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

Iowa DOT Project TR-475
CTRE Project 02-107

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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.

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Iowa DOT Project TR-475
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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.

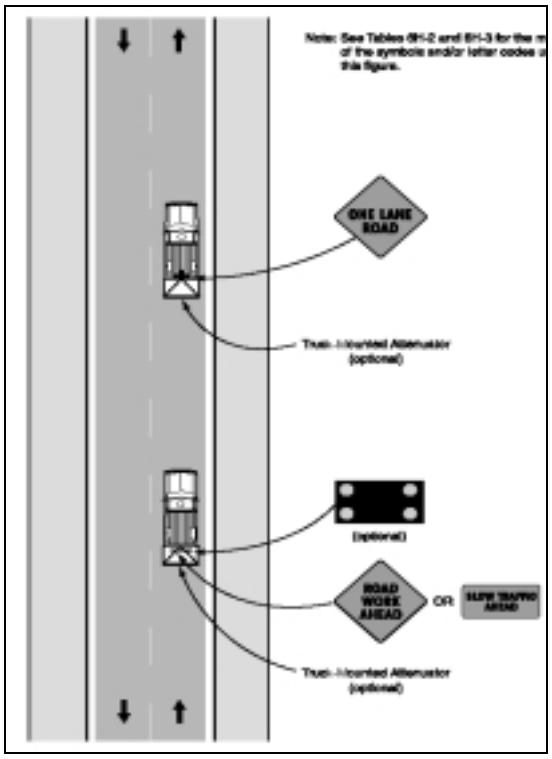

Figure 1. MUTCD Schematic for Mobile Operation on Two-Lane Road

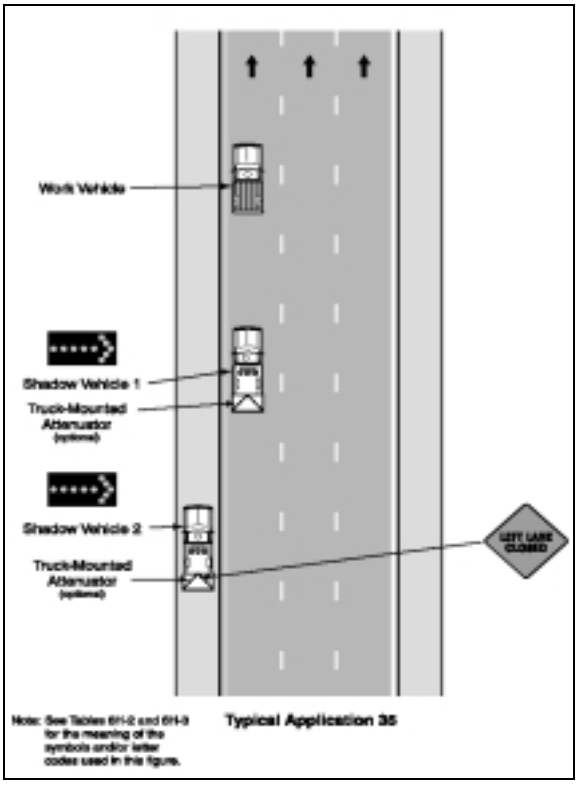

Figure 2. MUTCD Schematic for Mobile Operation on Multilane Road

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.

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