

SYNTHESIS OF BEST PRACTICE FOR INCREASING PROTECTION AND VISIBILITY OF HIGHWAY MAINTENANCE VEHICLES

Iowa DOT Project TR-475
CTRE Project 02-107

Sponsored by
the Iowa Department of Transportation
and the Iowa Highway Research Board



**Iowa Department
of Transportation**



*Center for Transportation
Research and Education*

IOWA STATE UNIVERSITY

Final Report • August 2002

Synthesis of Best Practice for Increasing Protection and Visibility of Highway Maintenance Vehicles

Abstract

The purpose of this research project is to study current practices in enhancing visibility and protection of highway maintenance vehicles involved in moving operations such as snow removal and shoulder operations, crack sealing, and pothole patching. The results will enable the maintenance staff to adequately assess the applicability and impact of each strategy to their use and budget.

The report's literature review chapter examines the use of maintenance vehicle warning lights, retroreflective tapes, shadow vehicles and truck-mounted attenuators, and advanced vehicle control systems, as well as other practices to improve visibility for both snowplow operators and vehicles. The chapter concludes that the *Manual on Uniform Traffic Control Devices* does not specify what color or kind of warning lights to use. Thus, a wide variety of lights are being used on maintenance vehicles. The study of the relevant literatures also suggests that there are no clear guidelines for moving work zones at this time.

Two types of surveys were conducted to determine current practices to improve visibility and safety in moving work zones across the country and in the state of Iowa. In the first survey of state departments of transportation, most indicated using amber warning lights on their maintenance vehicles. Almost all the responding states indicated using some form of reflective material on their vehicles to make them more visible. Most participating states indicated that the color of their vehicles is orange. Most states indicated using more warning lights on snow removal vehicles than their other maintenance vehicles. All responding state agencies indicated using shadow vehicles and/or truck-mounted attenuators during their moving operations. In the second survey of Iowa counties, most indicated using very similar traffic control and warning devices during their granular road maintenance and snow removal operations. Mounting warning signs and rotating or strobe lights on the rear of maintenance vehicles is common for Iowa counties. The most common warning devices used during the counties' snow removal operations are reflective tapes, warning flags, strobe lights, and auxiliary headlamps.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Department of Transportation.

CTRE's mission is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability while improving the learning environment of students, faculty, and staff in transportation-related fields.

Synthesis of Best Practice for Increasing Protection and Visibility of Highway Maintenance Vehicles

Iowa DOT Project TR-475
CTRE Project 02-107

Principal Investigator

Ali Kamyab

Research Scientist, Center for Transportation Research and Education

Principal Contributor

Tom McDonald

Safety Circuit Rider, Center for Transportation Research and Education

Research Assistant

Brandon Storm

Preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its research management agreement with the Center for Transportation Research and Education.

Center for Transportation Research and Education

Iowa State University

2901 South Loop Drive, Suite 3100

Ames, IA 50010-8632

Phone: 515-294-8103

Fax: 515-294-0467

www.ctre.iastate.edu

Final Report • August 2002

Table of Contents

ACKNOWLEDGEMENTS	ix
INTRODUCTION.....	1
LITERATURE REVIEW.....	3
Introduction	3
Moving Operations Guidance	3
Warning Lights.....	5
Shadow Vehicles and Truck-Mounted Attenuators	7
Retroreflective Tape.....	8
Advanced Vehicle Control Systems.....	9
Practices to Improve Snowplow Visibility.....	10
Summary	12
SURVEYS.....	13
Introduction	13
Survey of State Departments of Transportation.....	13
Survey of Iowa Counties	16
Summary	17
REFERENCES.....	19
Appendix A—Moving Operation Guidelines	
Appendix B—Photos of State DOT Maintenance Vehicles	
Appendix C—Survey Form for State Departments of Transportation	
Appendix D—Survey Form for Iowa Counties	
Appendix E—State Survey Responses: Warning Lights	
Appendix F—State Survey Responses: Reflective Tape	
Appendix G—State Survey Responses: Vehicle Color	
Appendix H—State Survey Responses: Snow Removal Devices	
Appendix I—State Survey Responses: Moving Work Zone Guidelines and Equipment	
Appendix J—Iowa County Survey Responses: Traffic Control Devices for Routine Maintenance Operations	
Appendix K—Iowa County Survey Responses: Warning Devices for Snow Removal Operations	
Appendix L—Truck Specifications for Paint, Warning Lights, and Reflective Tape	

List of Figures

Figure 1. MUTCD Schematic for Mobile Operation on Two-Lane Road.....	4
Figure 2. MUTCD Schematic for Mobile Operation on Multilane Road.....	4
Figure 3. Side and Rear View of a Minnesota DOT Snowplow.....	9
Figure 4. Maintenance Truck with Applied Scoop.....	11
Figure 5. Safety Fence with Reflective Tape.....	12
Figure 6. Dual Speed Display.....	12

List of Tables

Table 1. Recommendations for the Assignment of Shadow Vehicles	7
Table 2. Recommendations for the Application of Truck-Mounted Attenuators	8

ACKNOWLEDGEMENTS

The authors would like to thank the Iowa Highway Research Board for sponsoring this project. The contributions of advisory committee members (listed below in an alphabetical order) were invaluable to the project's completion.

- Don Allis, Dallas County
- Bill Kreinbring, Iowa Department of Transportation
- Ken Lang, City of Ames
- Ed Schmanke, City of West Des Moines
- Dan Sprengeler, Iowa Department of Transportation

The authors would also like to thank all individuals who provided information for the project's literature search and surveys. Thanks also to Steve Andrie, director of the Center for Transportation Research and Education at Iowa State University, for supporting this research.

INTRODUCTION

Despite the availability of many new crash attenuators, lights, and reflective materials, a large number of crashes are still attributed to poor visibility of maintenance vehicles and personnel in moving work zone operations. The new materials have greatly improved safety and visibility; however, there is no concise summary of products and practices available to advise maintenance supervisors and personnel.

The purpose of this research project is to study current practices in enhancing visibility and protection of highway maintenance vehicles involved in moving operations such as snow removal and shoulder operations, crack sealing, and pothole patching. This project report provides the most recent information on current moving operation practices throughout the country and the state of Iowa. It will enable the maintenance staff to adequately assess the applicability and impact of each strategy to their use and budget.

An advisory committee was invited to assist in the study. The committee, composed of representatives from cities, counties, and the state provided valuable advice and recommendations in conducting the project.

The report's literature review chapter examines the use of maintenance vehicle warning lights, retroreflective tapes, shadow vehicles and truck-mounted attenuators (TMAs), and advanced vehicle control systems (AVCSs), as well as other practices to improve visibility for both snowplow operators and vehicles.

The literature review chapter concludes that the *Manual on Uniform Traffic Control Devices* (MUTCD) does not specify what color or kind of warning lights to use. Thus, a wide variety of lights are being used on maintenance vehicles.

The study of the relevant literatures also suggests that there are no clear guidelines for moving work zones at this time. Furthermore, it reveals the insufficiency of investigative studies of the equipment and techniques used to enhance the safety of public and workers in moving maintenance operations. This is in contrast to the stationary operations where researchers have enormously contributed to the field throughout the years. A compilation of current moving work zone practices in similar studies is believed to be helpful in identifying future research areas and fulfilling the existing literature gap. These studies should examine the moving operations in rural and urban areas as well, which demand separate investigations. Due to different traffic characteristics, recommendations made for the safety improvement at rural areas may not be applicable to urban environments.

As part of this research, two types of surveys were conducted to determine current practices to improve visibility and safety in moving work zones across the country and in the state of Iowa. A summary of the survey responses is included in the survey chapter of the report.

In the first survey, state departments of transportation (DOTs) were contacted either by e-mail or phone. Several Wisconsin counties were also contacted since the state's policy allows contracting of roadway maintenance to local counties. Most participating state agencies indicated

using amber warning lights on their maintenance vehicles. Some states also use white, blue, and/or red warning lights. A few states have started using light emitting diode (LED) service and warning lights on their vehicles. Almost all the responding state DOTs indicated using some form of reflective material on their vehicles to make them more visible. The most common colors are red and white. Amber is also used. Most participating states indicated that the color of their vehicles is orange. White is the second most common color used. Most states indicated using more warning lights on snow removal vehicles than their other maintenance vehicles. Using a combination of colors rather than the amber color alone is also common for some states. A few states use snowplow deflectors along with rear airfoils to reduce the amount of airborne snow. All responding state agencies indicated using shadow vehicles and/or TMAs during their moving operations. Some states also have specific work zone guidelines set up to supplement the MUTCD.

To learn about work zone visibility practices throughout the state of Iowa, a mail survey was conducted in all 99 counties. The survey was sent to the county engineers, requesting information pertaining to their maintenance vehicles used during routine granular road maintenance and snow removal operations. The Iowa county survey indicates that most counties use very similar traffic control and warning devices during their granular road maintenance and snow removal operations. Mounting warning signs and rotating or strobe lights on the rear of maintenance vehicles is common for Iowa counties. The most common warning devices used during the counties' snow removal operations are reflective tapes, warning flags, strobe lights, and auxiliary headlamps.

LITERATURE REVIEW

Introduction

This chapter reviews current highway maintenance protection strategies for moving and temporary work zone operations. It primarily focuses on the use of warning lights, shadow vehicles and truck-mounted attenuators, retroreflective tape, and advanced vehicle control systems, as well as practices to improve visibility for both snowplow operators and vehicles. A summary of the MUTCD's passages pertaining to moving operations is also provided. The suggested guidelines and standards in the MUTCD are the basis for the practice of many state agencies in conducting their moving maintenance operations.

Moving Operations Guidance

Manual on Uniform Traffic Control Devices

The MUTCD's sections 6G.02 ("Work Duration") and 6H.01 ("Typical Applications") can be referred for detailed information on the suggested standards and guidelines of mobile operations (1).

The MUTCD divides work duration into five categories: (1) long term, (2) intermediate term, (3) short term, (4) short duration, and (5) mobile. Section 6G.02 of the MUTCD defines mobile operations (e.g., pavement marking operations and pothole patching) as those that move intermittently or continuously.

Per MUTCD instructions, "these operations shall have appropriate devices on the equipment (i.e., rotating lights, signs, or special lighting), or shall use a separate vehicle with appropriate warning devices." The MUTCD also states "when mobile operations are being performed, a shadow vehicle equipped with an arrow panel or a sign should follow the work vehicle, especially when motor vehicle traffic speeds or volumes are high" (1).

Figures 1 and 2 show MUTCD schematics of mobile operations on two-lane and multilane roads, respectively (1). According to the MUTCD, shadow and work vehicles shall display rotating lights or strobe lights. A TMA should be used on the shadow vehicle. The shadow vehicles should also be equipped with two high-intensity flashing lights mounted on the rear, adjacent to the sign.

On a multilane road, vehicles used for mobile operations should be made highly visible with appropriate equipment, such as rotating lights, strobe lights, flags, signs, and/or arrow panels. As seen in Figure 2, shadow vehicle 1, following the work vehicle on the mainline, should be equipped with an arrow panel and TMA. Shadow vehicle 2, traveling on the shoulder, should be equipped with an arrow panel.

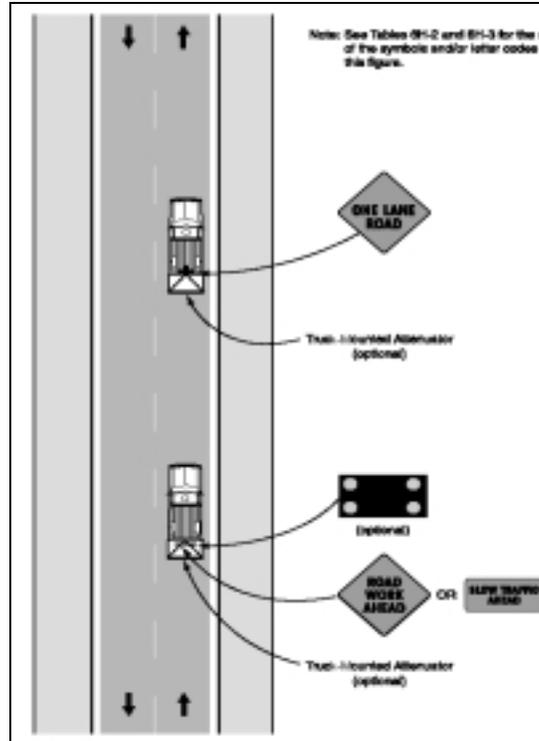


Figure 1. MUTCD Schematic for Mobile Operation on Two-Lane Road

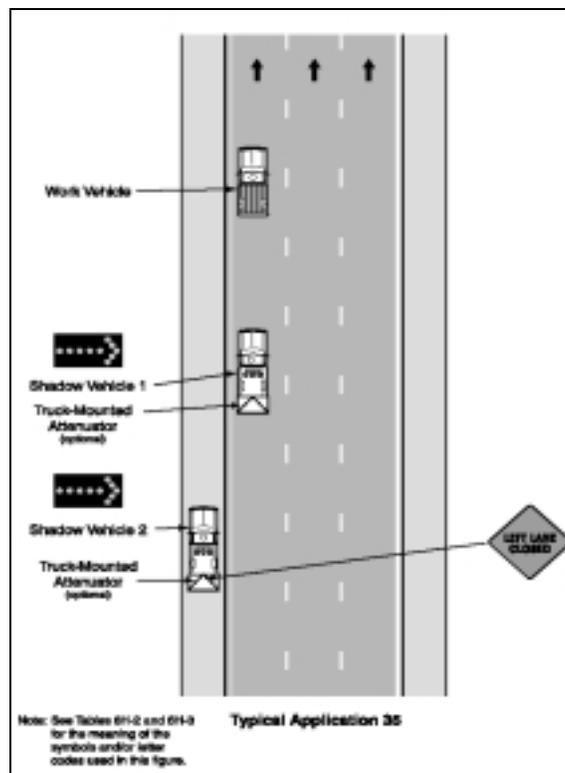


Figure 2. MUTCD Schematic for Mobile Operation on Multilane Road

Other Sources of Information on Moving Operations

For additional information about warning lights and control devices during various operations, readers are encouraged to refer to Appendix A of National Cooperative Highway Research Program (NCHRP) Report 337, *Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Operations*.

In addition, the Iowa Department of Transportation (Iowa DOT) has developed a traffic control layout for rumble strip milling operations on multilane roadways (reproduced here in Appendix A). The plan calls for the use of three shadow vehicles and at least two TMAs. Appendix A also includes the moving guidelines and policies on divided highways practiced by other state DOTs (i.e., Florida, Missouri, North Carolina, and Virginia).

Warning Lights

The MUTCD requires warning lights (e.g., rotating or strobe lights) on most maintenance vehicles. The purposes of warning lights are to warn motorists that a highway maintenance vehicle is on or near the roadway, to allow drivers to take actions with enough warning time, to define the shape and size of the vehicle, and to convey the intent of the vehicle.

There are many different warning lights that can be used on maintenance vehicles, and currently there is no uniform standard with respect to warning lights used by states (2). For example, Alaska, Colorado, Minnesota, Texas, and other state DOTs allow blue auxiliary lights along with standard amber lights during snow removal operations and other high-risk activities. The Texas DOT classifies an operation “high risk” if workers are to be out of the vehicle while in a lane of traffic and the maintenance vehicle travels at less than four mph or more than 30 mph below the traffic operating speed. It is believed that the use of blue lights signifies the activities as hazard-potential operations, which demand higher motorist alertness (2, 3).

Warning lights can vary by color, method of flashing, rate of flashing, and intensity. Studies have been conducted to see if certain configurations of warning lights are more effective than others in communicating the hazardousness of a work area. A Texas Transportation Institute (TTI) study concluded that an all-amber light bar system (with rotating elements) was effective for moving operations. It was also found that rotating beacons and flashing strobe-light combination systems worked well in both moving and stationary work zones. TTI found that using combined blue and amber lights, compared to using just amber lights, resulted in significant speed reductions at some study sites. Although not all study sites observed significant speed reductions, TTI recommended the use of combined blue and amber lights on vehicles engaged in high-risk maintenance activities (3).

In 1990, Hanscom and Pain developed some guidelines for warning lights in temporary and moving work zones under two different conditions: closed field and field experiment (4, 5). The closed-field study was conducted on an unopened four-lane divided highway. A dump truck with different lighting configurations traveling at 4, 14, or 28 mph was used. A van with the test subjects followed the dump truck at various speeds and distances. The test subjects were asked to

determine the speed that they were traveling and how fast they were closing on the service vehicle. The findings of the closed-field study are listed below.

- If only one type of light is used, four-way flashers provide the most accurate information about closure rate and service vehicle speed.
- Adding more of the same type of lights on the service vehicle does not increase the amount of information provided to the driver or enhances the driver's ability to extract information from the lights.
- Changing the location of the light(s) on the service vehicle does not increase information or the ability to extract information. It is important that the light can be seen from all directions.
- Lighting parameters (flash rates between 60 and 100 cycle per minute and medium versus high-intensity lights) had little effect on driver response.
- Adding a four-way flasher to any other warning light increases the amount of information provided to the driver. Similarly, combining a roof-mounted flasher light and rotating light increases the information input to the driver.

The field experiment, on the other hand, was conducted on seven sites on two-lane, four-lane, or four-lane divided roadways during short-term and moving operations. The measure of effectiveness of various light applications was determined from drivers mean lane change time and critical lane change time.

Four lighting systems were tested for *short-term lane closure operations* in the field experiment: light bar (sequence flashing six lights), two rotating lights plus one flashing light, double flash strobe, and four-way flashers plus one cab mounted flashing light. The study concluded that the most effective lighting system was the two rotating lights plus one flashing light compared to the baseline lights (i.e., two-bulb rotating beacons). The light bar was also found to be somewhat effective in improving the truck visibility.

Five light combinations were also examined in *moving operations* at eight mph in the field experiment: light bar, two rotating lights plus a flasher light, double flash strobe, four-way-flasher plus single flasher, and two side-mounted eight-inch flasher lights (Ohio Light). It was found that the light bar was the best warning light. The two rotating-plus-flasher lights and Ohio Light were found to be somewhat effective. No improvements in the truck visibility were observed with using the double flash strobe over the standard, two-bulb rotating beacons.

Some states use either rotating and/or strobe lights. The Missouri DOT changed their warning lights on most of their maintenance vehicles from revolving to strobe lights in 2002. The department switched to the strobe lights because it feels they are easier to see farther away and provide earlier warnings to drivers of approaching hazards. It justified switching the lights by pointing out that emergency-response vehicles, school buses, and utility-company vehicles use strobe lights because they believe strobe lights can be seen farther away (6).

Shadow Vehicles and Truck-Mounted Attenuators

Shadow vehicles and TMAs are used in work zones to provide additional safety to both motorists and workers. Shadow vehicles follow moving or temporary work zones at a short distance. Any vehicles not recognizing the work zone and taking appropriate actions may collide with the shadow vehicle instead of entering the work zone. A typical shadow vehicle is a large dump truck. If the shadow vehicle is equipped with a TMA, ideally the severity to both the shadow vehicle and the intruding vehicle will be minimized (7). Hanscom and Pain found that the use of a shadow vehicle following 500 feet behind a moving operation is more effective than lighting systems in making drivers change lanes (5).

No known standard has yet been established for the use of shadow vehicles equipped with TMAs in work zones. The *Virginia Work Area Protection Manual* suggests using TMAs on limited-access highways during mobile maintenance operations (e.g., pavement markings), stationary lane closures, and other situations as warranted (7).

Humphreys and Sullivan developed some guidelines to determine the assignment of shadow vehicles (7). The study “very highly” recommended using shadow vehicles on both freeways and non-freeways when there is no formal lane closure, but the operation involves exposed personnel. Tables 1 and 2 present the recommendations for the use of shadow vehicles and TMAs during both lane and shoulder closures.

Table 1. Recommendations for the Assignment of Shadow Vehicles

Closure/Exposure Condition	Freeway	Non-Freeway with Speed Limit		
		>=50 mph	40–45 mph	<=35 mph
Shadow vehicle for no formal lane closure for operation involving exposed personnel	Very highly recommended	Very highly recommended	Very highly recommended	Very highly recommended
Shadow vehicle for no formal lane closure for operation NOT involving exposed personnel	May be justified*	May be justified*	May be justified*	May be justified*
Shadow vehicle for no formal shoulder closure for operation involving exposed personnel	Highly recommended	Highly recommended	Recommended	Recommended
Shadow vehicle for no formal shoulder closure for operation NOT involving exposed personnel	May be justified*	May be justified*	May be justified*	May be justified*

*May be justified on the basis of special conditions encountered on an individual project.

Table 2. Recommendations for the Application of Truck-Mounted Attenuators

Closure/Exposure Condition	Freeway	Non-Freeway with Speed Limit		
		>=50 mph	40–45 mph	<=35 mph
Shadow vehicle for no formal lane closure for operation involving exposed personnel	Very highly recommended	Highly recommended	Recommended	Desirable
Shadow vehicle for no formal lane closure for operation NOT involving exposed personnel	Highly recommended	Highly recommended	Recommended	Desirable
Shadow vehicle for no formal shoulder closure for operation involving exposed personnel	Highly recommended	Recommended	Recommended	Recommended
Shadow vehicle for no formal shoulder closure for operation NOT involving exposed personnel	May be justified*	Recommended	Desirable	May be justified*

* May be justified on the basis of special conditions encountered on an individual project.

Retroreflective Tape

Retroreflective tape is used to increase visibility of objects during both nighttime and low light conditions. Retroreflection occurs when a surface returns a portion of directed light back to its source. Retroreflective material appears brightest to observers located near the light source, making it ideal to use for night visibility. The National Highway Traffic Safety Administration (NHTSA) required all heavy trailers to be treated with some form of conspicuous materials before June 2001 (8). An investigation of crashes involving heavy trailers after this requirement found that there was a reduction of side and rear impacts into heavy trailers in the dark.

Retroreflective tape is also used on maintenance vehicles. A number of state DOTs apply a form of reflective material to maintenance vehicles that are used at night or high-risk daytime operations. In 1996, The New Jersey DOT applied reflective tape to all of its vehicles used in nighttime operations. 3M provided marking guidelines for each vehicle type for optimum visibility. The New Jersey DOT also applies reflective materials to most snowplows and vehicles used during emergency operations (9).

Similarly, the Minnesota and Iowa DOTs apply a form of reflective tape to their snowplows. Minnesota DOT uses red and white 3M reflective tapes. The tape is applied to various areas of the vehicle, including the sides, rear, bumpers, parts of the plow, various sections of the underbody, and sander. Figure 3 shows a Minnesota DOT truck with the applied reflective materials. Appendix B contains more pictures of Minnesota maintenance vehicles. A few pictures of other state DOTs' (i.e., Alaska, California, Iowa, and Virginia) maintenance vehicles are also included in Appendix B.



Figure 3. Side and Rear View of a Minnesota DOT Snowplow

TTI conducted a study on the effectiveness of retroreflective magnetic strips on Texas DOT work vehicles. An eight-inch-wide orange and fluorescent-orange checkerboard magnetic strip was applied to flagger vehicles. It was determined that the retroreflective strips have an insignificant impact during daytime but could improve the visibility of vehicles during nighttime operations. The study recommended adding retroreflective tape to flagger vehicles (10).

Advanced Vehicle Control Systems

AVCSs are developed to reduce risk to both operators and motorists at work areas. AVCSs have been applied to shadow vehicles and snow-removal trucks.

Shadow Vehicles

Shadow vehicles follow moving maintenance operations to essentially block approaching errant motorists entering the work area. Thus, shadow vehicle drivers are always at risk. In 1986, for example, a semi-trailer driver fell asleep and collided with a Minnesota DOT shadow vehicle. The driver of the shadow vehicle was paralyzed. In another instance, a shadow vehicle driver in Alabama was killed not long after the incident in Minnesota (11, 12).

Due to the high risk involved in driving shadow vehicles, AVCS devices have been developed to remove the driver from the vehicle. The two types of AVCS devices developed are remote driven vehicles (RDV) and fully autonomous shadow vehicles (11, 12).

The RDV development was sponsored in parts by the Minnesota DOT and the Strategic Highway Research Program (SHRP). The RDV can remotely be controlled from several hundred feet away, substantially reducing the risk to the driver. The RDV is designed for the use in low-speed operations (e.g., pothole patching) where controlling the truck is easy. The cost for converting a truck to a RDV is about \$75,000. It is suggested that a conversion kit will be available for about \$35,000 in the future.

The fully autonomous vehicle, on the other hand, requires no operator. Prototypes have been developed using different on-board navigation/guidance systems, such as laser-based systems,

machine vision and radio frequency direction-finding antenna array systems, and differential global positioning systems (DGPS). An advantage of fully autonomous vehicles is their operability in both high- and low-speed operations.

Snowplows

During snow blowout conditions, snowplow drivers sometimes have to guess where the edge of the roadway is, which can lead to roadside damage. The AVCS could be used to provide the driver with lateral assistance by either making a fully automatic steering control (similar to vehicle cruise control systems where a driver can take control of the vehicle), edge-of-road warning systems, and forward collision warning systems (12). The AVCS application may also allow the driver to operate at a higher speed and more efficiently in a safe environment. The AVCS snowplows would operate by using a magnetic guide path in the road and/or DGPS.

The Advanced Highway Maintenance and Construction Technology (AHMCT) Center developed the Advanced Snowplow (ASP) to assist snowplow operators to remove snow more efficiently and safely (13). The ASP includes a lane position indicator, lane departure warning, and collision warning system (CWS). During the 1998–1999 winter season, the ASP was field-tested on parts of Interstate 80 in California and US 180 in Arizona where snow removal operations are significantly difficult during the wintertime. The study sites were mounted with magnetic marker systems, used by the lane position indicator, and the lane departure warning system. The study concluded that the use of the ASP could lead to improved safety and efficiency.

Practices to Improve Snowplow Visibility

In a large part of the nation, snow and ice control can be one of the most hazardous duties for maintenance crews. Snowplowing becomes significantly dangerous because of the reduction in visibility from blowing snow, reflected headlight glare, and obscured windows.

National Cooperative Highway Research Program Study

A NCHRP study investigated methods to improve visibility for the snowplow's driver and the snowplow vehicle itself (14). The study concluded that “steady-burning light bars, mounted along the rear edges of the snowplow truck, will improve drivers' ability to detect changes in the snowplow vehicle's speed and will provide an indication of the vehicle's width.” It also indicated that the use of side vanes with a 20-degree angle on the rear of the truck reduces snow accumulation on the rear of the snowplow vehicle, allowing rear lighting to be seen more effectively.

The NCHRP study also included an investigation of different applications that can be applied to snowplows to increase visibility and safety. It was indicated that front plows with deflectors, with a trap angle of about 50 degrees, reduces the amount of debris blown onto the windshield. “Packing flaps” at the discharge end of front plows also reduce the size of the snow cloud around the snowplow vehicle. The study found that mounting narrow-beam lights as far from the

driver's line of sight as possible will reduce the glare to the snowplow driver. The study recommended placing narrow-beam lights on the passenger side of snowplows.

Iowa DOT Studies and Recommendations

In 1995, the Iowa DOT conducted a study to investigate crashes involving the department's snowplows (15). It was determined that "the rear end of DOT snowplow trucks need to be more visible to provide drivers of approaching vehicles more time to respond." To provide better illumination on the rear of the truck, mounting a set of diverging lights on the rear of the box was recommended. The use of rear deflectors was also recommended to reduce the amount of airborne snow and the snow accumulation on the back of the snowplow trucks. The study recommended applying reflective tapes to the upper side of the dump boxes, tailgates, and cab protectors, which has been implemented by most maintenance garages in Iowa.

In 1999, the Iowa DOT conducted a follow up study to investigate whether or not the recommended strategies were effective in improving the snowplow visibility. Due to the effectiveness of snowplow deflectors all old snowplows were advised to be equipped with deflectors. New snowplows being applied to Iowa DOT vehicles do not require the use of a deflector due to its design to reduce the amount of airborne snow. The research team also examined the impact of tailgate deflectors. They recommended the use of "scoop" tailgate deflectors, manufactured by SPI Industries (see Figure 4) on all new trucks added to the fleet and to all trucks currently being operated on the interstate to decrease the amount of snow accumulation on the back of the vehicles (16, 17).



Figure 4. Maintenance Truck with Applied Scoop

The Iowa DOT also investigated using Teflon spray to help eliminate snow buildup on the back of trucks. It was determined not to be effective in eliminating snow buildup.

To improve the visibility of the taillights, the Ames Maintenance Shop designed and developed taillight air blasters. A blast of air, controlled by the driver, removes snow build up on the taillights. The study recommended installing the taillight air blasters on all trucks operating on interstates and four-lane roadways. The estimated cost to install one of these devices is approximately \$120 (16).

Another method the Iowa DOT has experimented with to make the rear of snow removal vehicles more visible is placing reflective tape on orange safety fence mounted on the tailgates of the snow removal vehicles (see Figure 5). The orange safety fence will blow in the wind going down the roadway, not allowing as much snow to accumulate onto the reflective tape placed on the safety fence compared to the reflective tape placed on the truck. With the reflective tape not being covered with as much snow, the vehicle is more visible from behind.



Figure 5. Safety Fence with Reflective Tape

The Iowa DOT recommends the future evaluation of rearview cameras and dual-speed displays on interstate trucks (see Figure 6, 18). Rearview cameras allow snowplow drivers to view approaching vehicles. The dual speed displays on the snowplow tailgates would be set off by an approaching vehicle and show the snowplow truck's speed and the approaching vehicle's speed.



Figure 6. Dual Speed Display

Summary

It is evident that there are many protection strategies that can be taken to improve the safety in moving work zones. Some of those strategies are commonly used, while others are not widely accepted or applied. The MUTCD does not specify what color or kind of warning lights to use, which is one reason why there is a wide variety of lights used on maintenance vehicles. There are no clear guidelines for moving work zones at this time, but a compilation of practices may be helpful in revising or making future plans. There have been studies done to find the best forms of some strategies to increase visibility and safety. Future studies for increasing visibility and safety in moving work zones would be beneficial; the studies could be updated as technology changes.

SURVEYS

Introduction

Surveys were conducted to determine current practices of improving visibility and safety in moving work zones. Two types of surveys were conducted: a survey of state DOTs and a survey of Iowa counties. This chapter documents the responses of both the state DOTs and the Iowa counties. The survey instruments are reproduced in Appendixes C and D. Complete responses to both surveys are listed in detail in Appendixes E through K.

Survey of State Departments of Transportation

Forty-eight state DOTs were contacted either by e-mail or phone. Several Wisconsin counties were also contacted since the state's policy allows contracting of roadway maintenance to local counties. Thirty-four state DOTs and three Wisconsin counties responded to the survey, about a 71 percent response rate. A copy of the survey form is included in Appendix C.

Warning Lights

All contacted state DOTs use at least, if not exclusively, amber warning lights. Some states use a combination of warning light colors on their maintenance vehicles. Alabama and Rhode Island use white, amber, and red warning lights. Alaska, Colorado, and Mississippi use an amber and blue combination on some of their vehicles. Minnesota and Nebraska use white warning lights along with the amber and blue lights. White or clear lights are typically used during daytime conditions. Georgia, Illinois, and North Dakota use amber and white lights on their maintenance vehicles. Louisiana is the only responding state that uses an amber and red combination.

Most warning lights used on state maintenance vehicles are either rotating or strobe lights. Strobe lights are the most common type used by the state DOT's. It is believed that strobe lights can be seen better than rotating ones. A few states are starting to use LED warning lights and LED operating lights (i.e., taillights, brake lights, and turn signals). Colorado, Connecticut, Idaho, Illinois, Missouri, and Eau Claire County in Wisconsin use LED operating lights on their maintenance vehicles. Vermont is experimenting with LED lights mounted on the discharge end of wing plows. Minnesota and Tennessee are also experimenting with LED strobe warning lights. Both Pennsylvania and New Hampshire are starting to phase in LED lights with new vehicles. Georgia and Massachusetts are also considering mounting LED lights on their maintenance vehicles.

The quantity and placement of warning lights varies from state to state. It is common among the states to have at least one warning light on top of their maintenance vehicles.

Among the responding state agencies surrounding Iowa, Illinois, Minnesota, and Nebraska use amber along with white warning lights. The other surrounding states use only amber warning lights. Quantity, placement, and type vary from state to state. Appendix E includes complete responses on quantity and placement of warning lights.

Reflective Tape

Most state agencies apply some form of reflective material to their vehicles, especially to their large dump trucks. Over half of the responding agencies use red and white reflective tapes on the rear and down both sides of their larger vehicles. California, for example, applies a six-inch orange reflective stripe on both sides of the larger vehicles' cabs. An orange and white diagonal reflective stripping is applied across the rear of a vehicle if it is wider than 80 inches. Furthermore, Idaho applies a reflective yellow stripe on the sides and back of all of its pickups and trucks. Massachusetts DOT applies a blue and green reflective stripe down both sides of the vehicle.

Some states apply reflective tapes to their small vehicles. Alaska, California, Georgia, Idaho, Minnesota, and Vermont, for example, add reflective tape to their pickups. The Connecticut DOT applies tapes on its supervisor vehicles as well. Along with applying reflective stripes, California, Colorado, Louisiana, and New Hampshire apply reflective emblems to their vehicles. Appendix B contains pictures of several state DOTs' maintenance vehicles.

All responding state agencies surrounding the state of Iowa reported using some form of reflective tape on their large vehicles. Illinois applies an amber strip on its vehicles, and most of the other surrounding states as well as Iowa use a red and white combination. Appendix F includes complete responses on reflective tapes.

Vehicle Color

Highway maintenance vehicles are generally distinguishable by their distinct colors. Most state agencies choose a bright color for their maintenance vehicles. Orange and yellow are the most popular colors for the state DOTs' vehicles. However, due to lower initial cost and higher resale values, white-color vehicles are being used more frequently.

A combination of colors is also being used on maintenance vehicles. The cabs of California's larger trucks are, for example, white with an orange color on the back (see Appendixes B and L). Idaho's large vehicles are very similar, except behind the cab is painted yellow. New York's larger vehicles are yellow with blue-colored hoods. It is suggested that blue is easier than yellow on the driver's eyes.

A few states use white on their smaller vehicles and either orange or yellow on their larger ones. Wisconsin's Eau Claire County uses a yellow-green or "slime green" color on their maintenance vehicles. It is believed that yellow-green is the most visible color under different lighting.

Midwest state DOTs including Iowa, Minnesota, and Nebraska indicated using the orange color on their larger vehicles. Missouri uses "highway yellow" and, as aforementioned, Wisconsin's Eau Claire County uses a "slime green" color on their vehicles. Appendix G includes complete responses on the states' vehicle colors.

Snow Removal Devices

Visibility of snow removal vehicles is generally improved by using warning lights, reflective tape, and other devices. Most state agencies apply more warning lights on their snow removal trucks than on standard ones. More lights would be placed either on the front cab or on the vehicle's rear. Vermont, for example, places rear facing lights in the rear body corner posts, along with two large strobes mounted on swinging plates on the tailgate. Iowa snowplow trucks use a dual amber rotating beacon and two amber rear directional alternate flashing strobes. Alaska, Colorado, and Vermont have even placed warning lights on end of the wing plow.

Placing different colors of warning lights than normal on the vehicles is also common by some state agencies. Arizona and Colorado, for example, apply blue warning lights along with amber lights on snow removal vehicles. Minnesota and Nebraska use white warning lights on their snowplow trucks. The white lights are mainly used during daytime conditions. Minnesota applies white-color lights to the rear of the box on all trucks with left-side wing plows.

LED lights are also being mounted on some states' snowplow vehicles. Idaho, for example, uses LED taillights on all snowplow trucks. Vermont and Colorado place LED warning lights on the end of the wing plow. New Hampshire mounts small strobe lights on the extension arms of the mirrors on some of their snowplow vehicles.

Some states apply more reflective tapes on snowplow trucks than on their normal maintenance vehicles. Alaska and Minnesota, for example, place reflective tapes on the wing plows. The Iowa DOT has experimented with applying reflective tapes to safety fence on the back of snowplow trucks. The safety fence blows in the air, not allowing snow and ice to accumulate onto the reflective tape (see Appendix B).

Another commonly used device on snowplow trucks is a snowplow deflector. Many states use some form of a deflector on the front plow to reduce the amount of airborne snow, and splash back onto the truck's windows. Some snowplow deflectors consist of a rubber strip hanging down in front of the plow; some extend out from the discharge end and then hang down. New York even uses a standard bug shield to prevent splash up on the windshield on some of its snowplow vehicles.

Not as commonly used as snowplow deflectors are airfoils, also known as rear or tailgate deflectors. Airfoils reduce amount of airborne snow from behind, and also the amount of snow accumulated on the rear of the vehicle. Alaska, Idaho, and New York are among the states that use airfoils on their snowplow vehicles.

Another tactic to make snowplow vehicles more visible is placing orange flags on them. Kentucky places flags on the plows, and Nevada puts orange flags on the rear of the vehicle.

Of the Midwest states surrounding the state of Iowa, Missouri and Nebraska are the ones that commonly use snow deflectors. The Illinois DOT has done some experiment on snow deflectors, but it did not find them applicable in Illinois. Wisconsin's Eau Claire County tried rear airfoils for some time during the winter season. It found the rear airfoils inapplicable in the county. Appendix H includes complete responses on snow removal vehicles.

Moving Work Zone Guidelines and Equipment

Almost all states use shadow vehicles, TMAs, and/or arrow boards in some of their moving work zone operations. Some states use these devices more extensively than others and have stricter guidelines for their usage. It is common for states to use one or two protective vehicles during moving operations on multilane roads. Normally the protective vehicles will have TMAs and arrow boards placed on them. Georgia, Massachusetts, and New Hampshire also mount changeable message signs on their TMA-equipped vehicles. Appendix A contains moving work zone guidelines being practiced by a few state DOTs, including Iowa's.

Iowa and all of the surrounding states responding use TMAs during moving operations on multilane divided roadways. Iowa has traffic control layouts for various maintenance operations; some are included in Appendix A. Many of the moving operations require the use of a shadow vehicle, and the use of TMAs and arrow boards is normally recommended. Missouri has an extensive plan for mobile operations. Illinois applies the MUTCD guidelines for requirements of the use of shadow vehicles and TMAs. Kansas uses a mobile radio transmitter to inform approaching drivers of stripping operations on multilane roads. Appendix I includes complete responses on moving work zone guidelines.

Survey of Iowa Counties

To learn about work zone visibility practices throughout the state of Iowa, a mail survey was conducted in all 99 counties. The survey, consisting of two questions, was sent to the county engineers, requesting information pertaining to their maintenance vehicles used during routine granular road maintenance and snow removal operations. Sixty-one counties responded to the survey, about a 62 percent response rate. A copy of the survey form is included in Appendix D.

Traffic Control Devices for Routine Maintenance Operations

The first question inquires about the counties' traffic control devices used to advise motorists of routine maintenance operations. The survey indicates that most Iowa counties use amber rotating or strobe lights and warning signs mounted on the rear of motor graders during routine maintenance operations. Only 11 of the counties that responded to the survey use advance warning signs for the routine maintenance. Placing flags onto the vehicles is another traffic control device used by some Iowa counties. Greene County installs a high-intensity strobe system onto their blades. Scott County uses white strobe lights on their vehicles' rear to improve visibility. Appendix J includes complete responses to this question.

Warning Devices for Snow Removal Operations

The second Iowa county survey question pertains to applied warning devices during snow removal operations. Out of 61 responses, 46 counties (75 percent) indicating using reflective tapes on their snow removal vehicles. Of the 46 counties that use reflective tapes on their vehicles, 19 counties indicated applying reflective tape to the plows. Fifty-one counties (84 percent) indicated mounting warning flags on the vehicles and/or plows.

Another common device used among the counties is auxiliary headlamps. Forty-three counties (70 percent) indicated using auxiliary headlamps above the front plow either mounted on the plow frame or onto the vehicle itself. Furthermore, 24 responded counties (39 percent) indicated using snowplow deflectors. The most common type of warning light used by Iowa counties is strobe lights. Appendix K includes complete responses to this question.

Summary

Two surveys with response rates of about 70 percent and 62 percent were conducted throughout the country and the state of Iowa, respectively. This report is the result of a comprehensive examination of mobile work zone guidelines and equipment reported by 36 transportation agencies throughout the country and 61 Iowa counties.

Most participating state agencies indicated using amber warning lights on their maintenance vehicles. Some states also use white, blue, and/or red warning lights. A few states have started using LED service and warning lights on their vehicles.

Almost all the responding state DOTs indicated using some form of reflective material on their vehicles to make them more visible. The most common colors are red and white; amber is also used. Most participating states indicated that the color of their vehicles is orange; white is the second most common color used.

Most states indicated using more warning lights on snow removal vehicles than their normal maintenance vehicles. Using a combination of colors rather than the amber color alone is also common for some states. A few states use snowplow deflectors along with rear airfoils to reduce the amount of airborne snow.

All responding state agencies indicated using shadow vehicles and/or truck-mounted attenuators during their moving operations. Some states also have specific work zone guidelines set up to supplement the MUTCD.

The Iowa county survey indicates that most counties use very similar traffic control and warning devices during their granular road maintenance and snow removal operations. Mounting warning signs and rotating or strobe lights on the rear of maintenance vehicles is common among the Iowa counties. The most common warning devices used during the counties' snow removal operations are reflective tapes, warning flags, strobe lights, and auxiliary headlamps.

REFERENCES

1. Federal Highway Administration (FHWA). *Manual on Uniform Traffic Control Devices*. Millennium edition. FHWA, U.S. Department of Transportation, Washington, D.C., December 2000.
2. Cameron, R. Emergency Warning Light Technology. *Transportation Research Circular 475: 11th Equipment Management Workshop*. Transportation Research Board, National Research Council, Washington, D.C., July 1997, pp. 52–58.
3. Ullman, G. L. Special Flashing Warning Lights for Construction, Maintenance, and Service Vehicles: Are Amber Beacons Always Enough? *Transportation Research Record 1715*. Transportation Research Board, National Research Council, Washington, D.C., 2000, pp. 43–50.
4. Hanscom, F. N., and R. F. Pain. *Warning Lights on Service Vehicles in Work Zones*. VTI Rapport 351A. National Swedish Road and Traffic Research Institute, Linköping, Sweden, 1990, pp. 57–69.
5. Hanscom, F. N., and R. F. Pain. *Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Operations*. NCHRP Report 337. Transportation Research Board, National Research Council, Washington, D.C., December 1990.
6. Missouri Department of Transportation. Flash! New Warning Lights Grab Motorists' Attention. April 30, 2002. http://www.modot.state.mo.us/news/2002_htm/newsrelease/may/4-30-02.htm. Accessed May 3, 2002.
7. Humphreys, J. B., and T. D. Sullivan. Guidelines for the Use of Truck-Mounted Attenuators in Work Zones. *Transportation Research Record 1304*. Transportation Research Board, National Research Council, Washington, D.C., 1991 pp. 292–302.
8. Morgan, C. *The Effectiveness of Retroreflective Tape on Heavy Trailers*. Report DOT HS 809 222. National Highway Traffic Safety Administration, U.S. Department of Transportation, March 2001.
9. 3M. New DOT Safety Standard for Maintenance Vehicles Set to Protect Workers During Nighttime Operations. http://www.3m.com/us/safety/tcm/solutions/pia_dotstd.jhtml. Accessed May 13, 2002.
10. Fontaine, M. D., P. J. Carlson, and H. G. Hawkins, Jr. *Evaluation of Traffic Control Devices for Rural High-Speed Maintenance Work Zones: Second Year Activities and Final Recommendations*. FHWA Report FHWA/TX-01/1879-2. Texas Transportation Institute, College Station, Texas, October 2000.

11. Federal Highway Administration. Moving Barrier Protects Work Crews. <http://www.fhwa.dot.gov/winter/roadsvr/CS080.htm>. Accessed March 12, 2002.
12. Raytheon E-Systems. *Advanced Vehicle Control Systems (AVCS) for Maintenance Vehicle Applications*. Raytheon E-Systems, Falls Church, Virginia, December 20, 1996.
13. Ravani, B., et al. *Advanced Snowplow Development and Demonstration: Phase I: Driver Assistance*. AHMCT Research Report UCD-ARR-99-06-30-03. California AHMCT Program, University of California, Davis, Davis, California, June 1999.
14. National Cooperative Highway Research Program. Improved Visibility for Snowplowing Operations. *NCHRP Research Results Digest 250*. Transportation Research Board, National Research Council, Washington, D.C., November 2000.
15. Iowa DOT. *Continuous Quality Improvement Snow Plow Accident Study Report*. Iowa Department of Transportation, Ames, Iowa, June 1996.
16. Iowa DOT. *Snowplow Study Team Recommendations*. Iowa Department of Transportation, Ames, Iowa, November 1999.
17. SPI Industries, Inc. The Scoop. March 26, 2002. <http://www.spiplastics.com/thescoop.htm>. Accessed May 21, 2002.
18. Stalker Radar. The Stalker Speedboard. http://www.stalkerradar.com/law_speedboard.html. Accessed May 21, 2002.

APPENDIX A

MOVING OPERATION GUIDELINES

Florida
Iowa
Missouri
North Carolina
Virginia

Florida: Moving Operation Guidelines

State of Florida Department of Transportation Moving Operation Guidelines

Mode-Warning

Mode-Pass Left/Right

Mode-Pass Left/Right

Moving Operations

General Notes

- These illustrations are representative of general conditions.
- The intensity of light and the position of panels shall be as specified in index No. 600
- The Advance Warning Vehicle (Optional) may be used at the direction of the Engineer. If an Advance Warning Vehicle is operated within the travel way, and approved Truck Mounted Attenuator will be required on the Advance Warning Vehicle but not required on the Shadow Vehicle. The Advance Warning Arrow Panel and Warning Sign are required on both the Advance and Shadow Vehicle.
- For general TCZ requirements and additional information refer to index No. 600
- If the work vehicle speed exceeds the minimum legal speed limit on limited access facilities and one half the posted speed limit on other facilities, the engineer in charge may delete requirements for shadow vehicle and attenuators. The work vehicle will be required to have an advance warning arrow panel and sign message.

Symbols

- Work Vehicle with Flashing Beacon
- Shadow (S) Or Advance Warning (AW) Vehicle with Advance Arrow Panel and Sign Message
- Truck Mounted Attenuator (TMA)
- Lane Identification and Direction of Traffic

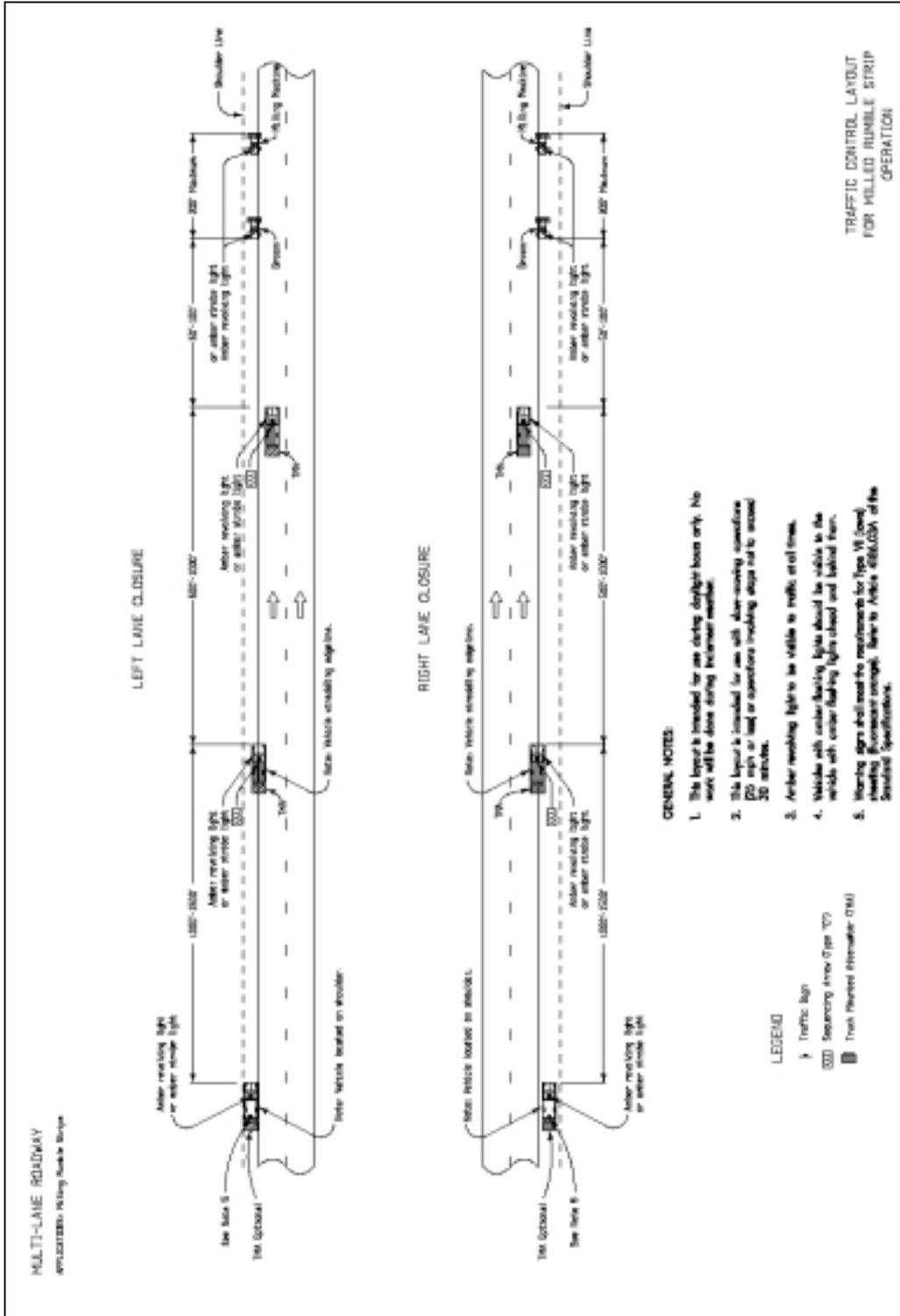
Typical Applications

- Striping
- RPM Placement
- Vegetation Control

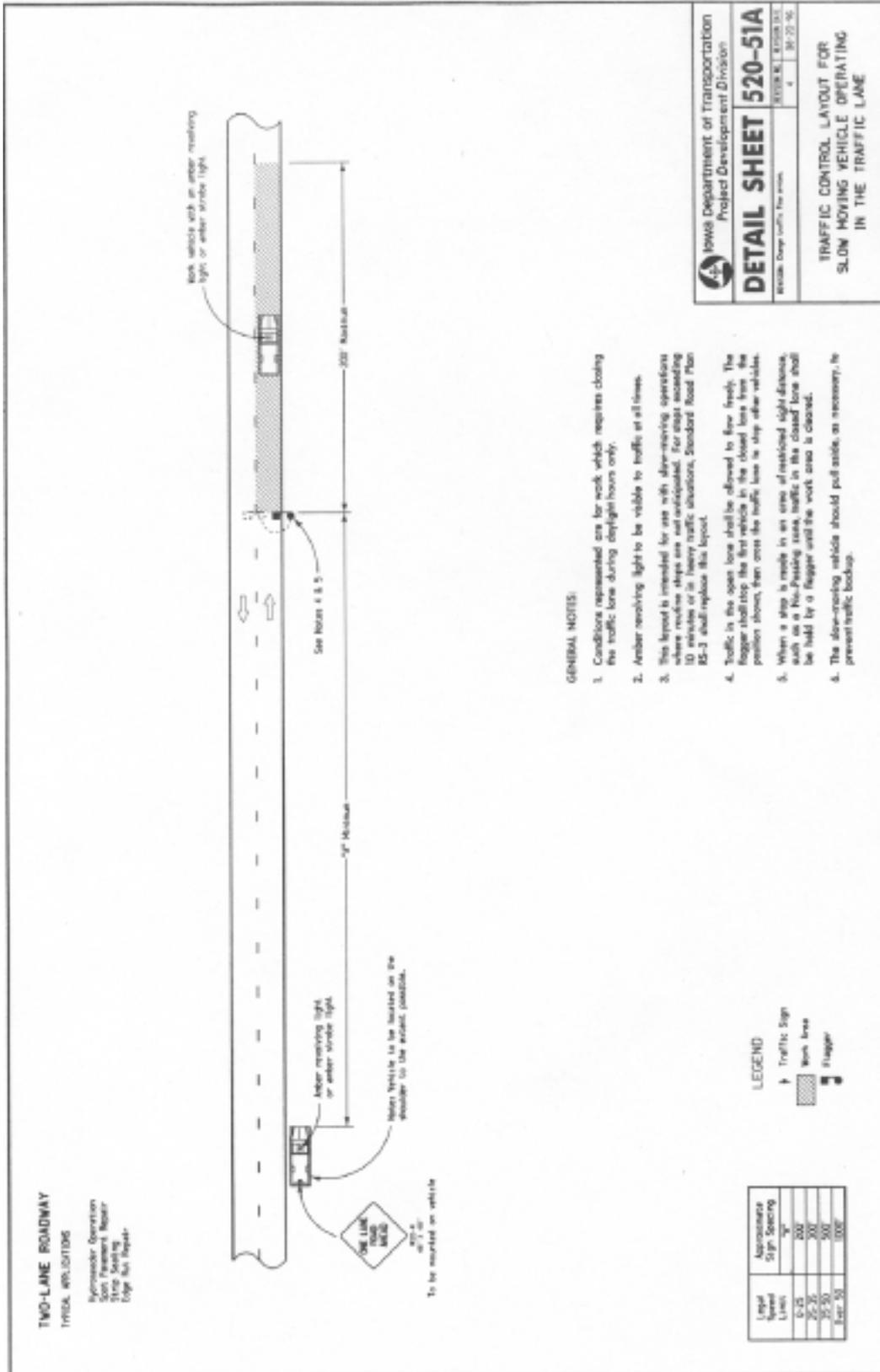
Conditions

Moving Operation

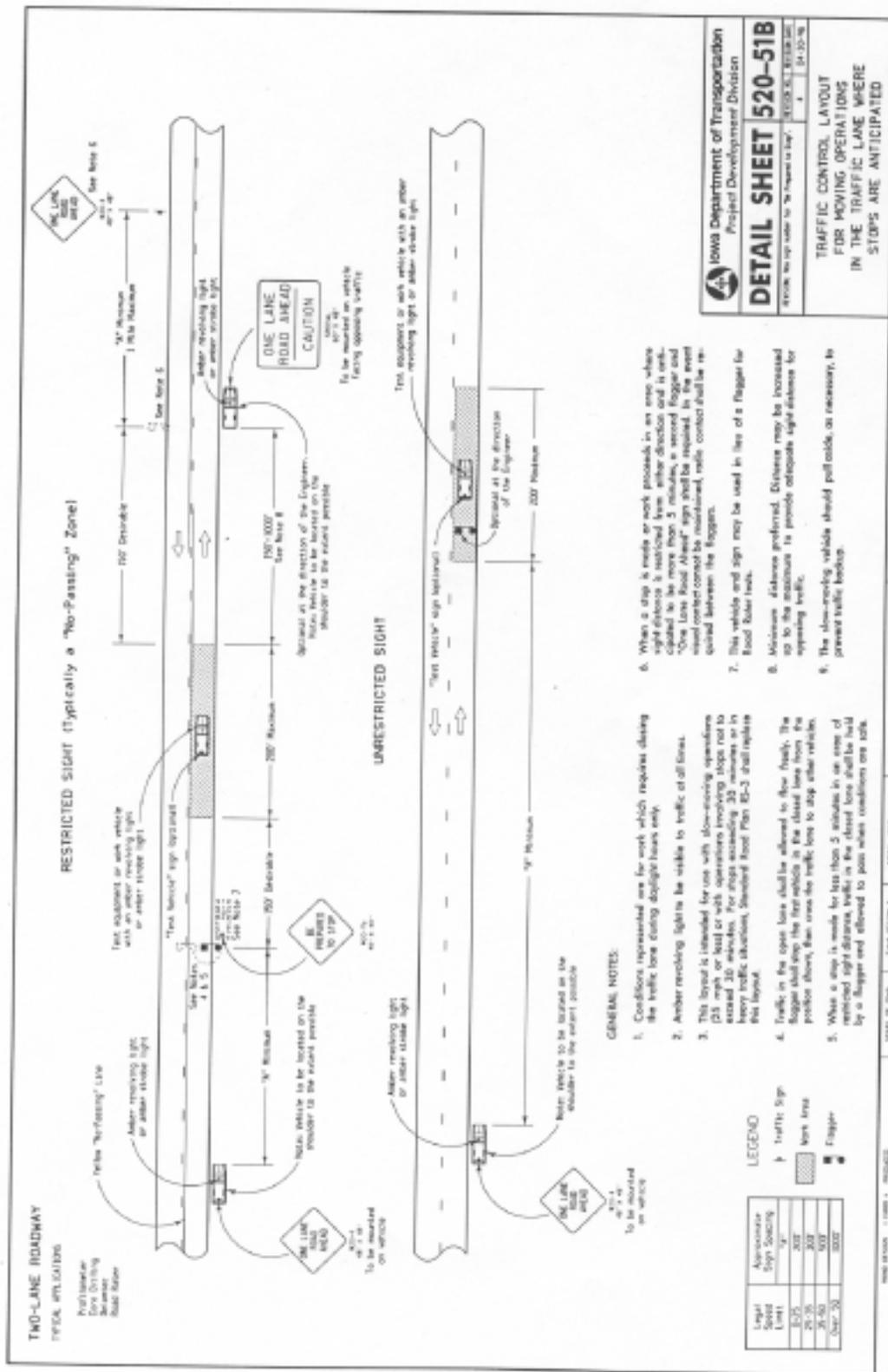
Iowa: Traffic Control Layout for Milled Rumble Strip Operation



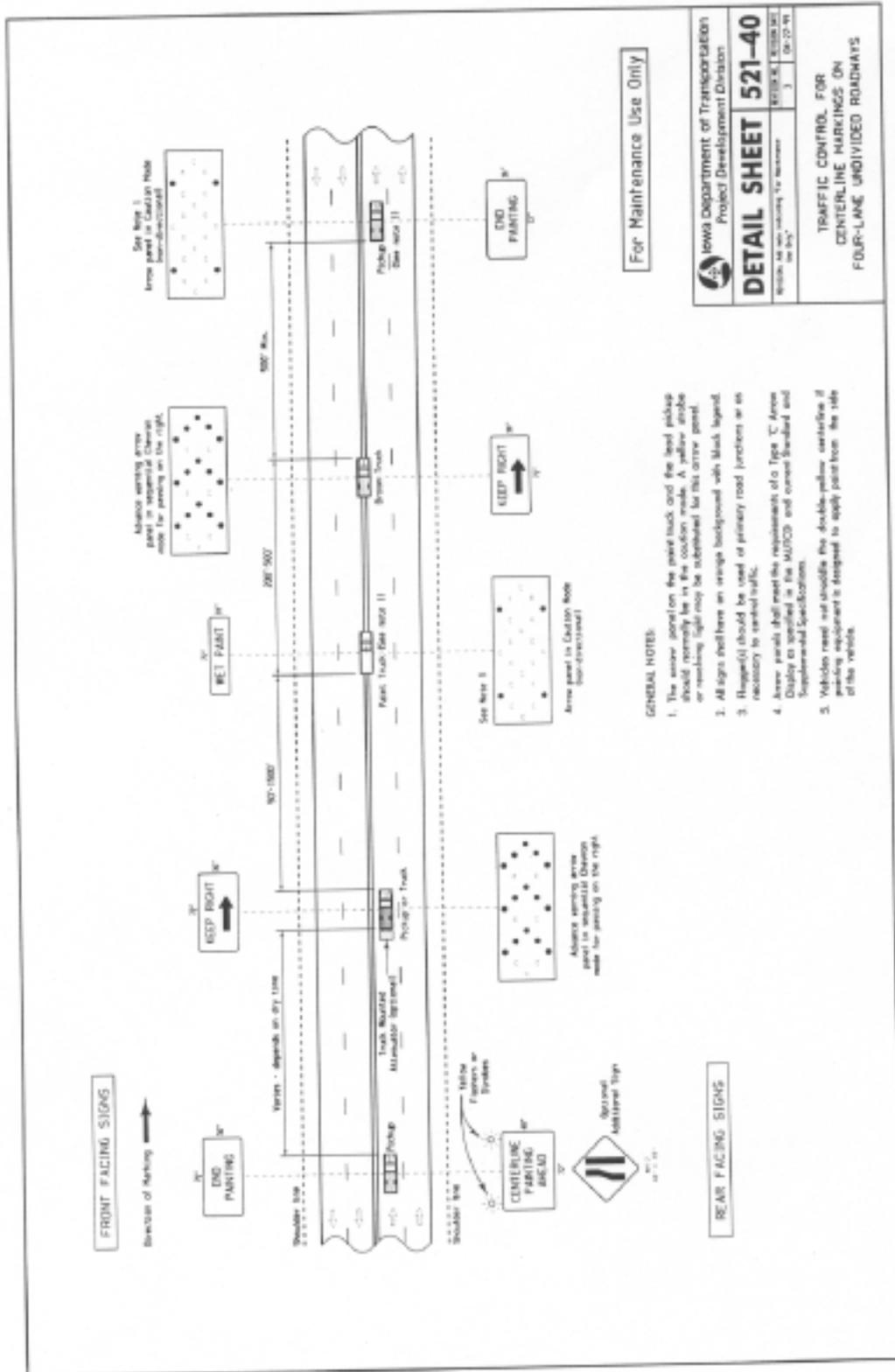
Iowa: Traffic Control Layout for Slow Moving Vehicle Operating in the Traffic Lane (Two-Lane Roadway)



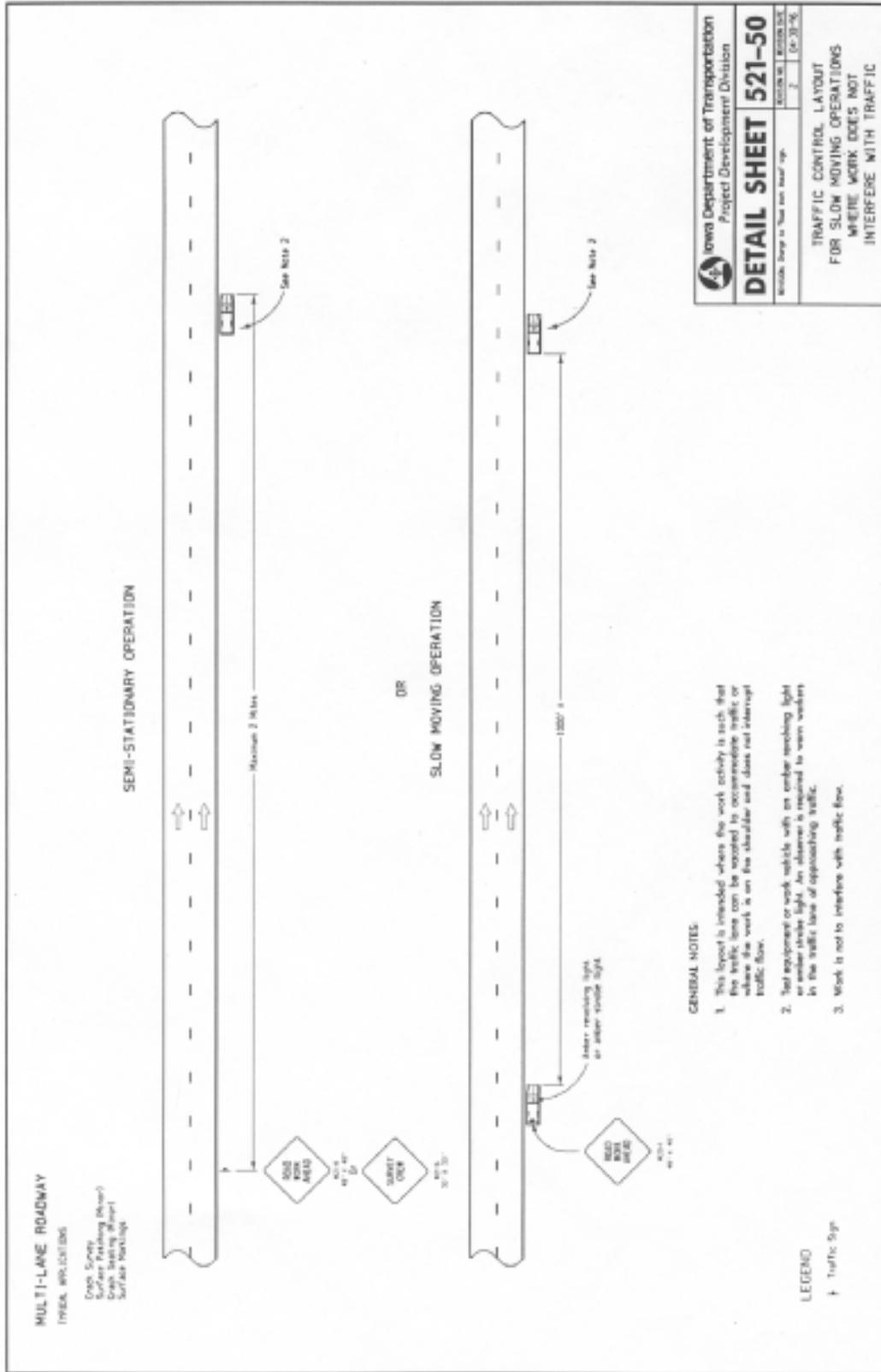
Iowa: Traffic Control Layout for Moving Operations in the Traffic Lane Where Stops Are Anticipated



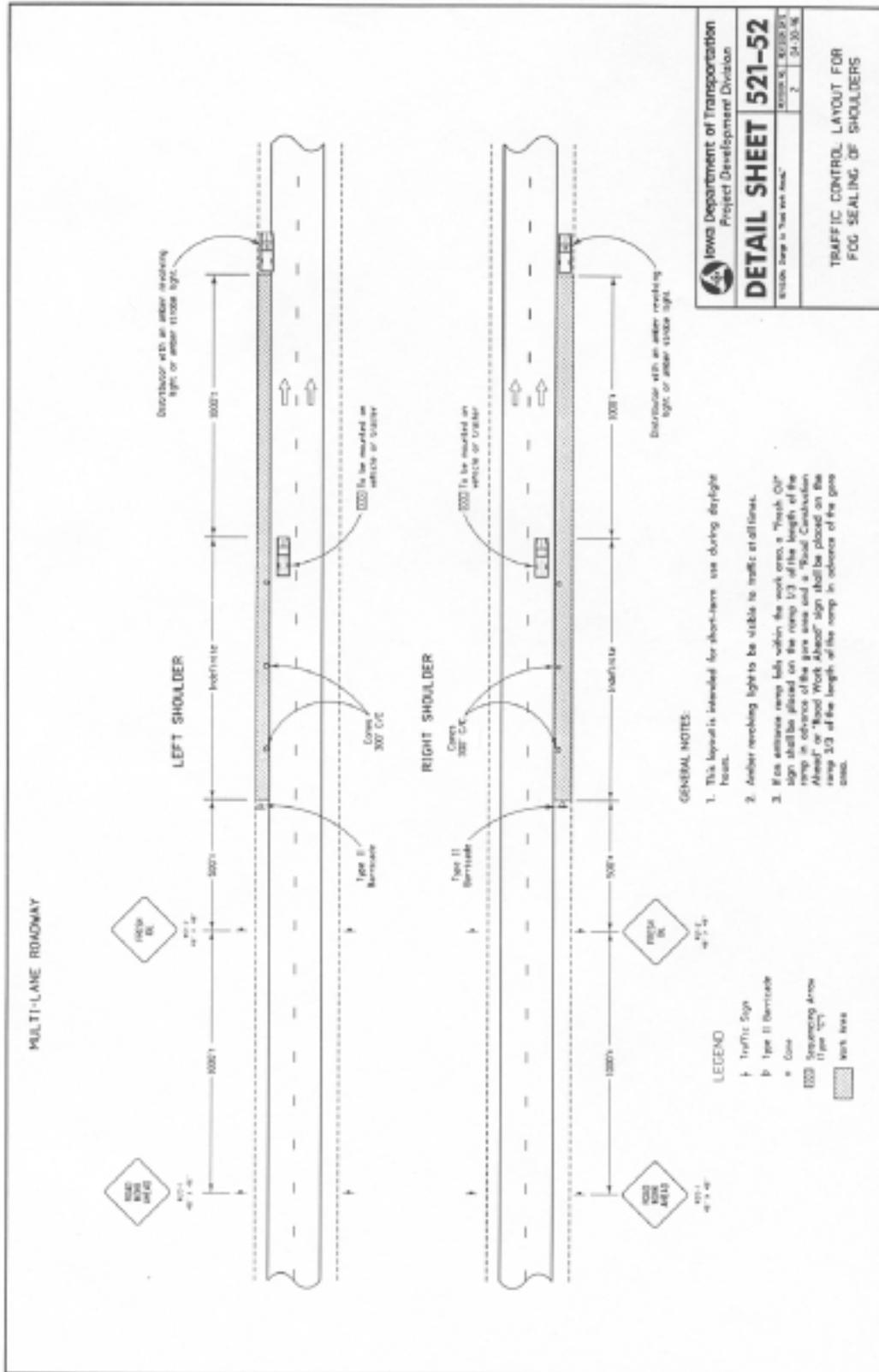
Iowa: Traffic Control for Centerline Markings on Four-Lane Undivided Roadways



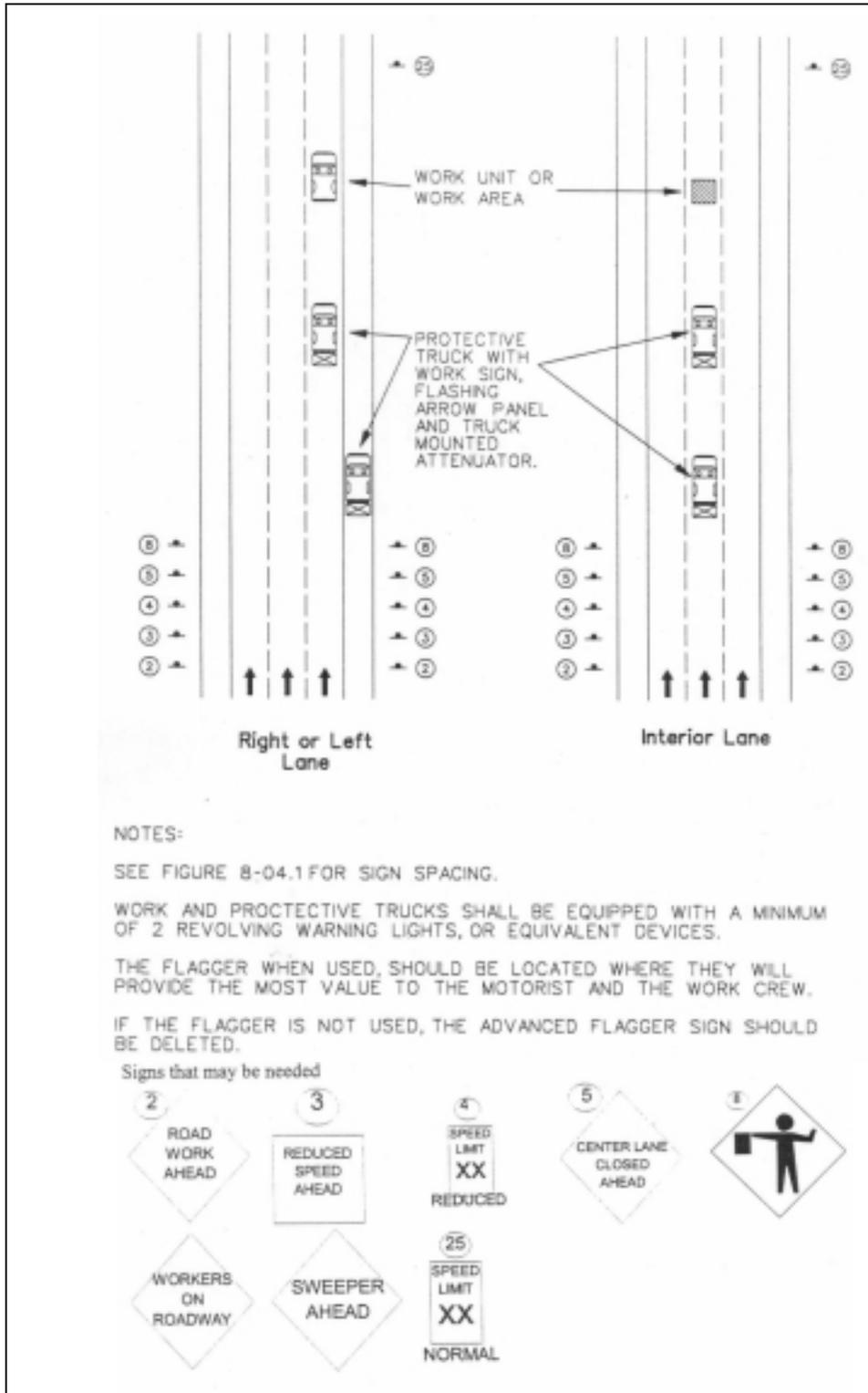
Iowa: Traffic Control Layout for Slow Moving Operations Where Work Does Not Interfere with Traffic



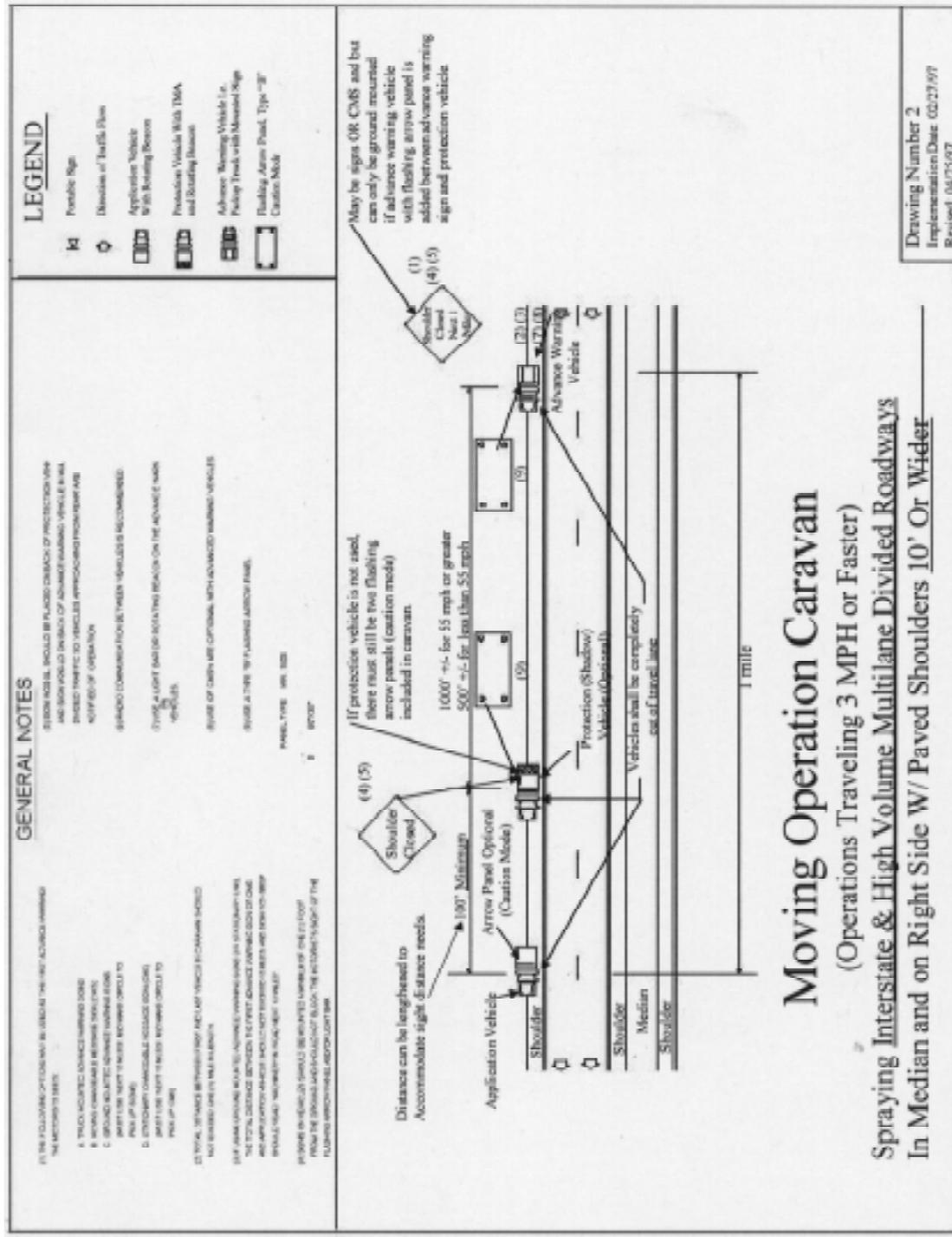
Iowa: Traffic Control Layout for Fog Sealing Shoulders



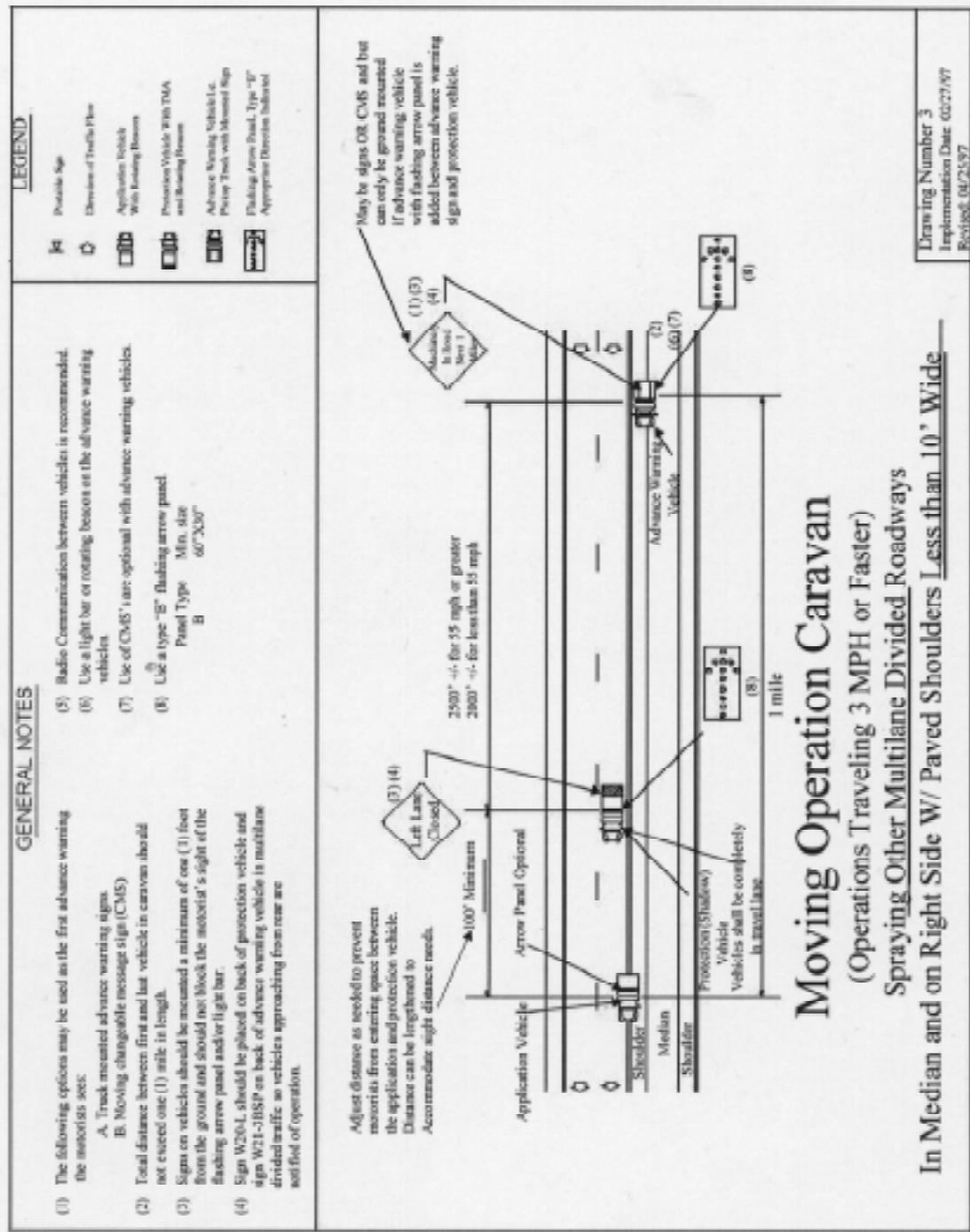
Missouri: Multilane Divided Highway Moving Operation Guidelines



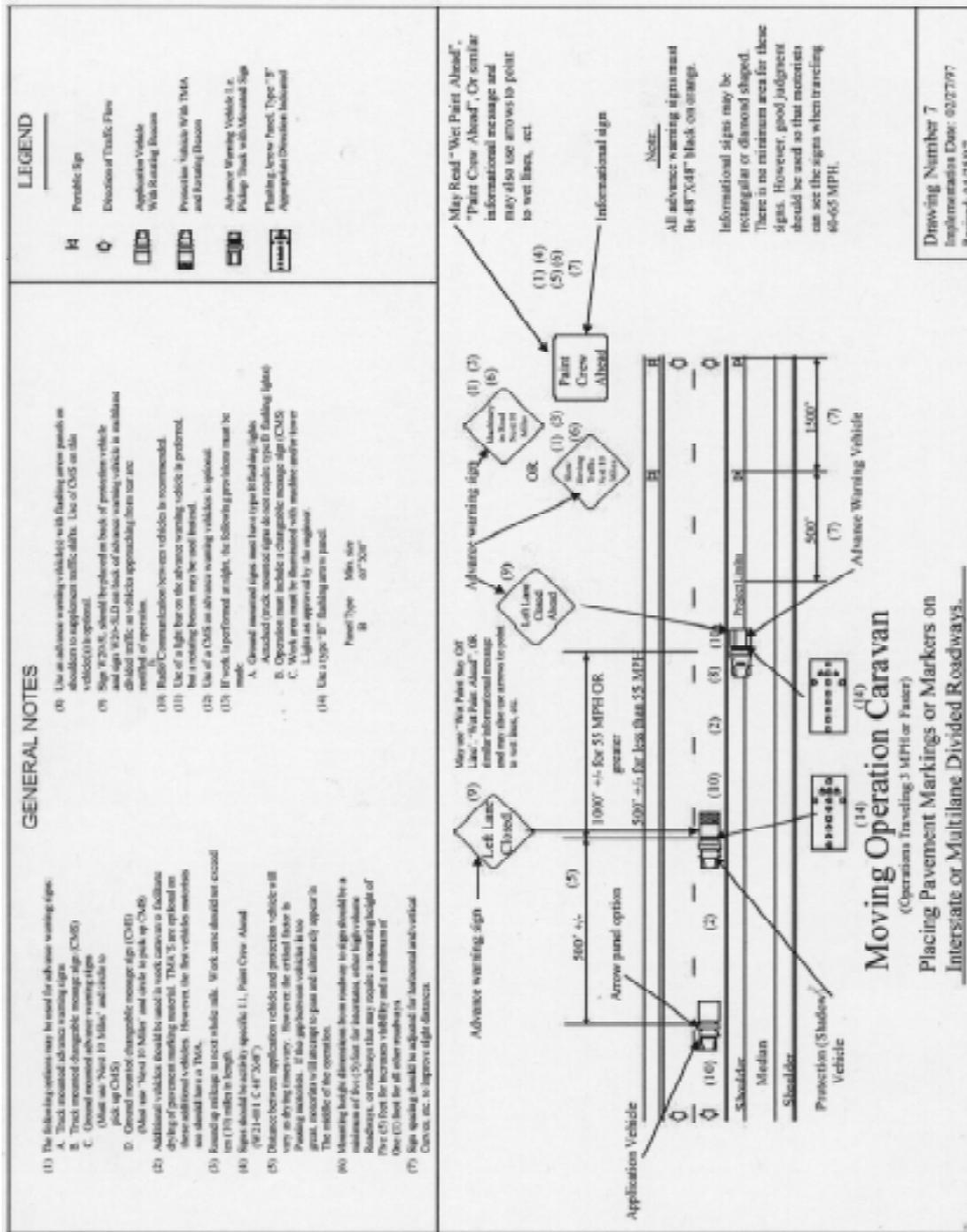
North Carolina: Spraying Interstate and High Volume Multilane Divided Roadways with Paved Shoulders 10' or Wider



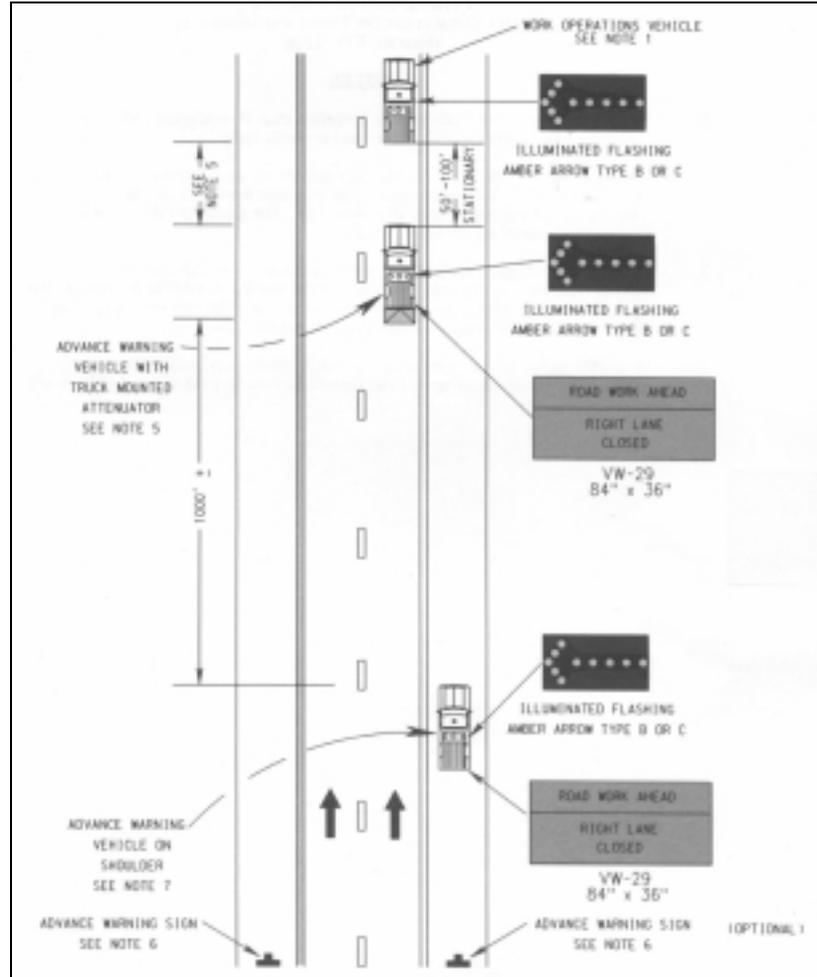
North Carolina: Spraying Other Multilane Divided Roadways with Paved Shoulders Less Than 10' Wide



North Carolina: Placing Pavement Markings or Markers on Interstate or Multilane Divided Roadways

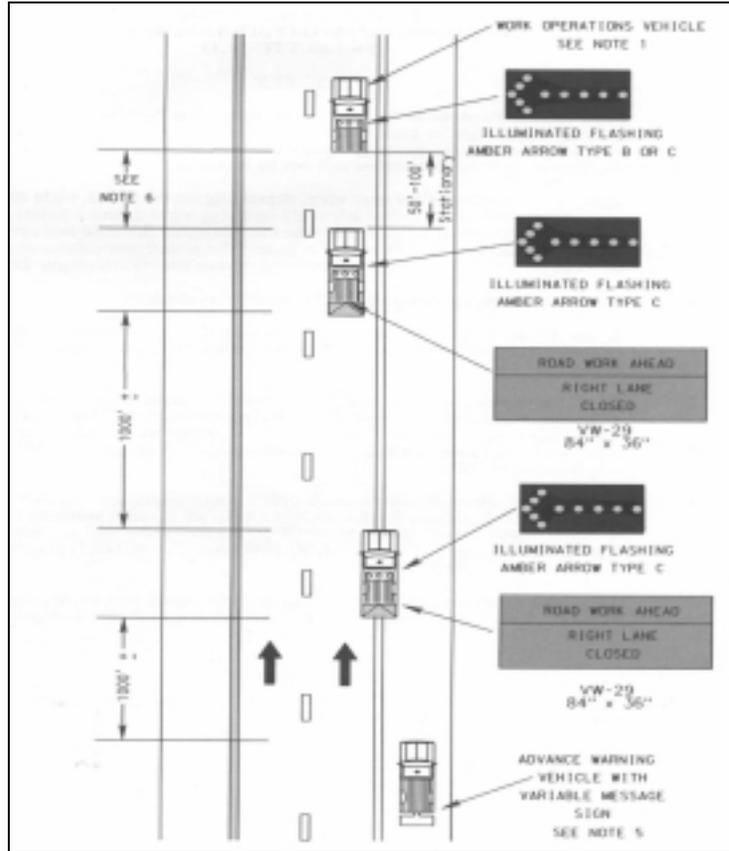


Virginia: Mobile Operation on Four-Lane Roads



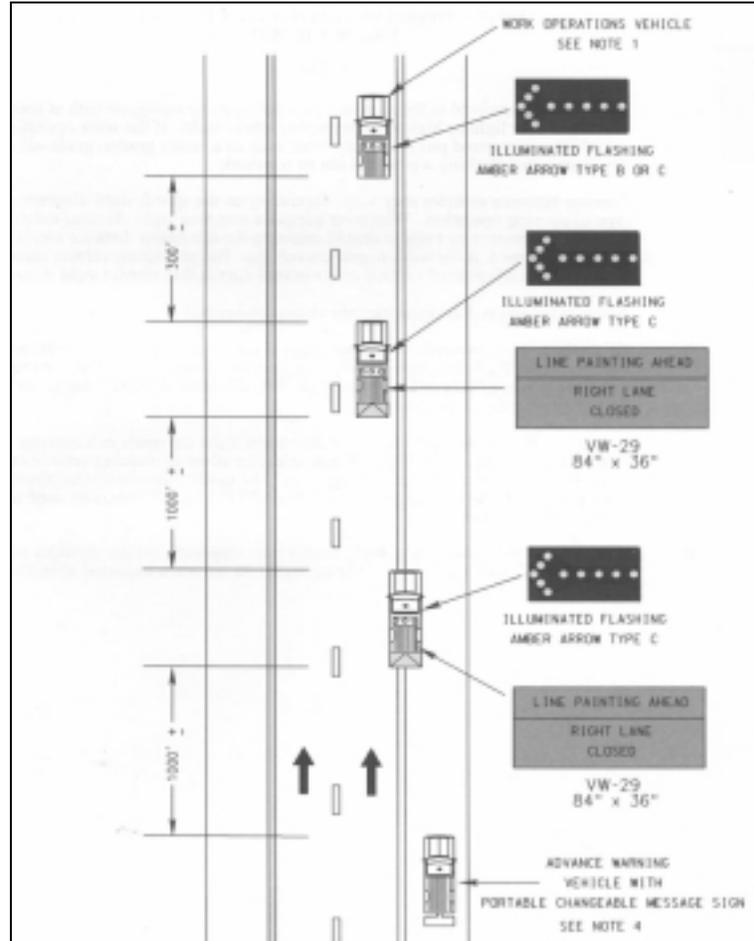
1. Each vehicle involved in the mobile operation shall be equipped with at least one rotating amber light or high intensity amber strobe light. If the work operations vehicle is a motorized piece of equipment, such as a motor grader, grade-all, etc., the illuminated flashing arrow will not be required.
2. Spacing between vehicles may vary, depending on the speed, sight distance, and type of operation. Whenever adequate stopping distance exists to the rear, the protection vehicle should maintain the minimum distance and proceed at the same speed as the work operation vehicle. The protection vehicle should slow down in advance of vertical or horizontal curves that restrict sight distance.
3. Arrow direction and designation may change as needed.
4. A mobile operation is defined as an operation that does not extend beyond 15 minutes in the immediate area. (The immediate area is defined as a $1000' \pm$ linear distance.)
5. When the work operations vehicle is stationary, the advance warning vehicle following the operations vehicle shall be in a position 50'-100' in advance of the operations vehicle to provide protection. When the work operations vehicle is moving, the advance warning vehicle following the operations vehicle shall follow at a distance of $300' \pm$.
6. Actual conditions may dictate more traffic control device needs in a mobile operation. On high speed, high volume roads, an advance warning vehicle on the shoulder with an arrow board and sign should be used. Also, in certain situations appropriate stationary signing ("SPRAYING NEXT 2 MILES") may be used to further enhance safety.
7. If the first advance warning vehicle cannot run completely on the shoulder and is partially in the travel lane, it shall be equipped with a truck mounted attenuator.

Virginia: Mobile Operation on Limited Access Highways



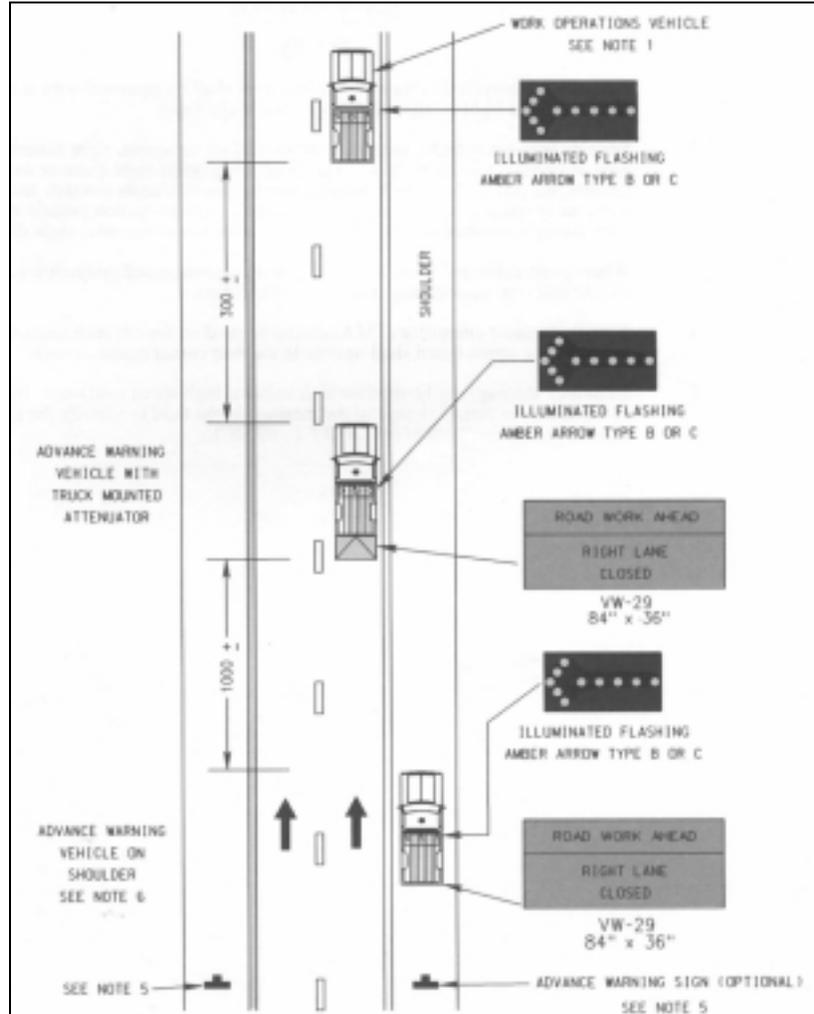
1. Each vehicle involved in the mobile operation shall be equipped with at least one rotating amber light or high intensity amber strobe light. Illuminated flashing arrows on the advance warning vehicles shall be type C, and on the operations vehicle a type B or C. If the work operations vehicle is a motorized piece of equipment, such as a motor grader, grade-all, etc., the illuminated flashing arrow will not be required.
2. Spacing between vehicles may vary, depending on the speed, sight distance, and type of mobile operation. Whenever adequate stopping distance exists to the rear, the protection vehicle should maintain the minimum distance and proceed at the same speed as the work operation vehicle. The protection vehicle should slow down in advance of vertical or horizontal curves that restrict sight distance.
3. Arrow direction and designation may change as needed.
4. A mobile operation is defined as an operation that does not extend beyond 15 minutes in the immediate area. (The immediate area is defined as a 1000' ± linear distance.)
5. The first advance warning vehicle shall travel along the paved shoulder with either a flashing arrow, or a portable changeable message sign (PCMS) advising of the operation ahead ("PATCHING AHEAD"), and lane closure information ("RIGHT LANE CLOSED", "MERGE LEFT"). The second advance warning vehicle, with a truck mounted attenuator, shall straddle the edge line, partially on the shoulder and partially in the lane. The third advance warning vehicle with a TMA shall be in the travel lane. If the first advance warning vehicle cannot run completely on the shoulder and is partially in the travel lane, it shall be equipped with a TMA.
6. When the work operations vehicle is stationary, the advance warning vehicle following the operations vehicle shall be in a position 50'-100' in advance of the operations vehicle to provide protection. When the work operations vehicle is moving, the advance warning vehicle following the operations vehicle shall follow at a distance of 300'±.

Virginia: Moving Operations on Limited Access Highways



1. Each vehicle involved in the mobile operation shall be equipped with at least one rotating amber light or high intensity amber strobe light. Illuminated flashing arrows on the advance warning vehicles shall be type C, and on the operations vehicle a type B or C. If the work operations vehicle is a motorized piece of equipment, such as a motor grader, grade-all, etc., the illuminated flashing arrow will not be required.
2. Spacing between vehicles may vary, depending on the speed, sight distance, and type of mobile operation. Whenever adequate stopping distance exists to the rear, the protection vehicle should maintain the minimum distance and proceed at the same speed as the work operation vehicle. The protection vehicle should slow down in advance of vertical or horizontal curves that restrict sight distance.
3. Arrow direction and designation may change as needed.
4. The first advance warning vehicle shall travel along the paved shoulder with either a flashing arrow, or a portable changeable message sign (PCMS) advising of the operation ahead (“LINE PAINTING AHEAD”), and lane closure information (“RIGHT LANE CLOSED”, “MERGE LEFT”). The second advance warning vehicle, with a truck mounted attenuator, shall straddle the edge line, partially on the shoulder and partially in the lane. The third advance warning vehicle with a TMA shall be in the travel lane
5. If the first advance warning vehicle cannot run completely on the shoulder and is partially in the travel lane, it shall be equipped with a TMA.
6. Each vehicle involved in the moving operation shall have radio communication between vehicles.

Virginia: Moving Operation on Four-Lane Roads



1. Each vehicle involved in the mobile operation shall be equipped with at least one rotating amber light or high intensity amber strobe light. If the work operations vehicle is a motorized piece of equipment, such as a motor grader, grade-all, etc., the illuminated flashing arrow will not be required.
2. Spacing between vehicles may vary, depending on the speed, sight distance, and type of mobile operation. Whenever adequate stopping distance exists to the rear, the protection vehicle should maintain the minimum distance and proceed at the same speed as the work operation vehicle. The protection vehicle should slow down in advance of vertical or horizontal curves that restrict sight distance.
3. Arrow direction and designation may change as needed.
4. When the moving operation is completely off the travelway, only one advance warning vehicle will be required. A TMA will not be required. Change the second line of the message to "RIGHT SHOULDER," change arrows to the four corner caution mode.
5. Actual conditions may dictate more traffic control device needs in a moving operation. On high speed, high volume roads, an advance warning vehicle on the shoulder with an arrow board and sign should be used. Also, in certain situations, appropriate stationary signing ("SPRAYING NEXT 2 MILES") may be used to further enhance safety.
6. If the first advance warning vehicle cannot run completely on the shoulder and is partially in the travel lane, it shall be equipped with a TMA.

APPENDIX B

PHOTOS OF STATE DOT MAINTENANCE VEHICLES

Alaska
California
Iowa
Minnesota
Virginia

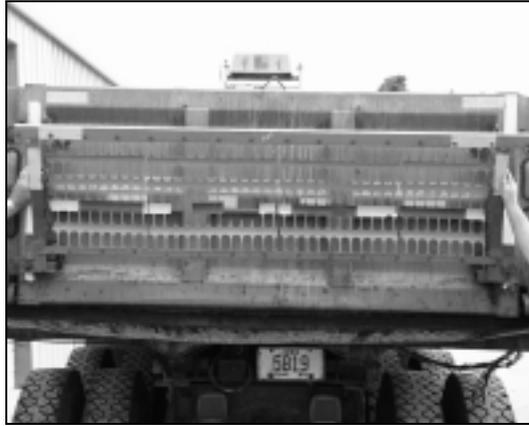
Alaska



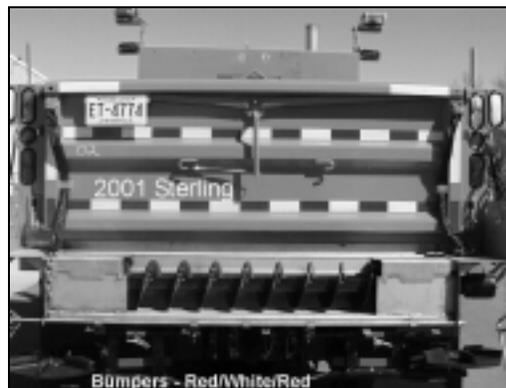
California



Iowa



Minnesota





Virginia



APPENDIX C

SURVEY FORM FOR STATE DEPARTMENTS OF TRANSPORTATION

The Center for Transportation Research and Education (CTRE) at Iowa State University is working on a project with the Iowa DOT trying to find the best practices for increasing protection and visibility of highway maintenance vehicles. If you have time, we would appreciate if you could answer the questions below. You can do so by either replying back to bstorm@iastate.edu, calling 515-296-6686, or by fax at 515-294-0467; please direct all responses to Brandon Storm. If someone else would be better informed to answer our questions, could you please forward it to the appropriate person, and we apologize for any inconvenience?

1. What are the warning light characteristics on your maintenance vehicles?
(i.e., color, strobe or rotating, LED, amount and placement on vehicle)
2. What color are you maintenance vehicles?
3. Does your state use reflective tape on maintenance vehicles? If so, where is it placed, and what color and type is it?
4. Does your state do anything to make snowplows more visible?
(i.e., snowplow deflectors, tailgate deflectors, special lights (different colors than normal vehicles))
5. What are your guidelines regarding the use of shadow vehicles, TMAs, arrow boards, and message boards in moving operations, such as paint stripping or pothole patching? (If possible, a copy of your states policy for moving work zones would be appreciated.)

If you would like to receive a copy of our final report, please include your mailing address.

Thank you for your time,

Brandon Storm
bstorm@iastate.edu
Undergraduate Research Assistant
CTRE, Iowa State University

ISU Research Park
2901 S. Loop Dr., Suite 3100
Ames, IA 50010-8632
Attn.: Brandon Storm

APPENDIX D
SURVEY FORM FOR IOWA COUNTIES

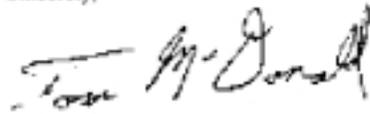
Dear County Engineer,

As part of a study of best practices for increasing the protection and visibility of highway maintenance vehicles, the Center for Transportation Research and Education is surveying Iowa county engineers. This research project, which is sponsored by the Iowa Highway Research Board, will also include a survey of other states and agencies to determine their best practices.

This survey is designed to elicit information about the methods Iowa county personnel use to provide visibility and warning to motorists during granular road maintenance and snow removal operations.

Please take a few minutes to complete the survey and return it by July 1, 2002, using the postage paid self-mailer. Thank you for your assistance.

Sincerely,



Tom McDonald, Safety Circuit Rider
515-294-6384, tmcdonal@iastate.edu

Sincerely,



Ali Kamyab, Research Scientist
515-294-4303, kmb@iastate.edu

Visibility of Highway Maintenance Vehicles Survey

1. These traffic control devices are used to advise motorists of routine maintenance operations by motor graders in this county (check all that apply):

Advance warning signs, such as Road Work Ahead

Warning signs mounted on the motor grader, such as Stay Back 50 Feet:

On front

On back

Rotating amber lights or strobe lights on vehicle

Other, please describe:

No special warning devices are routinely used during motor grader operations.

2. These warning devices are used to advise motorists of snow removal operations in this county (check all that apply):

Reflective tape on the
 Vehicle
 Plows (wing, plow or front plow)

Warning lights on the vehicle
Please specify amount, kind (strobe, rotating, LED, etc.), and placement of warning lights (include warning lights on plows):

Snowplow deflectors
 Tailgate deflectors / airfoils
 Flags on the vehicle or plows
 Auxiliary headlamps
Please describe where they are placed:

APPENDIX E

STATE SURVEY RESPONSES: WARNING LIGHTS

State	Warning Light Usage
Alabama	Use white, amber, and some red warning lights. Believe the white and amber strobe combinations are effective. Place warning lights above the cab, and integrate some into the headlights.
Alaska	Use Whelen strobes that have flash tubes rather than rotating elements. The flash tube gives a 360 degree visibility. Each vehicle normally has two lights mounted on the roof of the cab, 1 blue light on the right, and one amber light on the left.
Arizona	Use rotating amber lights on maintenance vehicles. Pickup lights are placed on the toolbox with a light stand. Also use some light bars.
Arkansas	Use rotating yellow lights.
California	Use amber rotating or strobe lights. Amount and type of light depends on level of severity vehicle is subject to. All vehicles have at least one amber single rotator. They may also have an amber mini light bar, and amber light stick, one way flashing light with one or more at corners with flasher, and/or flashing arrow sign.
Colorado	Use Whelen strobe lights on maintenance vehicles, and Whelen snow and fog lights on snow removal vehicles. Snow removal vehicles run a combination of amber and blue lights, while normal maintenance vehicles run only amber lights. Snowplows have strobes on the left and right hand side of the cab. Also place strobes on the corner posts of the bed on the rear, so snowplow has a total of 4 strobes. Place a LED warning light on the end of the wing plow. Use LED service lights with signal alert.
Connecticut	Have two Whelen 360 degree amber strobes on front cab guard, and two 360-degree amber strobes on the back placed on the side. In 1999 put LED taillights in, the dump body and cab lights are soon to be all LED lights.
Florida	Use yellow flashing lights placed on a light bar.
Georgia	Use an amber and clear strobe combination. Pickups have two light bars, dump trucks have two warning lights on the cab protector. Bucket trucks have at least four lights, some maybe in the front grill. Cars have dash mounted amber lights and sometimes amber and clear in the rear window deck. Mowers have one amber on the cab. Vans have either one amber or have a roof bar with amber and clear. Fixing to get into LEDs.
Idaho	ID vehicles are equipped with a mixture of lights in effort to accommodate various conditions. Pickups and other maintenance equipment that is utilized during summer maintenance have a single dual halogen rotating light. This same light configuration is used on pretty much all equipment other than snowplows. Snowplows have a Whelen Superstrobe Comet Flash light mounted on the truck cab. At the top /center rear of the sander is a dual rotating halogen light. Each truck is equipped with four amber halogen lights on the sides of the sander, two per side. These lights are equipped with a flasher unit to give the appearance of a bouncing ball, i.e. the lights flash side to side, top to bottom. All snowplow trucks are equipped with LED taillights. Dump bodies have a total of four lights and sanders have a total of four lights. If a truck has a slide-in sander, the vehicles could
Illinois	Use 96-inch strobe light bar on cab that extends past the rock guard. Have strobes on dump body posts that face the rear. Also on top of the dump body post have LED stop and turn taillights. Have experimented with white and amber combination, but think it seems more difficult for drivers to comprehend. Believe that the LED lights are best to use.

Iowa	Use a 360 degree amber rotating beacon. Snowplow trucks use a dual amber rotating beacon and two amber rear directional alternate flashing strobes. Amber warning lights are required per Iowa code.
Kansas	Put yellow strobe lights on maintenance vehicles. Some state workers want to put white strobes on vehicles, but it is currently against state legislation.
Kentucky	Use yellow strobe lights placed on the cab.
Louisiana	Use a combination of red and amber warning lights.
Maine	Use amber strobe halogens. Normally one is placed on the roof and one is placed on the back.
Massachusetts	Use amber strobes, placed on highest point of vehicle. Extra strobes may be placed on the dump body. Do not use LED lights yet, but are looking into them.
Minnesota	Snow plows are equipped with six amber strobes. Four of these are mounted in two housings on top of the stationery cab shield. The other two are mounted on the top rear of the dump box. In addition to this put two white strobes on the rear of the box on all left hand wing trucks. Districts have the option of adding the white strobes to the other plow trucks. White strobes are used only during daylight hours. Other vehicles are using either a, double rotating or strobe light, most of these lights are amber, some are blue. Trying a few L.E.D. lights on vehicles, but only with other lights, not by themselves.
Mississippi	Use amber and blue strobe light bars.
Missouri	Use two amber rotating strobes lights on top of the bed on each side. Have LED operating lights that are side mounted on the box. Signal trucks use either red or yellow.
Nebraska	For stripping and slow moving operations have rotating: white, blue, and amber lights. White is mainly used during snow removal. Lights are placed on top of the box. Do not have LED lights.
Nevada	Use yellow strobe lights placed on top of the cab.
New Hampshire	Use mainly roof mounted flashing ambers on dump trucks. Some snowplows have small strobes mounted on the extension arms of the mirrors. Also mount some lights on the backside near the tailgate. Pickups use roof mounted amber strobes. Starting to phase in LED lights with new vehicles.
New York	Use two amber rotating strobes placed on the cab, and two alternating amber warning lights on the rear of the vehicle.
North Carolina	Lighting of maintenance vehicles varies by vehicle type and function. Use a combination of strobes and rotating beacons with a preference for strobes. The primary color of warning lights is yellow; however use clear lights to a large degree as well. Pickups use a 22" or a 44" low-profile light bar mounted on the cab. A sign truck has a 44" light bar with an arrow stick or a 44" light bar with six high-intensity lights, 2 mounted on the rear, and 4 mounted on the side. Single-axle and tandem dump trucks have two high-intensity strobe lights mounted on each side of the cab protector. Incident Management Assistance Patrol vehicles are also equipped with additional warning strobe lights.

North Dakota	Have two yellow strobes and two white strobes (mainly for daytime) elevated on the box for rear viewing. Also put two yellow 360 degree rotary strobes on the cab.
Ohio	ODOT safety lighting consists of amber halogen strobe lighting. The change to strobes occurred in 1986. The array is two strobes mounted on a light bar on top of the cab and two rear facing lights on each side of the front of the bed.
Oklahoma	Use amber strobe lights.
Pennsylvania	Use yellow flashing lights, normally two placed on the cab. New trucks are starting to use LED lights.
Rhode Island	Use red and white Whelen strobe lights.
South Carolina	Use amber rotating, strobe, and ball lights. Place lights in the center of cab.
Tennessee	Older vehicles use amber flash lights, some of the new lights are amber LED strobes. Typically the lights are placed on the cab, and some may be placed on the rear.
Vermont	Use amber warning lights. Most warning lights are strobes, but are experimenting with LEDs. Snowplow trucks have a 360 degree light mounted either on a bar on top of the cab or on the upper mirror brackets so that there is a light on each side. There are rear facing lights in the rear body corner posts. Also two large strobes mounted on swinging plates on the tailgate so that they aim directly back whether the body is up or down. Presently experimenting with LEDs mounted on the discharge end of the wing plow. Pickups, vans, and service vehicles have different configurations depending how the vehicle is set up. If there is no obstruction, a single mounted roof top 360 degree strobe light is used. If there are obstructions then on or more lights are added to the rear of the vehicle.
Virginia	For a single axle dump truck 30,000 GVW the strobe light is to be mounted on a self-leveling bracket. Location of mounting to be center on top or front leading edge of cab shield. Virginia rotating amber lights have a minimum of two halogen sealed beams enclosed within an amber colored dome. Sealed beams are at least 60,000 candle-power and have a flash rate of 80 to 100 flashes per minute. Rotating lights shall be approximately 8 1/2 inches or greater in diameter and height, 6 inches in height for multi-light bars. High intensity amber strobe lights consist of a double flash unit, with a flash rate 80 ± 10 flashes per minute. The strobe lights shall be approximately 6 5/8 inches in diameter and 7 1/2 inches in height or greater. During snow removal an auxiliary snow removal headlight with park/turn lamps is used. Use clear halogen head lamps and amber park/turn lamps that are mounted in the grill or fender area providing a minimum height to center of sealed beam of 66" above road surface. If fender mounted, the lights must be mounted far enough forward to allow aiming with mechanical headlight aimer. Final location subject to VDOT approval. Headlight to be controlled from switch located in cab control console. Use a spreader light to provide light for checking sand spreader operation. This light is to be mounted under the left rear corner of the dump body, facing down. This lamp is a shock mounted Truck-lite 40204 clear lens or equal. To be controlled from a control console mounted switch with On/Off maintained action and include light to indicate function.
Wisconsin, Dane County	Use alternating lights on the tailgate, and a revolving amber light on cab. Use extend lights above the plow in the front. Also have stop lights on top of the tailgate. Supervisors can have red and yellow lights on their vehicles (have to flash at same time).

Wisconsin,
Eau Claire
County

Use a pair of twin amber rotating beacons. Also mount a flashing strobe or beacon on each side of the dump box. Started going to flashing LED lights on the dump box. Also have started using LED service lights.

Wisconsin,
Fond Du Lac
County

Use yellow strobes and 4-way flashers on tailgate.

APPENDIX F

STATE SURVEY RESPONSES: REFLECTIVE TAPE

State	Reflective Tape Usage
Alabama	Do not use reflective tape on smaller vehicles anymore due to lower resale value. Use red and white reflective tape on larger vehicles.
Alaska	Have striping installed on all maintenance vehicles. Stripes are either orange or white, depending on the vehicle color.
Arizona	Do not commonly use reflective tape on maintenance vehicles.
Arkansas	Use red and white bands of reflective tape along the sides and across the back of the bumper of vehicles.
California	Passenger vehicles have a rear 3" to 4" orange horizontal stripe using 4" 3M Scotchlite orange reflective tape. Light duty vehicles have a 5" to 6" horizontal orange stripe applied to both sides and rear of all light duty utility vehicles using 3M Scotchlite orange reflective tape. Orange and white diagonal reflective striping is applied to the rear of vehicles having a width greater than or equal to 80 inches. Large trucks have a 6" horizontal orange stripe of 3M Scotchlite orange reflective tape on both sides of the cab. Orange & white diagonal reflective striping is applied across the rear of the vehicle. Vehicles also have a white reflective "Caltrans" sticker on the rear, and a reflective "CT."
Colorado	Use red and white reflective tape on service vehicles. Have a stripe down both sides, and across the tailgate. The Colorado DOT logo is also reflective.
Connecticut	Put contiguity tape on tailgates of dump trucks. Supervisor vehicles have red and white reflective tape on the tailgates. Normal pickups have a 1" orange reflective tape down the sides of the vehicle.
Florida	Continuity markings are red and white, and are normally two inches wide around the whole truck.
Georgia	Use reflective tape on most vehicles. For small vehicles, the tape is same color as the vehicle. On large dump trucks use red and white reflective tape.
Idaho	As of May 1, 2002, all work vehicles, (everything except sedans and passenger vans) with a factory installed bed, will be equipped with reflective yellow striping tape on the sides and back. The striping tape used is 3M Diamond grade sheeting. Pickups are equipped with a 4" wide stripe. All other vehicles such as 1-ton truck and larger that are equipped with an aftermarket utility, flatbed or bump body have white cabs with the reflective striping and bodies are painted DuPont No. 7893 yellow. The bodies also feature a reflective yellow stripe. Construction equipment is painted the manufacturer's standard safety yellow or DuPont No. 7893 yellow.
Illinois	Put a four-inch band of amber reflective tape under the rock shield on both sides below the top rub rail.
Iowa	Iowa uses red and white (silver) DOT C-2 reflective tape on tailgate and sides of snowplow (dump) trucks and side and rear of 10,000 GWR and larger trailers.
Kansas	Apply high intensity reflective tape on dump trucks, but have a problem of snow covering it during snow removal operations.
Kentucky	Do not use much reflective tape.

Louisiana	Do not use reflective tape on any vehicles except lowboy trailers. Do use a reflective emblem on the doors to identify DOT vehicles with state logo.
Maine	Put red and white reflective tape on the sides of vehicles.
Massachusetts	Have a blue and green reflective stripe down both sides of the vehicle.
Minnesota	Red and white reflective tape is used on all plow trucks. Some other vehicles use the tape, but there are no standards. The tape is made by 3M. See attached pictures.
Mississippi	Use red and white reflective tape on larger vehicles.
Missouri	Put contiguity tape on all new trucks and salt spreaders.
Nebraska	Apply reflective tape to vehicles.
Nevada	Use silver and red reflective tape on tailgates of vehicles.
New Hampshire	Use red and white reflective tape. On patrol trucks tape is placed on bumpers, some also have some on the side. The decals are also reflective.
New York	Are experimenting with 3M reflective tapes on the back of vehicles, and on the back of wing plows.
North Carolina	Trailers have reflective tape around the perimeter of the trailer. Flat-bed trucks have reflective tape around the perimeter of the bed. Some field units will add reflective tape to equipment at various locations to supplement visibility when they expect to perform any night work. Incident management assistance patrol vehicles are marked with reflective decals (like those used on many law enforcement vehicles) along the sides, as well as reflective markings on the front and rear.
North Dakota	Use reflective tape on snowplow trucks.
Ohio	Trailers are taped according to FMVSS 108. Dump trucks are taped on the sides and rear of the dump body with 2 inch red and silver tape.
Oklahoma	Use red and white reflective tape.
Pennsylvania	Use red and white reflective tape.
Rhode Island	Use silver reflective tape.
South Carolina	Use red and white reflective tape on larger vehicles.
Tennessee	Use red and white reflective tape, especially on snowplows.
Vermont	Vehicles 12,000 lbs GVWR and under have a 3" reflective orange stripe down the sides and across the back. All larger vehicles have the DOT red/white reflectorized markings down the sides and across the back.
Virginia	Use red and white reflective tape along the sides of the dump box and on the hood of the cab

Wisconsin,
Dane County

Use 6-8 inch red and white reflective tape across the back and down the sides.

Wisconsin,
Eau Claire
County

Place red and white reflective tape on the back side of the tailgate. There is a L-shape pattern of reflective tape along the sides of the box.

Wisconsin,
Fond Du Lac
County

Have reflective tape on 5-ton dump trucks.

APPENDIX G

STATE SURVEY RESPONSES: VEHICLE COLOR

State	Vehicle Color Practices
Alabama	Vehicles are white.
Alaska	Vehicles are either orange (older vehicles) or white (newer). The graders and heavy equipment are manufacturers standard color.
Arizona	Vehicles above 1 ton are highway yellow. Vehicles a ton and less are white
Arkansas	Maintenance vehicles are white.
California	Vehicles cabs are white, for large trucks, bodies and accessories above the frame and behind the cab are orange.
Colorado	Smaller trucks are fleet white, larger vehicles are orange. Off road equipment is standard factory colors.
Connecticut	Vehicles are Omaha orange.
Florida	Vehicles are DOT yellow.
Georgia	Vehicles are school bus yellow
Idaho	As of May 1, 2002, all work vehicles, (everything except sedans and passenger vans) with a factory installed bed, will be painted white. All other vehicles such as 1-ton truck and larger that are equipped with an aftermarket utility, flatbed or bump body have white cabs and the bodies are painted DuPont No. 7893 yellow. Construction equipment is painted the manufacturer's standard safety yellow or DuPont No. 7893 yellow.
Illinois	No information
Iowa	Vehicles are orange.
Kansas	No information
Kentucky	Vehicles are mostly white.
Louisiana	Vehicles are white. Found that it was costing quit a lot extra to require all orange on maintenance vehicles.
Maine	Vehicle bodies are Omaha orange, and cabs are brown.
Massachusetts	Vehicles are highway yellow.
Minnesota	Plow trucks are orange, all others are variety of colors.
Mississippi	Vehicles are either white, orange, or blue.
Missouri	DOT trucks are "Highway Yellow."

Nebraska	Large vehicles are highway orange. Pickups are various colors.
Nevada	Heavy equipment and large trucks are yellow, Sedans and pickups are white.
New Hampshire	Maintenance vehicles are orange.
New York	Vehicles are yellow; the hood is flat blue to be easier on the driver's eyes.
North Carolina	All vehicles and equipment are painted yellow, commonly called "NCDOT Safety Yellow, " DuPont paint number 54701AK.
North Dakota	No information
Oklahoma	Vehicles are yellow or white.
Ohio	In 1994, ODOT started phasing in white as standard color for all licensed, motorized vehicles. This replaces the previous special yellow. The reasons are decreased cost, better delivery, better visibility and higher resale value. Off-road and construction equipment is purchased with manufacturer's standard colors. Snowplows are ordered in gloss black.
Pennsylvania	Vehicles are yellow.
Rhode Island	Vehicles are orange.
South Carolina	Vehicles are school bus yellow.
Tennessee	Old trucks are orange, new trucks are going to be white because of cost.
Vermont	Trucks over 12,000 lbs. GVWR are orange, the smaller vehicles are either blue, green, black, or white.
Virginia	The maintenance vehicles are to be factory painted orange in accordance with the color now used by the Virginia Department of Transportation, lead free, Du Pont color #LF74279AT or equivalent.
Wisconsin, Dane County	No information
Wisconsin, Eau Claire County	Vehicles are a yellowish green (slime green), considered most visible during all types of lighting.
Wisconsin, Fond Du Lac County	No information

APPENDIX H

STATE SURVEY RESPONSES: SNOW REMOVAL DEVICES

State	Snow Removal Device Usage
Alabama	No information
Alaska	On grader and truck wing tips have installed strobe lights. Use conspicuity tape on some wing plows, depending on the location. (Rural locations are on lane operations and don't have problems with motorists trying to pass on the right.) Dump boxes are equipped with strobe lights and deflectors to decrease the snow accumulation.
Arizona	Snowplows use amber strobe lights on the front. Have strobe lights on all 4 corners placed on the bumper. Have blue and amber strobes on the back. Use snowplow deflectors and tailgate deflectors
Arkansas	Use snowplow deflectors.
California	Apply work lights on the wing plow. May apply one or more one way flashing lights at corners of the dump box.
Colorado	Use the Whelen snow and fog lights on snow removal vehicles. Snow removal vehicles also run a combination of amber and blue lights. Snowplows have strobes on the left and right hand side of the cab. Place strobes on the corner posts of the bed on the rear, so snowplow has a total of 4 strobes. Place a LED warning light on the end of the wing plow. Use
Connecticut	Snowplows are J-style. Some drivers opt to put on deflectors.
Florida	No information
Georgia	Use snowplow deflectors. Have lights above the snowplow
Idaho	Snowplows have a Whelen Superstrobe Comet Flash light mounted on the truck cab. At the top /center rear of the sander is a dual rotating halogen light. Each truck is equipped with four amber halogen lights on the sides of the sander, two per side. These lights are equipped with a flasher unit to give the appearance of a bouncing ball, i.e. the lights flash side to side, top to bottom. All snowplow trucks are equipped with LED taillights. Dump bodies have four total and sanders have four total lights. If a truck has a slide-in sander, the vehicles could have as many as eight taillights. Use an air foil on the back of all sander bodies. Airfoil scoops air coming over the top of the sander and directs it over the back of the sander to keep the rear lights visible.
Illinois	Have done some experiments on snow deflectors, but don't seem necessary in Illinois
Iowa	Use snowplow deflectors on some plows. New plows being used do not require use of a deflector. Some snowplows use taillight air blasters. Experimenting with continuity tape placed on orange safety fence on the rear of the vehicle. Snowplow trucks use a dual amber rotating beacon and two amber rear directional alternate flashing strobes.
Kansas	No information.
Kentucky	Snowplow vehicles have lights on tailgate corners, and on the cab. Place flags on the plow, use snowplow deflectors, and place lights above the plow.
Louisiana	No information.

Maine	Run more lights on snowplows than normal maintenance vehicles.
Massachusetts	No information.
Minnesota	Snow plows are equipped with six amber strobes. Four of these are mounted in two housings on top of the stationery cab shield. The other two are mounted on the top rear of the dump box. In addition to this also put two white strobes on the rear of the box on all left hand wing trucks. Districts have the option of adding the white strobes to the other plow trucks. White strobes are used only during daylight hours. Other vehicles are use either a double rotating or strobe light, which most are amber, some are blue. Trying a few L.E.D. lights, only with other lights, not by themselves. Put reflective tape on wing plows and on the underbody.
Mississippi	No information.
Missouri	Commonly use snow deflectors.
Nebraska	Use some snowplow deflectors. White and amber warning lights are mainly used during snow removal.
Nevada	Place orange flags on the rear of snowplow vehicles.
New Hampshire	Some snowplows have small strobes mounted on the extension arms of the mirrors. Also mount some lights on the backside near the tailgate.
New York	Most plows have snow deflectors, and some have deflectors that extend out then down. Some snowplow vehicles use standard bug shields to prevent splash up on the windshield. Some vehicles have airfoils on the back of vehicles to prevent accumulation of snow on the rear of the vehicle.
North Carolina	On snowplow vehicles, use the standard lighting of two high-intensity strobe lights mounted each side of the cab protector. Also place a yellow strobe mounted on the rear of the in-body material spreaders. Some trucks are equipped with only a tailgate spreader. These trucks will have no additional light other than that standard on the dump truck. However, every tailgate on the dump bodies are striped with reflective (glass beaded) paint.
North Dakota	No information.
Ohio	Snowplows are ordered in gloss black. Additionally, attach 18" orange plastic tubes to the outside edge of the moldboard so drivers can see the plow placement.
Oklahoma	Use snowplow deflectors.
Pennsylvania	Use snowplow deflectors.
Rhode Island	No information.
South Carolina	No information.
Tennessee	No information.
Vermont	Use snowplow deflectors. Snowplow trucks have a 360 degree light mounted either on a bar on top of the cab or on the upper mirror brackets so that there is a light on each side. There

are rear facing lights in the rear body corner posts. Also two large strobes mounted on swinging plates on the tailgate so that they aim directly back whether the body is up or down. Presently experimenting with LED's mounted on the discharge end of the wing plow.

- Virginia During snow removal an auxiliary snow removal headlight with park/turn lamps is used. Use clear halogen head lamp and amber park/turn lamps that are mounted in the grill or fender area providing a minimum height to center of sealed beam of 66" above road surface. If fender mounted, the lights must be mounted far enough forward to allow aiming with mechanical headlight aimer. Final location subject to VDOT approval. Headlight to be controlled from switch located in cab control console. Use a spreader light to be provide light for checking sand spreader operation. This light is to be mounted under the left rear corner of the dump body, facing down. Lamp to be a shock mounted Truck-lite 40204 clear lens or equal. To be controlled from a control console mounted switch with On/Off maintained action and include light to indicate function.
- Wisconsin,
Dane County Have extend lights above the plow in the front.
- Wisconsin,
Eau Claire
County Have tried tailgate deflectors on one vehicle, but do not believe will use again.
- Wisconsin,
Fond Du Lac
County Started using snow deflectors.

APPENDIX I

**STATE SURVEY RESPONSES: MOVING WORK ZONE GUIDELINES AND
EQUIPMENT**

State	Moving Work Zone Guidelines and Equipment Usage
Alabama	No information.
Alaska	No information.
Arizona	Use TMAs and arrow boards mainly during stripping operations.
Arkansas	Use TMAs consistently in moving operations. Have arrow boards, normally one on the shoulder, then one later in the lane. Sometimes place changeable message signs before construction.
California	Use shadow vehicles, TMAs, and flashing arrow boards. The shadow vehicle remains about 3 seconds behind the work vehicles.
Colorado	Use 75 mph TMAs, place on older snow removal vehicle normally 30,000-40,000 GVWR. Place a 4' - 8' 22 light arrow board on TMA vehicles. Mainly use TMAs during paint stripping in the Denver area.
Connecticut	In moving work zones use three Connecticut TMAs along with truck mounted arrow boards.
Florida	On multi-lane roads, an advance warning vehicle with an advance warning arrow panel and message sign equipped with TMA is optional during moving operations. A shadow vehicle equipped with a TMA, an advance-warning arrow, and a sign message behind the work vehicle is required. The spacing between vehicles varies from rural and urban settings. The spacing between the shadow vehicle and the work vehicle in rural conditions is 500-800 feet and in urban is 300-500 feet. The spacing between the advance warning vehicle and the shadow vehicle in rural conditions is 500-1,500 feet and 300-500 feet in
Georgia	Use TMAs, message boards, and arrow boards (starting to get truck-mounted message and arrow boards).
Idaho	ITD does not have a policy at this time regarding the use of shadow vehicles and TMAs, but do have several units in each district. It is up to the District Maintenance Engineer to set district policy regarding their use.
Illinois	Use the MUTCD for requirements of TMAs and shadow vehicles.
Iowa	Use shadow vehicles and TMAs in some moving work zones.
Kansas	During paint stripping have a TMA and an arrow board on both the shadow vehicle and the stripping vehicle. Use a mobile radio transmitter to tell drivers of stripping operations
Kentucky	Use TMAs and arrow boards on 4-lane roads often.
Louisiana	Follow the striping and raised marker operations with a protective vehicle. Marking operations always have a crash attenuator mounted to a vehicle meeting the attenuator manufacturer's specs for weight rating. Usually a 10 yard dump truck partially loaded with sand is used. For other maintenance operations have a Maintenance Traffic Control Handbook which follows fairly closely to the MUTCD Part IV. Do make using an attenuator on the shadow vehicle optional and suggest the use if it is available. Each of the nine District Offices have at least one attenuator truck. It is usually used on Interstate work in such as protecting the sweeping operation and work involving lane closures, and if available it is used on other high volume routes.

Maine	Use TMAs, 6-foot arrow boards with strobe halogen boards.
Massachusetts	Use TMAs, arrow boards, and variable message signs, which some are truck mounted.
Minnesota	No information.
Mississippi	Use TMAs, and arrow boards in moving work zones.
Missouri	Use two protective trucks in moving operations, both have a flashing arrow board, a work sign, and a TMA. The first protective truck should be a minimum of 150 feet behind the work unit or area. For mechanized operations: the trailing protective truck shall have an advance lane closure sign mounted on it. The sign shall not block the flashing arrow. Signing on the protective truck can be either lane or work related. Shoulder mount signs are required if workers are on the roadway. If the operation is mechanized signing placed on the protective trucks is adequate. When the left or right lane is closed the trailing protective truck should be on the shoulder when the shoulder is wide enough.
Nebraska	Use of TMAs, shadow vehicles, and arrow board depends on the operation. During stripping on interstates use TMAs.
Nevada	Use shadow vehicles and/or TMA's on all moving operations except snow plowing. However, there is no formal policy.
New Hampshire	Use TMAs extensively, and are dedicating some vehicles strictly for TMAs. Trucks with TMAs contain variable message signs.
New York	Have about 225 TMAs, most are test level three category. If TMAs are available, then at least the first vehicle approached will have a TMA. If there are enough TMAs available, all vehicles in the moving work zone will have TMAs. TMA vehicles also contain arrow boards.
North Carolina	No information.
North Dakota	Normally have two TMAs per district, which are mainly used on four-lane roads but not consistently. Use some shadow vehicles but there is no standard. Commonly use arrow boards during moving operations.
Ohio	ODOT uses the Manual of Uniform Traffic Control Devices to determine work zone safety practices.
Oklahoma	Use arrow boards, TMAs, and shadow vehicles according to MUTCD.
Pennsylvania	Use TMAs and arrow boards in moving operations.
Rhode Island	Use TMAs and arrow boards in moving operations. Some arrow boards are truck mounted, some are trailer mounted.
South Carolina	Use "escort service" during moving operations.
Tennessee	Require the use of TMAs and arrow boards in mobile operations. The first vehicle approached must have a TMA, and the other vehicles are recommended to have a TMA.

Vermont	TMA's are placed on the tail supply vehicle in paint stripping operations. That vehicle, as well as the paint truck have arrow boards. Do not use shadow vehicles. Mowing operations are signed. Pothole repair is signed, usually has a flag person and possibly an arrow board. Message signs and/or arrow boards are more commonly used in stationary
Virginia	For mobile operations where a lane is closed, an arrow board is used, and the vehicle displaying the arrow board is equipped with appropriate signing and/or lighting. Virginia uses TMA in mobile operations. The TMA vehicle should be 1,000 feet ± in advance of the work vehicle. For moving operations where volumes are light and visibility is good, a well-marked and well-signed vehicle may suffice for protection. If volumes and/or speeds are higher, a shadow or backup vehicle equipped as a sign truck, preferably supplied with a flashing arrow display, should follow the work vehicle. In addition, vehicles may be equipped with such devices as flags, flashing vehicle lights, TMA's, and appropriate signs. For moving and mobile operations on limited access highways, the first advance warning vehicle shall travel along the paved shoulder with either a flashing arrow, or a portable changeable message sign advising of the operation ahead, and lane closure information. If the first advance vehicle cannot run completely on the shoulder and is partially in the travel lane, it shall be equipped with a TMA. The second advance warning vehicle, with a TMA, shall straddle the edge line, partially on the shoulder and partially in the lane. The third advance warning vehicle, with a TMA shall be in the travel lane. For moving and mobile operations on four-lane roadways, on high speed, high volume roads, an advance warning vehicle on the shoulder with an arrow board and sign should be used. Another advance warning vehicle in the travel lane with a TMA is used, following at a distance of 300 feet when moving, and 50-100 feet when stationary. Also, in certain situations, appropriate stationary signing may be used.
Wisconsin, Dane County	Use TMA's, shadow vehicles, arrow boards, and message boards on four lane roads (40,000 - 10,000 vpd).
Wisconsin, Eau Claire County	Have two permanent mounted TMA's that use on multi-lane roads. TMA vehicles also have arrow boards mounted on them.
Wisconsin, Fond Du Lac County	Use shadow vehicles and TMA's always on US 41 (30,000 a day) and most expressways during moving operations. Also use arrow boards.

APPENDIX J

**IOWA COUNTY SURVEY RESPONSES: TRAFFIC CONTROL DEVICES FOR
ROUTINE MAINTENANCE OPERATIONS**

The following traffic control devices are used to advise motorists of routine maintenance operations by graders in the counties indicated.

County	Advance Warning Signs	Warning Signs on Motor Grader, Front	Warning Signs on Motor Grader, Back	Rotating Amber or Strobe on Vehicle	Other Traffic Control Devices
Adair	No	No	Yes	Yes	
Adams	No	No	Yes	Yes	
Allamakee	Yes	No	Yes	Yes	
Appanoose	No	No	Yes	Yes	
Black Hawk	No	No	Yes	Yes	
Boone	No	Yes	No	Yes	
Bremer	No	No	Yes	Yes	
Buena Vista	No	No	Yes	Yes	
Calhoun	No	No	Yes	Yes	
Carroll	No	No	Yes	Yes	Place flags on end of moldboard
Cedar	No	No	Yes	Yes	Place flags on each end of moldboard and on top of cab
Cerro Gordo	Yes	No	Yes	Yes	
Cherokee	No	No	Yes	Yes	
Chicksaw	No	No	Yes	Yes	
Clay	No	No	Yes	Yes	
Clinton	No	No	Yes	Yes	Place flags on front of machine
Crawford	No	No	Yes	Yes	Florescent flags extending above the cab and on the ends of the moldboard
Dallas	No	No	Yes	Yes	Put orange flags on eight foot fiber glass pole on front of machine. Orange flags on each end of moldboard are also used. Use backup alarms.
Decatur	No	No	Yes	Yes	
Deleware	No	No	Yes	Yes	
Des Moines	No	No	Yes	Yes	
Dubuque	No	No	Yes	Yes	
Emmet	No	No	Yes	Yes	
Floyd	No	No	Yes	Yes	
Franklin	No	No	Yes	Yes	
Greene	No	No	Yes	Yes	Installing high intensity strobes on blades
Guthrie	No	No	Yes	Yes	
Hamilton	Yes	No	Yes	Yes	
Henry	Yes	No	Yes	Yes	
Humboldt	No	No	Yes	Yes	
Jackson	Yes	No	Yes	Yes	
Johnson	No	No	Yes	Yes	
Jones	Yes	No	Yes	Yes	Place flags on mold board
Keokuk	No	No	Yes	Yes	
Lee	No	No	Yes	Yes	
Linn	No	No	Yes	Yes	Use slow moving vehicle signs
Louisa	No	No	Yes	Yes	
Lucas	No	No	Yes	Yes	
Madison	No	No	Yes	Yes	

Mahaska	No	No	Yes	Yes	
Marion	No	No	Yes	Yes	
Marshall	Yes	No	Yes	Yes	
Mills	No	No	Yes	Yes	Use backup alarms
Monona	No	No	Yes	Yes	
Osceola	No	No	Yes	Yes	
Page	No	No	Yes	Yes	
Plymouth	No	No	Yes	Yes	
Pocahontas	No	No	Yes	Yes	
Poweshiek	No	No	Yes	Yes	
Ringgold	No	Yes	Yes	Yes	
Sac	No	No	No	Yes	Use slow moving vehicle signs
Scott	Yes	Yes	No	Yes	Use a white strobe in rear
Shelby	No	No	Yes	Yes	
Sioux	Yes	No	Yes	Yes	
Story	No	No	Yes	Yes	
Tama	No	No	Yes	Yes	
Union	No	No	Yes	Yes	
Van Buren	No	No	Yes	Yes	Place flags on ends on moldboard
Warren	No	No	Yes	Yes	
Winnebago	Yes	No	Yes	Yes	
Winneshiek	Yes	No	No	Yes	

APPENDIX K

**IOWA COUNTY SURVEY RESPONSES: WARNING DEVICES FOR SNOW
REMOVAL OPERATIONS**

The following warning devices used to advise motorists of snow removal operations in the counties indicated.

County	Reflective Tape on Vehicles	Reflective Tape on Plows	Snowplow Deflectors	Flags on Vehicles or Plows	Warning Lights on Vehicles	Placement of Auxiliary Headlamps
Adair	Yes	Yes	Yes	Yes	Place some strobes on back of boxes, and some rotating warning lights on top of the truck	Place auxiliary headlamps on front of maintainers that shine above the V-plow
Adams	Yes	No	No	Yes	Use strobe warning lights	Do not use
Allamakee	Yes	No	No	Yes	Place strobes on the box cab protector and rear box corners	Place auxiliary headlamps just above the plow on the truck
Appanoose	Yes	No	No	Yes	Place strobes on truck and on back of sander	Place auxiliary headlamps above the plow
Black Hawk	Yes	Yes	Use airfoils	Yes	Use rotating warning lights	Place auxiliary headlamps on the plow mounting frame
Boone	Yes	Yes	No	Yes	Use strobe warning lights	Do not use
Bremer	No	No	No	Yes	Place a rotating amber double on cab shield of dump body	Place auxiliary headlamps on fender above plow
Buena Vista	Yes	No	Yes	Yes	Place strobe on four corners of trucks	Place auxiliary headlamps above the plow
Calhoun	Yes	No	No	Yes	Place strobe warning lights on all equipment	Auxiliary headlamps placed above plows
Carroll	Yes	No	Yes	No	Use a variety of strobe, LED, and rotating	Place auxiliary headlamps on plow push frame two to three inches above top of plow
Cedar	Yes	Yes	Yes	Yes	Place strobe lights on rear corners of box, and rotating light on top of cab	Use auxiliary headlamps
Cerro Gordo	Yes	No	Yes	Yes	Use warning lights	Use auxiliary headlamps mounted on frame of snowplow
Cherokee	Yes	No	No	Yes	Place a flashing beacon on top of vehicle	Place auxiliary headlamps on front of vehicle, the lights are hood height
Chickasaw	No	No	No	No	Use rotating warning lights	Do not use
Clay	Yes	Yes	No	Yes	Place strobe lights on top of cab bar	Place auxiliary headlamps on bar above top height of plow
Clinton	Yes	Yes	No	Yes	Place a Whelen strobe on the cab, and strobe in rear on the box	Place auxiliary headlamps above the plow on the truck
Crawford	Yes	Yes	Yes	Yes	Place strobe lights on top of the cab	Do not use
Dallas	Yes	Yes	Yes	Yes	Place strobe lights on top of cab and on both back corners of box	Place auxiliary lights on top of fenders or on snowplow mount. Put auxiliary lights on front of graders, and lights shining on each end of moldboard and on side shining on wing plow

Decatur	No	No	No	Yes	Place strobe lights on top of the cab of snow plow truck and motor grader. Strobes on back of the box of trucks and both sides of	Place auxiliary headlamps above plow on truck plow, mounted to plow frame
Delaware	Yes	No	Yes	Yes	Place strobe lights on the truck cab guarded and rear box posts	Place auxiliary headlamps on front plow mount
Des Moines	Yes	No	No	Yes	Use strobe and rotating warning lights	Place auxiliary headlamps on mounts off of the hood
Dubuque	Yes	Yes	No	Yes	Use a rotating light on top, and a strobe on the box	Do not use
Emmet	Yes	No	Yes	Yes	Place strobes on top of truck. Also have four-way type strobes in four-way flashers	Use auxiliary headlamps
Floyd	No	No	No	Yes	Use rotating amber lights	Do not use
Franklin	Yes	No	No	Yes	Moving from strobe to rotating warning lights	Place auxiliary lights on motor grader plows, and on A-frames for truck plows
Greene	Yes	No	No	No	Place high intensity strobe on each side of cab that is visible front and back	Place one just over plow and on high on cab
Guthrie	Yes	No	No	Yes	Use standard strobe lights on grader	Place auxiliary headlamps on the truck frame above the hood, not on the plow because there is less bounce on the lights this
Hamilton	Yes	No	Yes	Yes	Use strobe warning lights	Put an auxiliary light on front and on top of cab
Henry	No	No	Yes	Yes	Use one rotating light on truck cab and one at each corner of tailgate	Use auxiliary headlamps
Humboldt	No	No	No	No	Use strobe and rotating warning lights on top of cab	Do not use
Jackson	Yes	Yes	Yes	Yes	Place rotating strobe on top of cab of truck/grader	Place auxiliary headlamps in front of truck above the plow blade
Johnson	Yes	No	No	Yes	Place strobe lights on top of cab and rear of box	Put auxiliary headlamps on top of cab
Jones	Yes	Yes	Yes	Yes	Use mostly rotating and strobe lights top mounted on cab. Rear mount in boxes is mostly LED	Place auxiliary headlamps on front above plow. Use spinner lights for spreader wing lights Use aircraft spot lights
Keokuk	Yes	No	Yes	Yes	Place strobe lights on top and strobe lights in rear taillights	Place auxiliary headlamps in front above the plow
Lee	Yes	No	No	No	Use a strobe light on truck	Use an auxiliary headlamp located on the hood or bracket in front of truck
Linn	Yes	No	Yes	Yes	Place single or twin roto beam on top of cab, and strobe and LED on rear of trucks	Place auxiliary headlamps on snowplow frame or on hood of vehicle
Louisa	Yes	Yes	Yes	Yes	Use strobe lights	Do not use
Lucas	No	No	No	No	Place strobe and rotating warning lights above the vehicles cab	Place auxiliary headlamps mounted on the trucks snowplow brackets

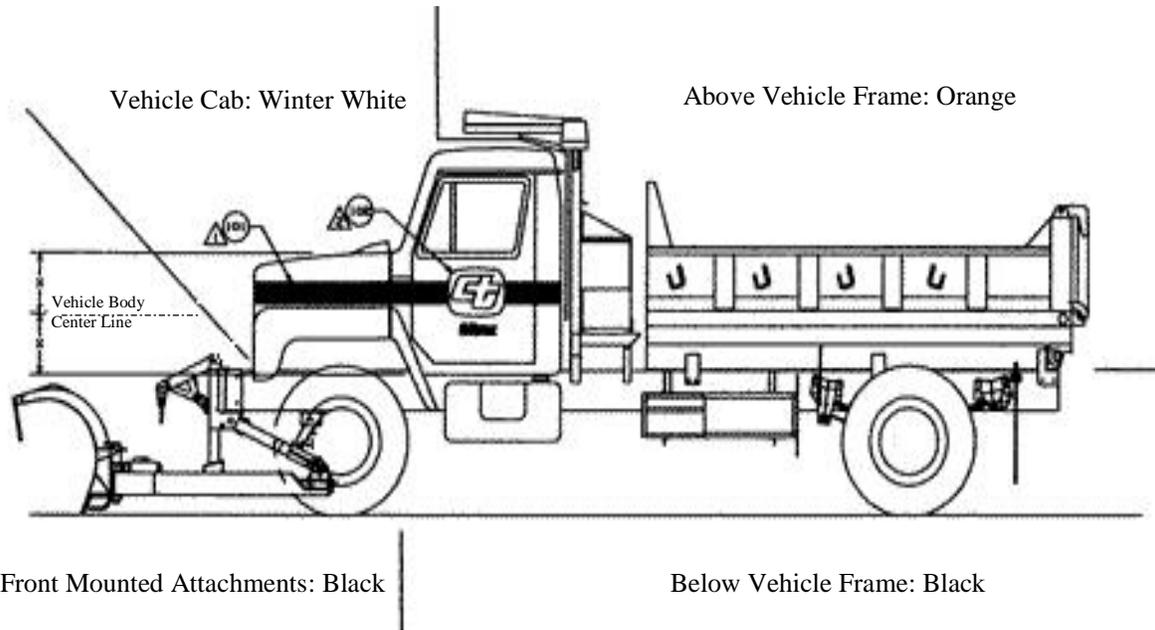
Madison	Yes	Yes	Yes	No	Place rotating warning lights on the box, and strobe lights on the taillights	Do not use
Mahaska	Yes	No	No	No	Use strobe and LED warning lights	Do not use
Marshall	Yes	Yes	Yes	Yes	Place rotating warning lights on the cab protector	Use auxiliary headlamps
Marion	No	No	No	Yes	Use rotating strobe lights	Use auxiliary headlamps
Mills	No	No	No	Yes	use flashing warning lights, regular lights, and backup warnings	Place auxiliary headlamps on the plow
Monona	Yes	No	No	Yes	Use rotating amber lights, strobe lights on back corners of dump body	Place an auxiliary headlamp above the plow
Osceola	No	No	No	Yes	Use rotating warning lights	Do not use
Page	No	No	No	Yes	Place strobe lights on top	Do not use
Plymouth	No	No	No	Yes	Use strobe lights	Place auxiliary headlamps on top of cab on a light bar
Pocahontas	No	No	Yes	Yes	Use on strobe and one revolving	Use auxiliary headlamps
Poweshiek	Yes	Yes	No	Yes	Place strobe lights on some and rotating on others	auxiliary headlamps are placed on plow mounts
Ringgold	Yes	No	Yes	Yes	Place a strobe on front of the box	Do not use
Sac	No	No	No	Yes	Use warning lights	Place auxiliary headlamps on top of hood
Scott	Yes	Yes	Yes	Yes	Use a rotating strobe, and also a rear white strobe in taillights	Do not use
Shelby	Yes	No	No	Yes	Place a strobe light at front of box and a strobe in each rear corner of box	Do not use
Sioux	Yes	No	No	Yes	Use strobe (rotating) flashing strobe lights	Place auxiliary headlamps on brackets mounted to bumper or truck
Story	Yes	Yes	Yes	No	Use rotating amber lights	Do not use
Tama	No	No	No	Yes	Use rotating amber lights	Place auxiliary headlamps above plow on hood
Union	Yes	No	No	Yes	Place amber strobe lights on back of boxes	Place auxiliary headlamps on front of vehicles to shine above plows
Van Buren	Yes	Yes	No	No	Use a strobe only on the truck	Do not use
Warren	Yes	No	No	Yes	Use various warning lights	Use auxiliary headlamps
Winnebago	Yes	No	Yes	Yes	Place strobes on top of headache board	Place auxiliary headlamps on frame of plow
Winneshiek	Yes	Yes	Yes	Yes	Use strobes, rotating, LED, and flashing warning lights	Place auxiliary headlamps on top of hitch

APPENDIX L

**TRUCK SPECIFICATIONS FOR PAINT, WARNING LIGHTS, AND REFLECTIVE
TAPE**

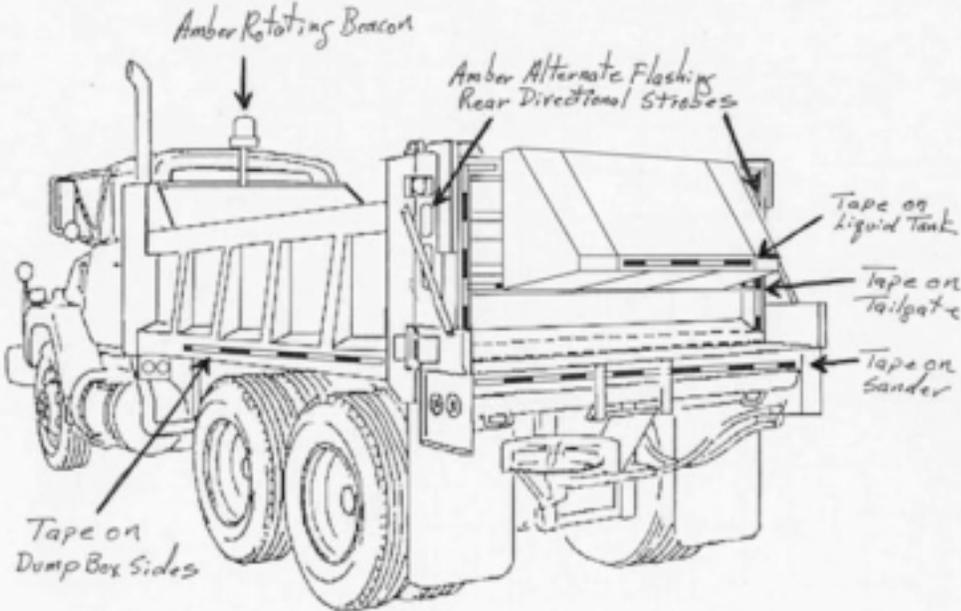
**California
Iowa
Virginia**

California: Truck Paint and Decal Schematic



Iowa: Warning Light and Reflective Tape Diagram

Placement Diagram for Reflective Tape



Virginia: Truck Lighting Schematic

