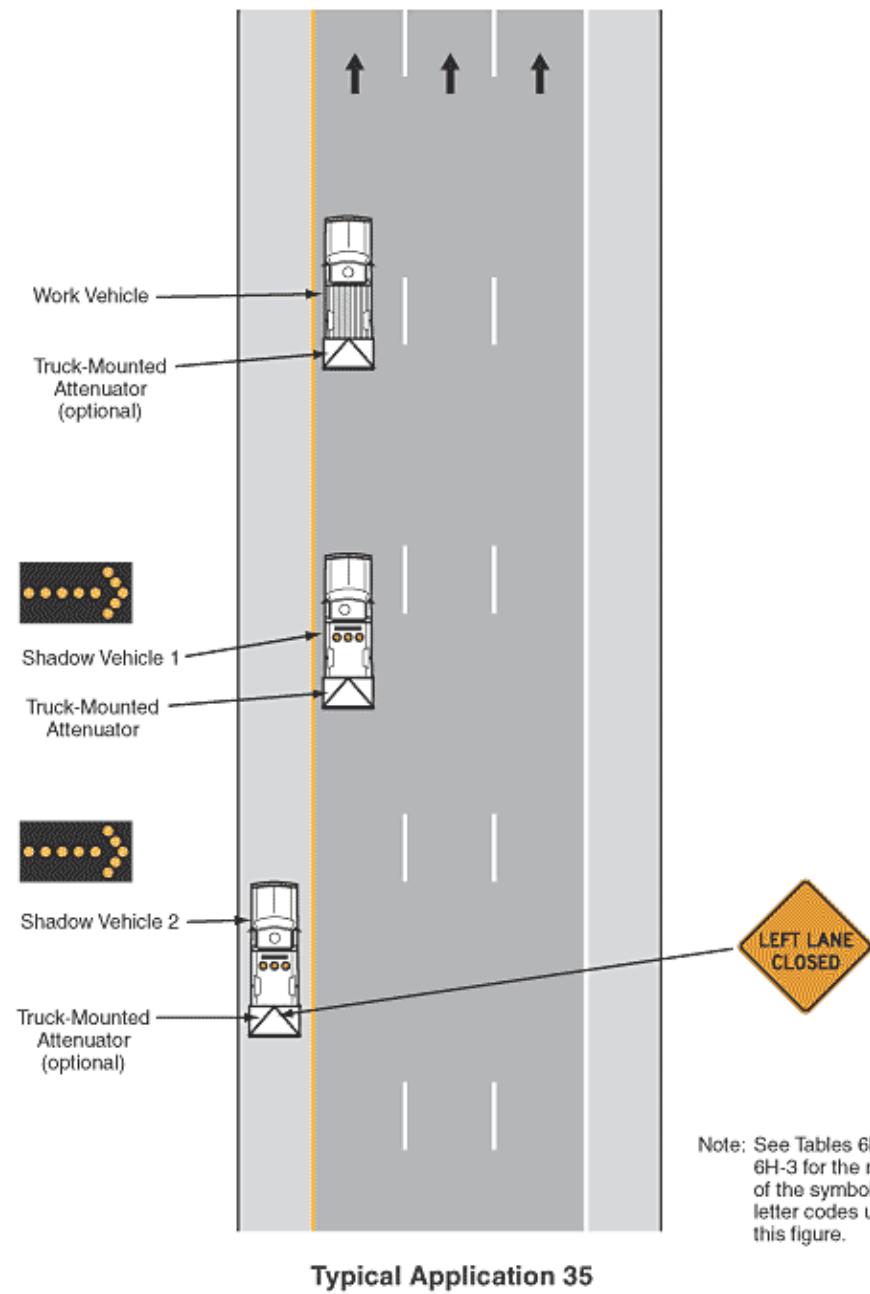


Figure A-1. MUTCD figure 6H-35 mobile operation on multi-lane road (TA-35).

NMTA - 6 Night Striping Operation on Multi-Lane Highway - Coning Not Required

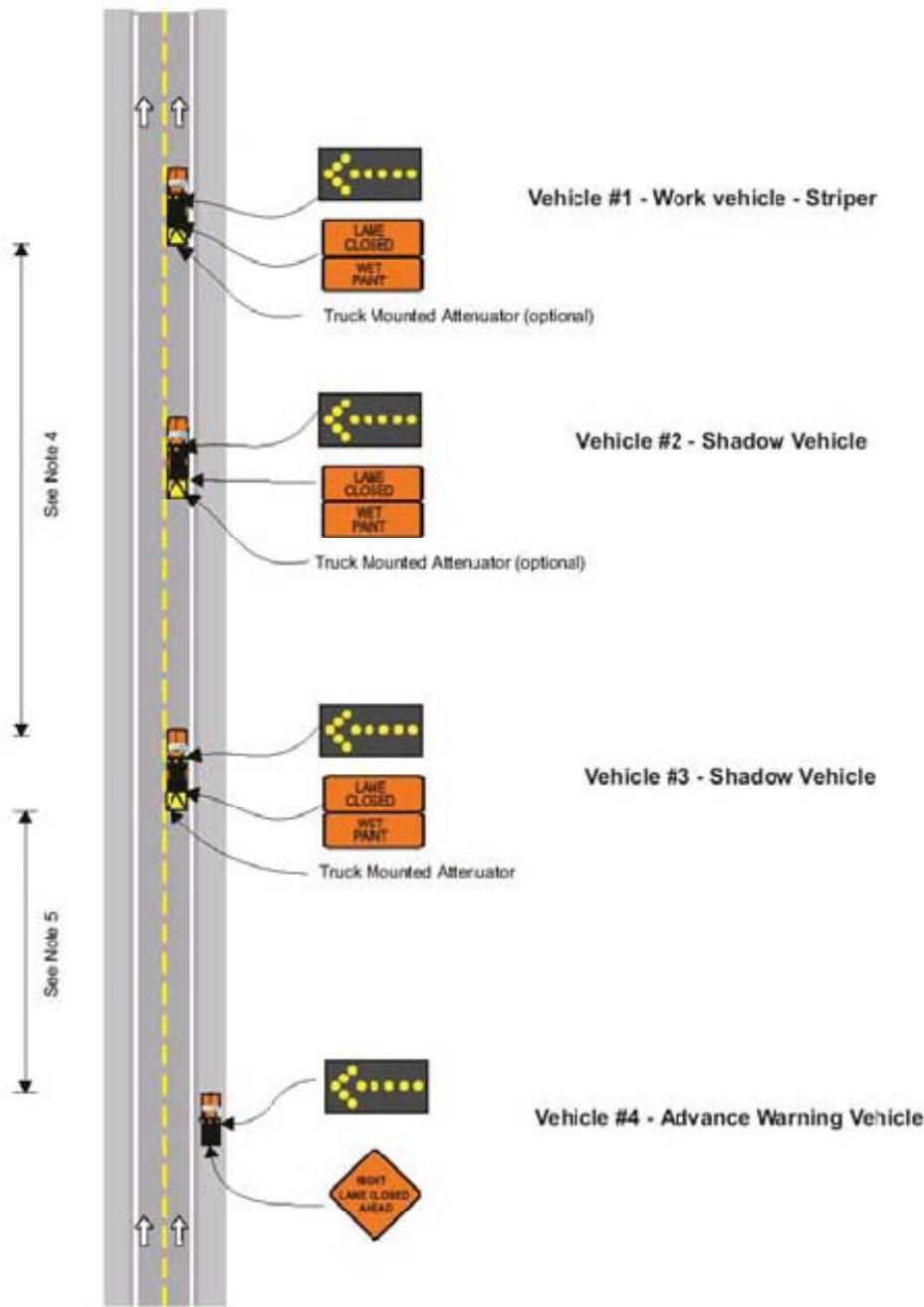


Figure A-2. NMTA 6 from Traffic Control Handbook for Mobile Operations at Night: Guidelines for construction, maintenance, and utility operations.

NMTA - 7 Night Striping Operation on Multi-Lane Highway - Narrow Shoulders and Restricted Sight Distance

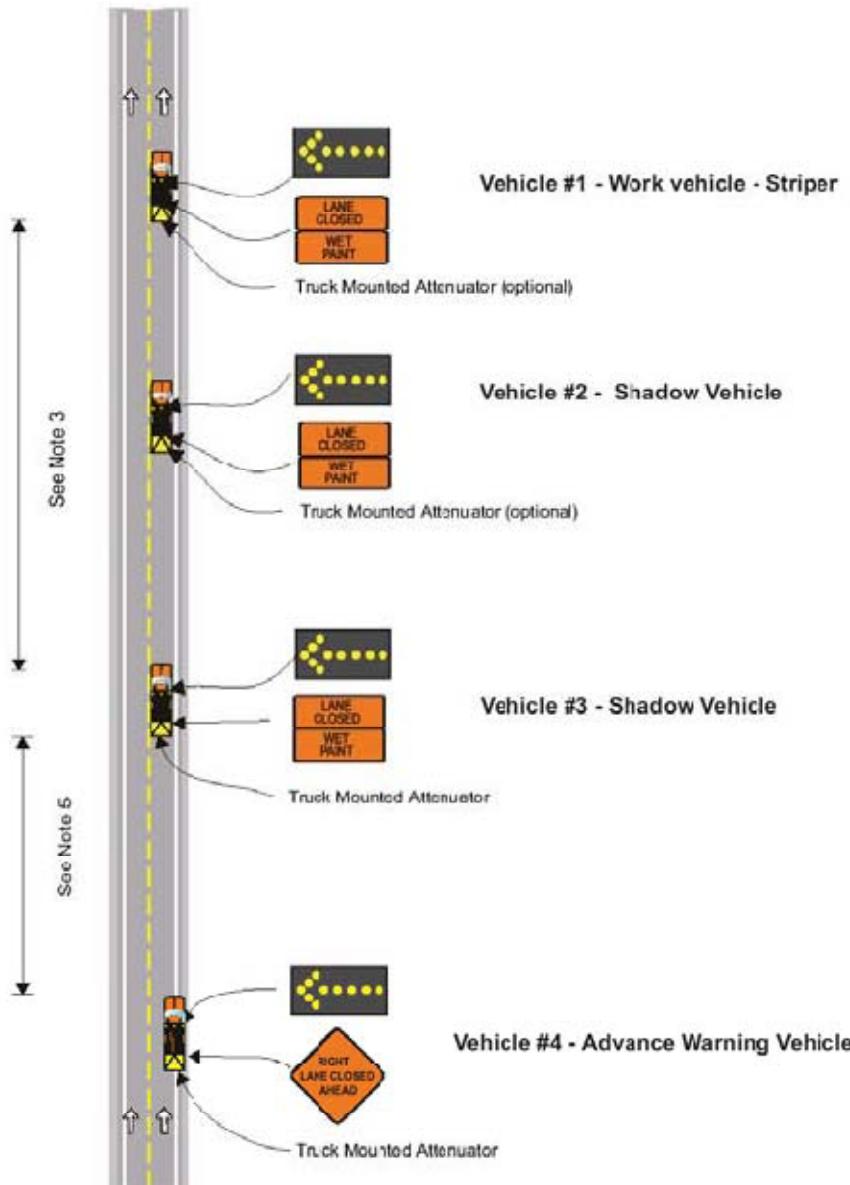


Figure A-3. NMTA 7 from Traffic Control Handbook for Mobile Operations at Night: Guidelines for construction, maintenance, and utility operations.

NMTA - 8 Night Mobile Operation on Interior Lane of Multi-Lane Highway

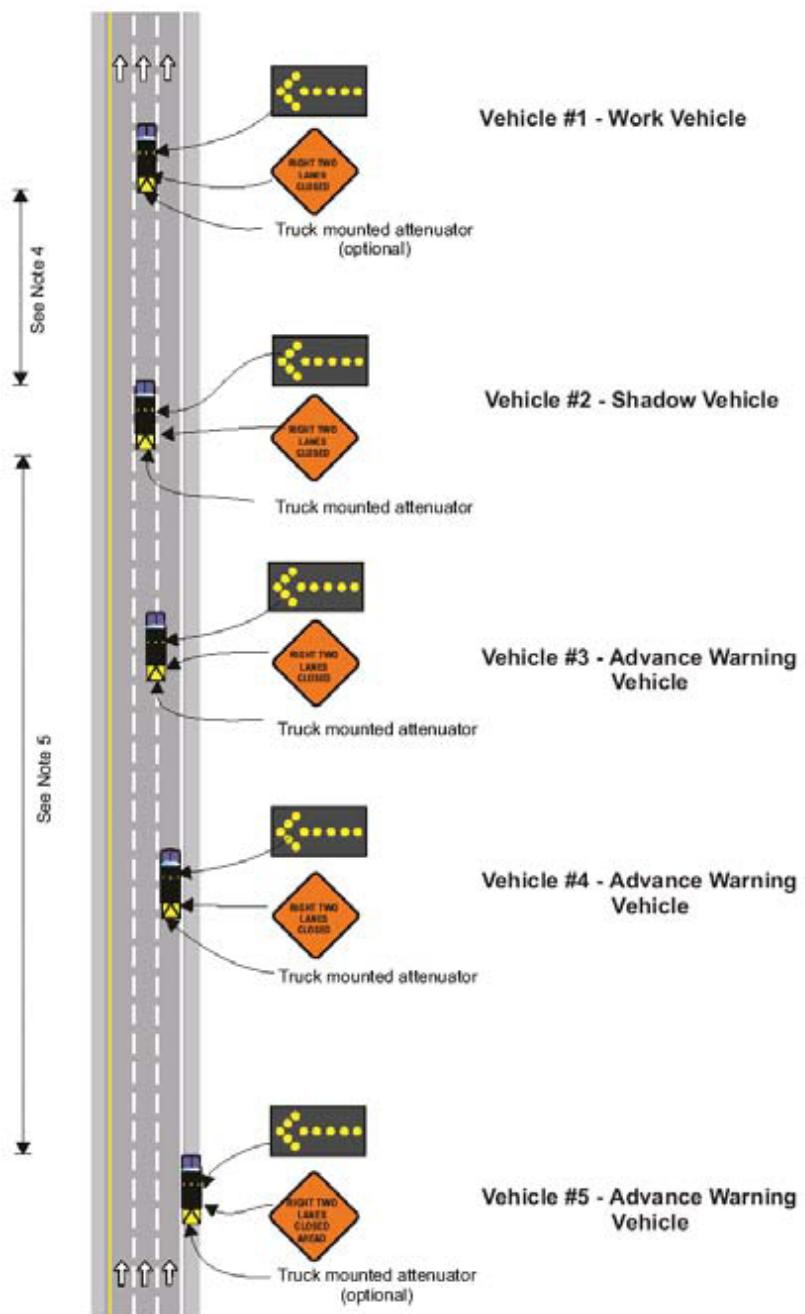


Figure A-4. NMTA 8 from Traffic Control Handbook for Mobile Operations at Night: Guidelines for construction, maintenance, and utility operations.

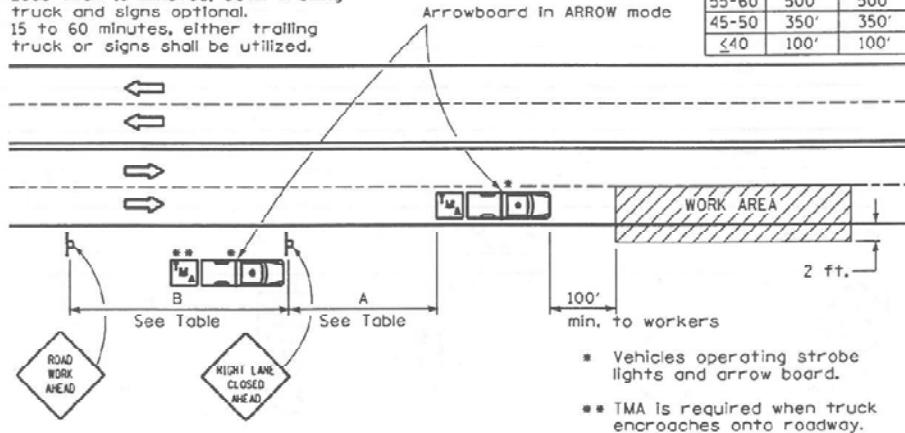
WZ 40

**ALL SPEEDS
MULTILANE
UP TO 60 MINUTES**

Less than 15 minutes, both trailing truck and signs optional.
15 to 60 minutes, either trailing truck or signs shall be utilized.

For left lane closure use corresponding left lane information. If median \geq 10 ft., signs are required in median.

TABLE OF SIGN SPACING		
SPEED MPH	LENGTH A	LENGTH B
65	1000'	1600'
55-60	500'	500'
45-50	350'	350'
≤ 40	100'	100'



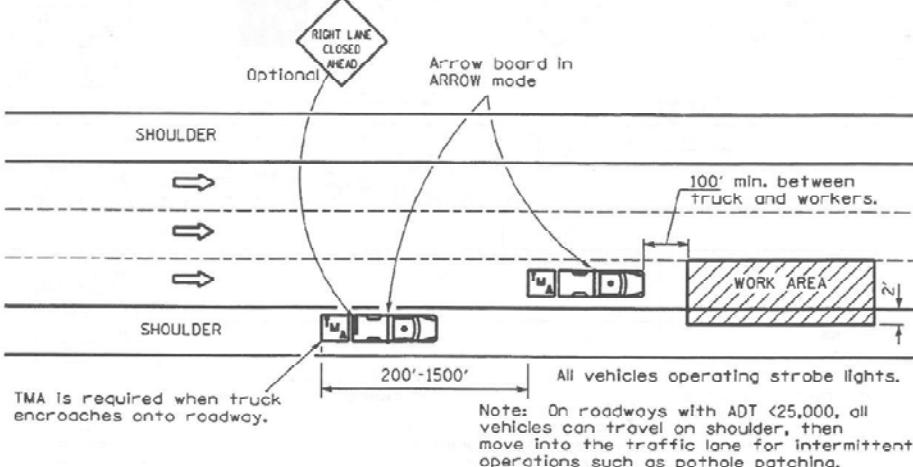
69

Figure A-5. WZ40-All speeds multi-lane up to 60 minutes from IDOT Work Site Protection Manual.

WZ 46

**ALL SPEEDS
INTERMITTENT / MOVING OPERATION
NO TIME LIMIT
MORE THAN 4 MILE PER DAY**

If work production <4 mile/day,
WZ48 must be utilized.



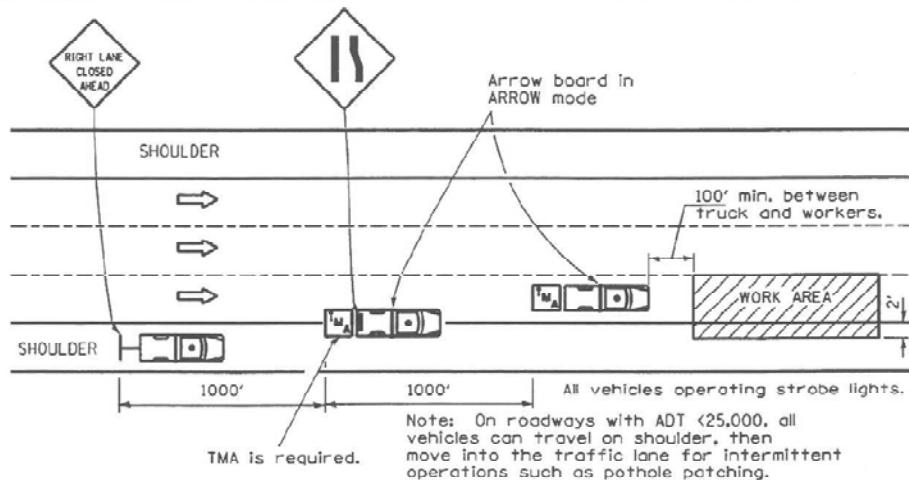
78

Figure A-6. WZ46 – All speeds, intermittent / moving operation, no time limit, more than 4 miles per day from IDOT Work Site Protection Manual.

**ALL SPEEDS
INTERMITTENT / MOVING OPERATION
NO TIME LIMIT
MORE THAN 4 MILE PER DAY**

WZ 46A

If work production <4 mile/day,
WZ48 must be utilized.

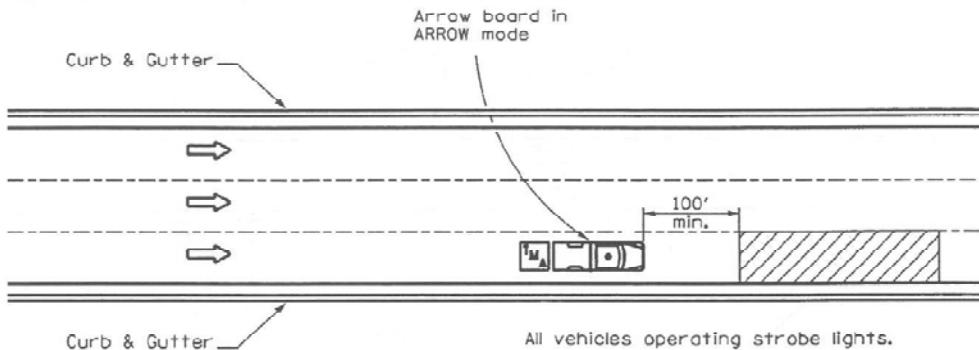


79

Figure A-7. WZ46A – All speeds, intermittent / moving operation, no time limit, more than 4 miles per day from IDOT Work Site Protection Manual.

**45 MPH OR LESS
INTERMITTENT / MOVING OPERATION
WITH CURB AND GUTTER
ONE LANE CLOSURE**

WZ 47



81

Figure A-8. WZ47 – 45 MPH or less, intermittent / moving operation with curb and gutter, one lane closure from IDOT Work Site Protection Manual.

WZ 48

**ALL SPEEDS
INTERMITTENT / MOVING OPERATION
NO TIME LIMIT
LESS THAN 4 MILE PER DAY**

Flashing Arrow board in ARROW mode
All vehicles operating strobe lights

Note:
Minimum distance is 200 ft. at start of operation. Maximum distance is two miles, but in no case to exceed one half the length required for one normal day's operation.

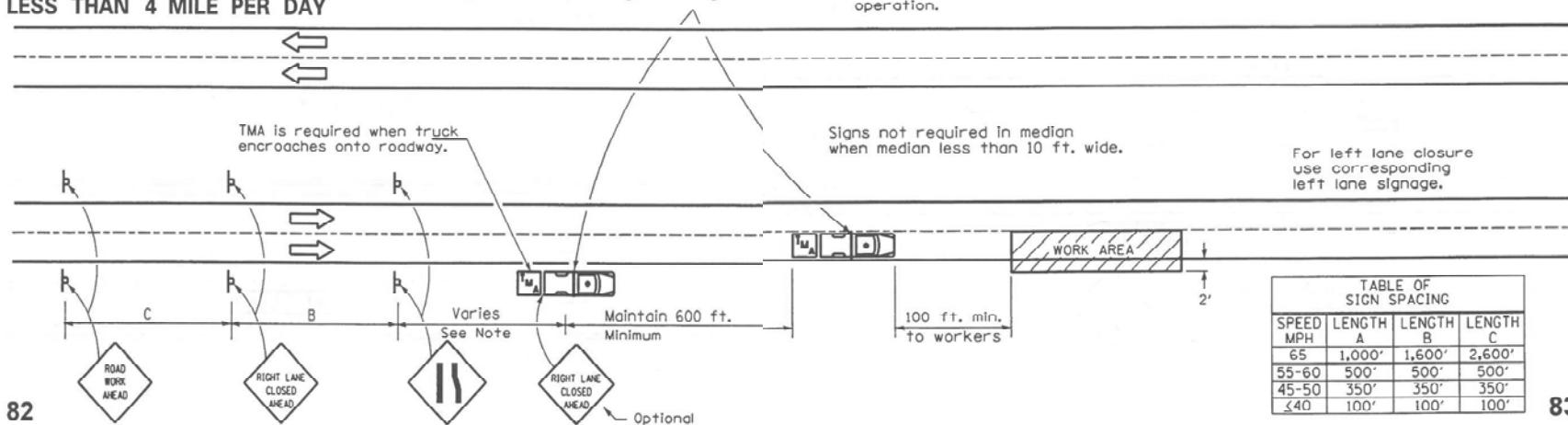
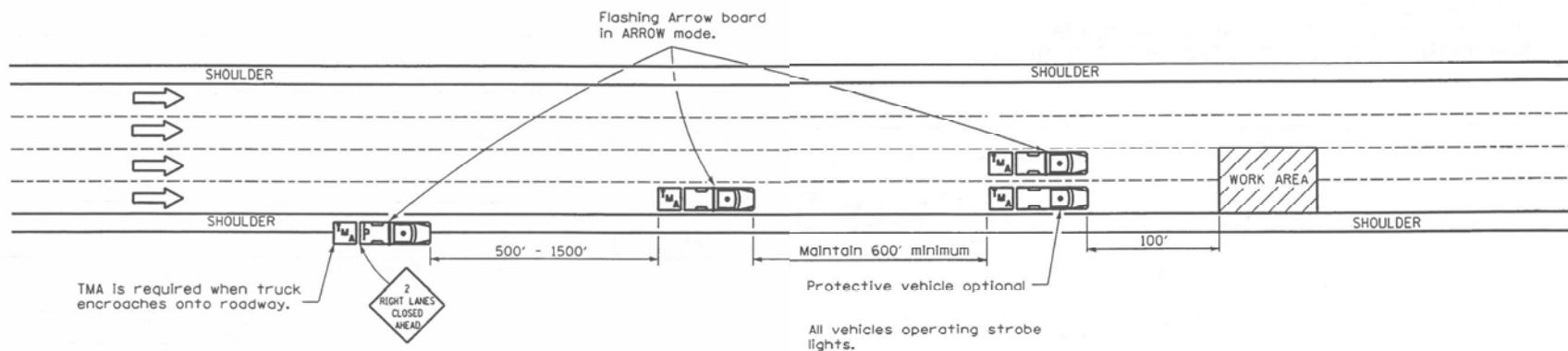


TABLE OF SIGN SPACING			
SPEED MPH	LENGTH A	LENGTH B	LENGTH C
65	1,000'	1,600'	2,600'
55-60	500'	500'	500'
45-50	350'	350'	350'
≤40	100'	100'	100'

Figure A-9. WZ 48 – All speeds, intermittent / moving operation, no time limit, less than 4 miles per day from IDOT Work Site Protection Manual.

**INTERMITTENT / MOVING OPERATION
TWO LANE CLOSURE**

WZ 49

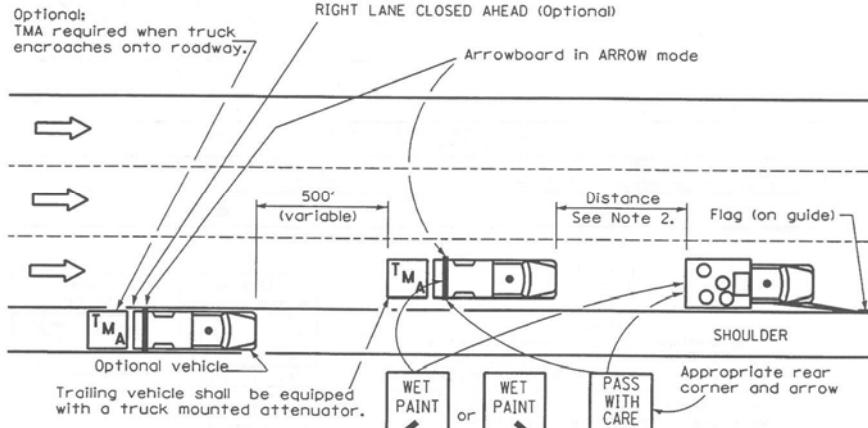


84

Figure A-10. WZ49 – Intermittent / moving operation, two lane closure from IDOT Work Site Protection Manual.

85

ALL SPEEDS
MULTILANE MOVING OPERATION



90

Notes:

WZ 52

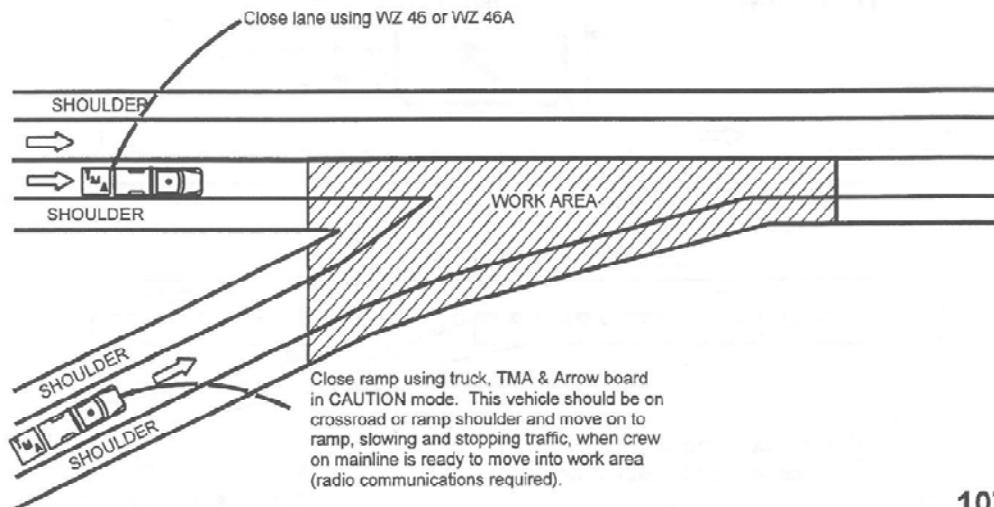
1. Striping machine and all vehicles in convoy (except law enforcement vehicles) are to have headlights operating and are to display an amber colored oscillating, rotating, flashing or strobe lights. At least one amber light is to be visible from any direction.
2. Distance trailing vehicle(s) follows striping machine will vary depending on terrain and susceptibility of painted line to wheel tracking, whenever adequate stopping site distance exists to rear, the protection vehicle shall maintain minimal distance. The protection vehicle should slow down in advance of vertical and horizontal curves that restrict sight distance.
3. Striping operation may be supported by additional traffic control devices.
4. Use WET PAINT and PASS WITH CARE signs on striping operations.
5. On curb and gutter sections, truck on shoulder is not required.

91

Figure A-11. WZ52 – All speeds, multi-lane moving operation from IDOT Work Site Protection Manual.

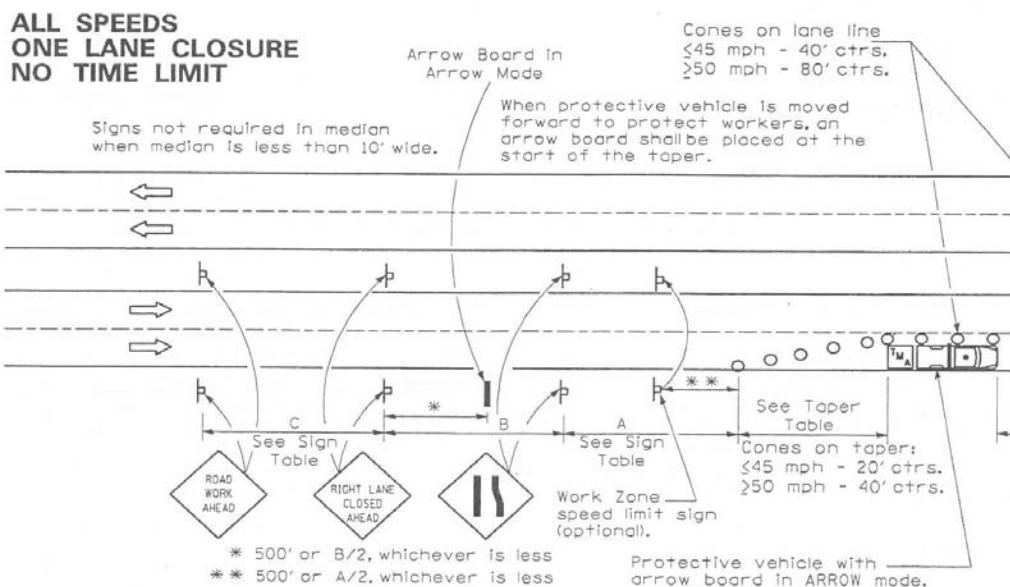
**MOVING OPERATION FOR WORK AT
ENTRANCE RAMP (15 MIN. AND LESS)**

WZ 63



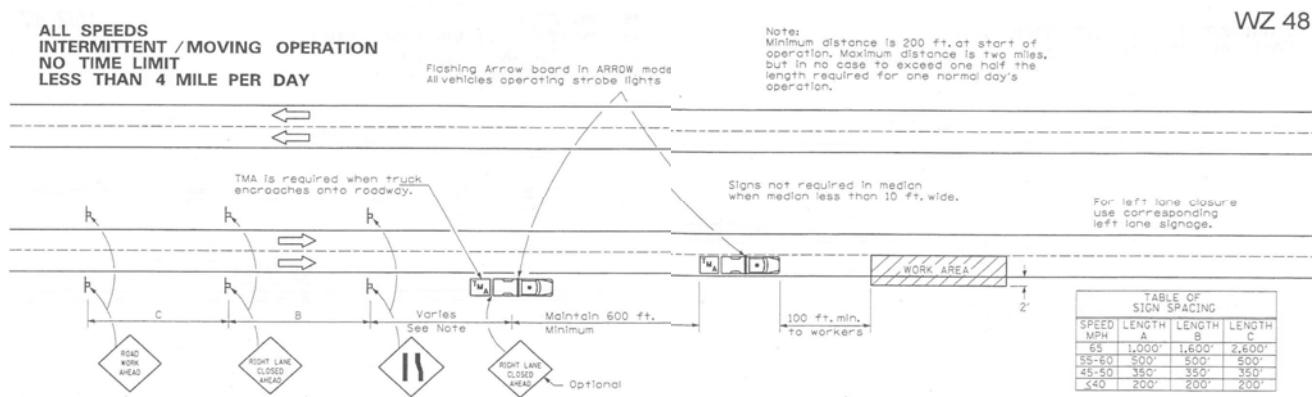
107

Figure A-12. WZ63 – Moving operation for work at entrance ramp from IDOT Work Site Protection Manual.



76

Figure A-13. WZ40 – All speeds multi-lane up to 60 minutes from Supplement to IDOT Work Site Protection Manual.



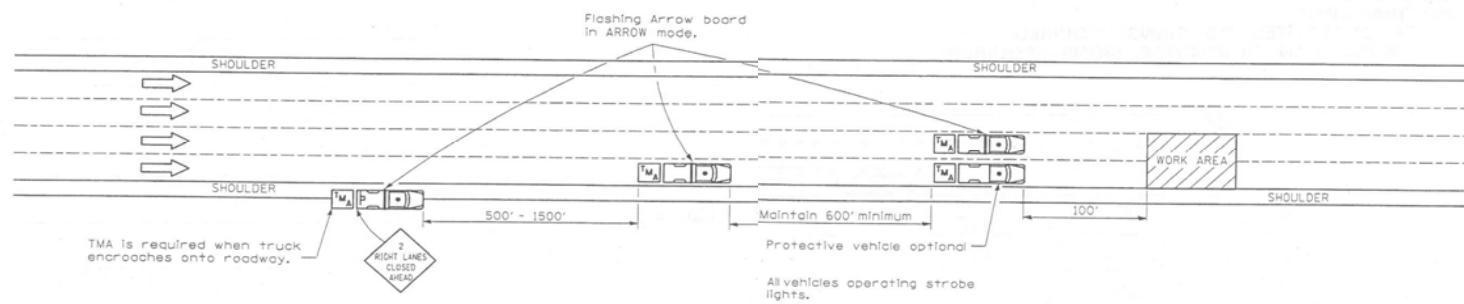
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87

Figure A-14. WZ 48 – All speeds, intermittent / moving operation, no time limit, less than 4 miles per day from Supplement to IDOT Work Site Protection Manual.

**INTERMITTENT / MOVING OPERATION
TWO LANE CLOSURE**

WZ 49

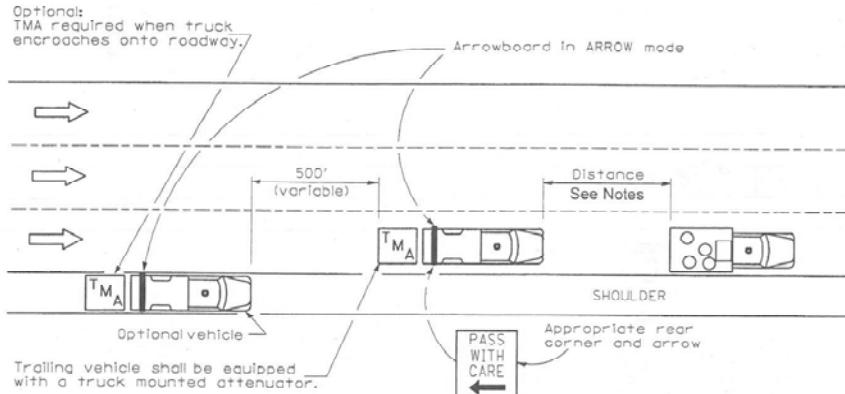


88

89

Figure A-15. WZ49 – Intermittent / moving operation, two lane closure from Supplement to IDOT Work Site Protection Manual.

**ALL SPEEDS
MULTILANE MOVING OPERATION**



94

Figure A-16. WZ52 – All speeds, multi-lane moving operation from Supplement to IDOT Work Site Protection Manual.

WZ 52

Notes:

All vehicles in convoy (except law enforcement vehicles) are to have headlights operating and are to display an amber colored oscillating, rotating, flashing or strobe lights. At least one amber light is to be visible from any direction.

Distance trailing vehicle(s) follows vary depending on terrain, whenever adequate stopping sight distance exists to rear, the protection vehicle shall maintain minimal distance. The protection vehicle should slow down in advance of vertical and horizontal curves that restrict sight distance.

On curb and gutter sections, truck on shoulder is not required.

95

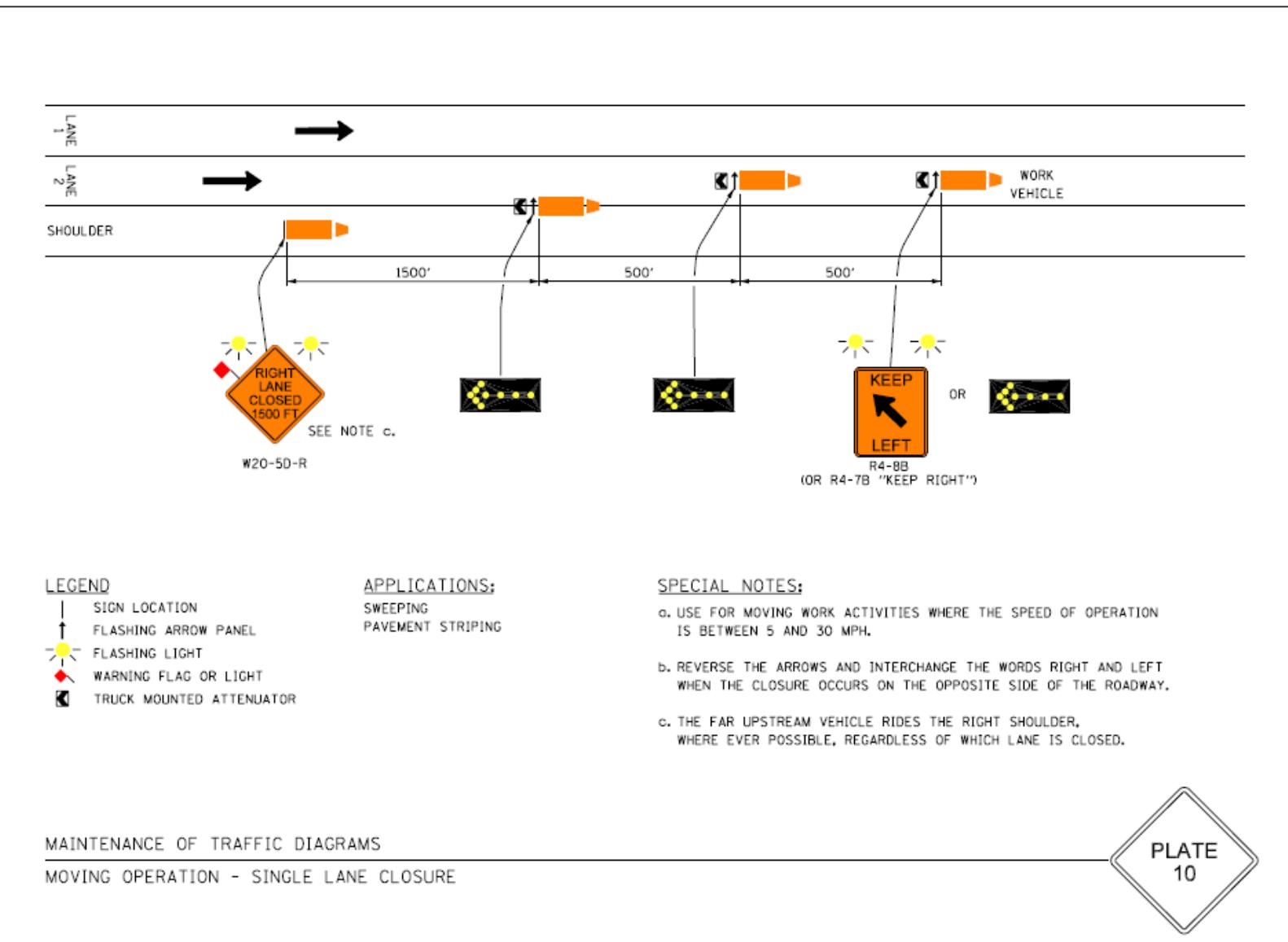


Figure A-17. Plate 10 from Illinois Tollway Roadway Traffic Control and Communications Guidelines.

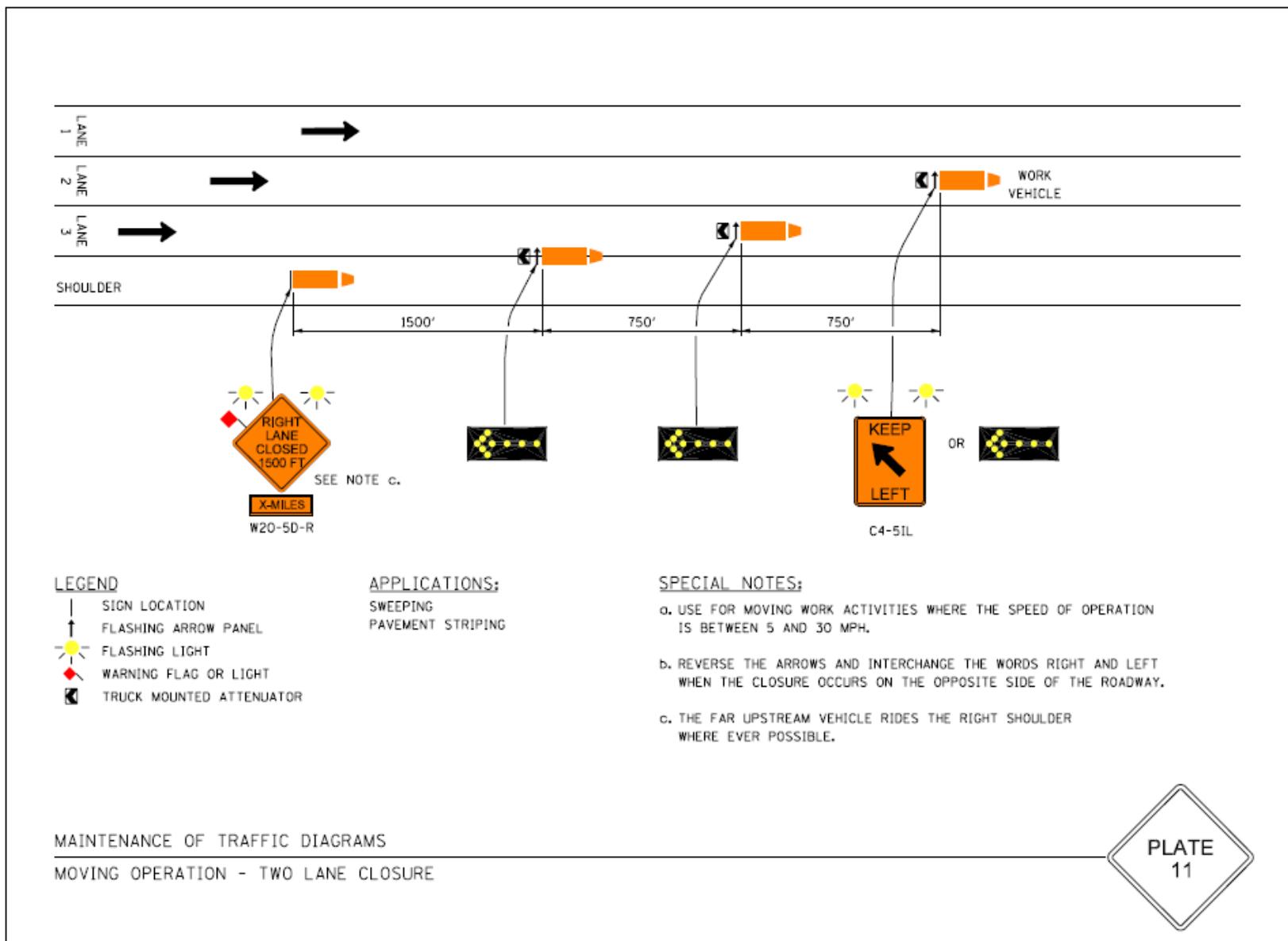


Figure A-18. Plate 11 from Illinois Tollway Roadway Traffic Control and Communications Guidelines.

Mobile Operation on a Multi-Lane Road

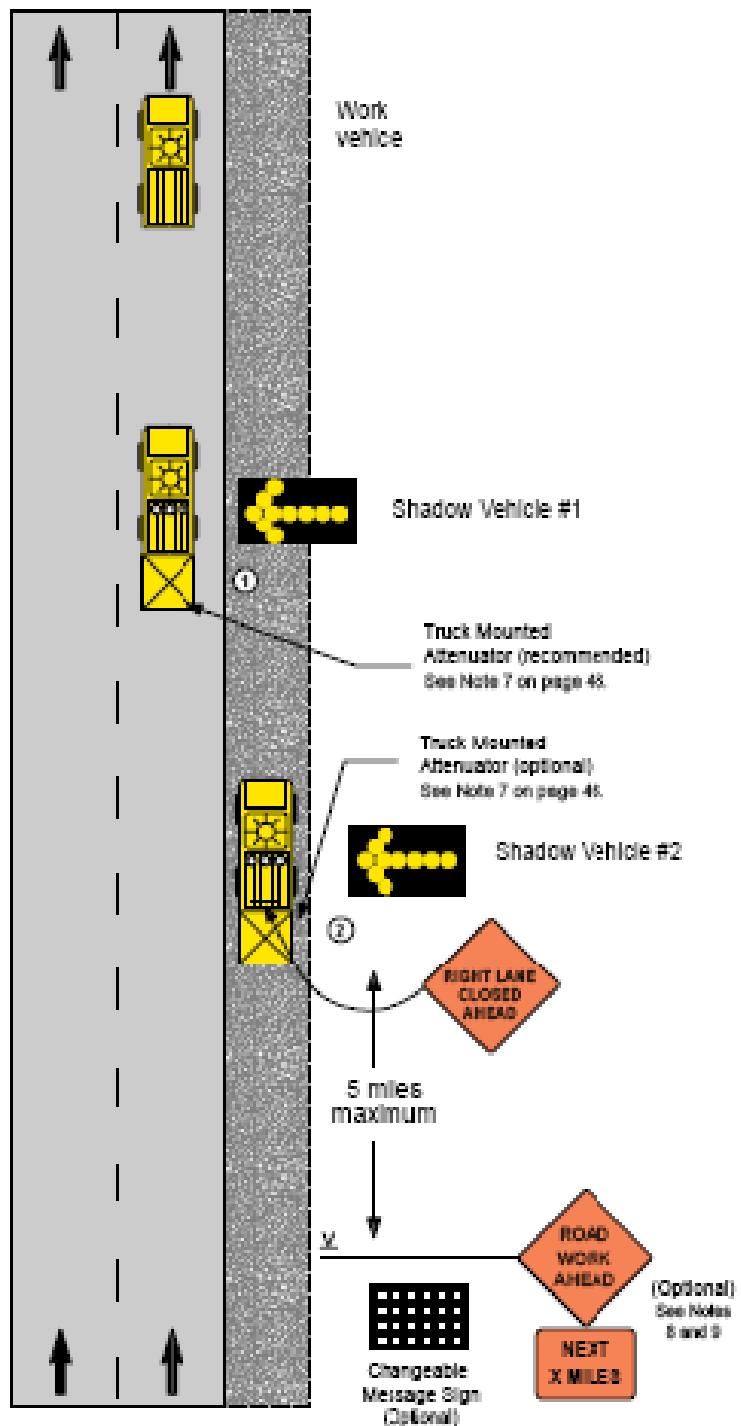


Figure A-19. Wisconsin DOT Work Zone Safety Guide.



Illinois Department
of Transportation



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN