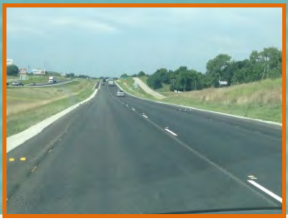


Guidance for the Use of Temporary Pavement Marking in Work Zones

January 2014

This material is based upon work supported by the
Federal Highway Administration
under Grant Agreement No. DTFH61-06-G-00004

ATSSA
SAFER ROADS SAVE LIVES

American Traffic Safety
Services Association

U.S. Department of Transportation
Federal Highway Administration

TABLE OF CONTENTS

Cover Photo Credits (from left to right)

1. *Resurfacing on Missouri Interstate 70 source: Matt Myers, Leidos*
2. *Resurfacing on Oklahoma Interstate 44 source: Matt Myers, Leidos*
3. *Resurfacing on Missouri Interstate 70 source: Matt Myers, Leidos*
4. *Lane shift on Missouri Interstate 70 source: Matt Myers, Leidos*

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Temporary pavement markings are an important element of a Traffic Control Plan (TCP) and provide drivers with clear and defined travel paths through work zones. The Manual on Uniform Traffic Control Devices (MUTCD), *Section 6F.77: Pavement Markings* emphasizes the need for adequate markings throughout work zones for any travel conditions. According to the MUTCD, temporary pavement markings for long-term work zones should perform as effectively as permanent pavement markings.

Temporary pavement markings and raised pavement markers can be installed using a variety of materials including paint, thermoplastic, epoxy, temporary tape, and raised pavement markers such as tabs and buttons. One of the most widely used materials for work zone pavement marking is traffic paint. Painted markings can be installed efficiently over long distances. Buttons, traffic paint, and temporary raised pavement markers can be useful for short-term work zones while pavement markings for long-term work zones could range from traffic paint to more durable products such as thermoplastic or epoxy.

When choosing a pavement marking product for work zones, transportation agencies consider several factors including:

Durability. Practitioners need to ensure the pavement marking chosen is durable enough to last during the life of the work zone. Premature degradation of the marking can be caused by excessive wearing by vehicles traveling directly on the pavement marking. Other factors such as weather, pavement surface, quality of the material used, practitioners experience in applying material, or pavement and air temperature at the time of installation can also impact durability.

Ease of Removal. Because the marking is to be temporary and is typically not placed at the same location as the subsequent permanent marking, it is important that the material can be removed from the pavement without leaving a significant "ghost" marking. For example, temporary tape is relatively easy to remove when compared to other commonly used temporary pavement marking materials. For other materials, (e.g., traffic paint), practitioners use various removal methods, such as grinding, water blasting, or shot blasting. Each method varies according to the amount of pavement scarring, time to remove, and cost. Grinding, water blasting, and shot blasting are three commonly used removal methods. Grinding is one of the fastest and cheapest methods used, but leaves a high degree of pavement scarring and may not completely remove the markings. Water blasting ranks high in degree of removal with little scarring, particularly on concrete pavement, but water blasting is much slower than grinding. Shot blasting scores slightly better than grinding in rate of removal, having slightly less cost, and less pavement scarring.

Cost. Highway agencies must account for the cost of the temporary pavement marking and include it in overall project costs. The different products used can vary in cost. Traffic paint can range from $0.05 to

$0.15 per foot installed. Durable markings such as epoxy or thermoplastic can range from $0.10 to $0.35 per foot installed.

Retroreflectivity. Retroreflectivity is necessary to delineate the correct path for road users, especially at night and during inclement weather. Recent innovations in temporary pavement marking in work zones include wet reflective pavement marking elements and sequential lighting devices.

- *Wet-reflective and Wet-recovery Pavement Marking.* The use of improved wet-weather visibility and wet-weather recovery pavement marking can provide road users improved visibility in inclement weather conditions. Some products can provide retroreflectivity even under a layer of water, and others quickly regain their retroreflectivity after a wet-weather event ends. Through FHWA's Highway for Life program, an All-weather paint (AWP) was recently evaluated under both a closed circuit test and at an active work zone. Researchers found AWP markings retained 50 to 70% of their dry-weather retroreflectivity values compared to standard markings, which retained 17% of their dry-weather retroreflectivity values.

Sequential Lighting. Sequential lighting added to temporary traffic control devices such as channelizers along a work zone taper provide additional information to drivers as they approach and travel through the work zone. Using sequential lighting can also lead to a reduction of speeds in the work zone. Another potential benefit from using sequential lighting is a reduction in the number of drivers merging over into the other lane at the last possible moment prior to a shifting taper. This type of treatment can be useful for night work zones which last throughout the evening, but will have minimal impact to the permanent pavement marking. Sequential lighting can reduce the need for temporary marking through the work zone taper, allowing quicker removal of the temporary traffic control when restoring the roadway to normal operation during the day.

Given the variety of temporary pavement markings and the factors that influence their use by transportation agencies, the goal of this document is to provide information on the advantages and disadvantages of temporary pavement marking.

Introduction

Background

Temporary pavement marking in work zones provide guidance to the driver on the safest and best path through a work zone. Temporary pavement markings identify changes in lanes and alignment. These markings help maintain a smooth flow of traffic through shifting and merging tapers. Temporary markings must also be easily removed as conditions dictate. Agencies and practitioners chose pavement marking materials to best address the conditions dictated by the work zone.

Purpose of Document

The MUTCD contains guidance to practitioners and agencies on temporary markings for short-, intermediate-, and long-term work zones. This document will cover the typical pavement marking materials used by agencies in work zones. Practitioners will also find information related to the importance of maintaining adequate pavement markings under heavy traffic or extreme weather conditions. Information related to methods on removing markings is referenced as well. Because agencies are increasingly setting up work zones at night, guidance on sequential lighting in the work zone is provided for practitioners' consideration.

Materials

Different pavement materials may be needed for various reasons. This section will provide general information on the types of materials, durability, and maintenance. The section will highlight different uses for these materials: paint, thermoplastic, epoxy, and temporary raised pavement markers such as tabs and buttons.

Types of Materials

A number of materials can be used to provide temporary pavement markings in work zones, including traffic paint, temporary tape, raised pavement markers, buttons, and tabs. The following bullets provide a brief overview of each material:

- *Traffic Paint.* Quick-drying paint with glass beads added to create retroreflectivity is a low-cost material for temporary work zones. This material is best applied at temperatures of 70 degrees F and above with little humidity, but can be applied when ambient temperatures are above 50 degrees F. Traffic paint is one the least durable liquid materials used.
- *Temporary Tape.* Preformed tapes are strips of plastic with an adhesive backing. Temporary tape can be removed by pulling the material up and does not require heat or other mechanical methods, although using these methods can result in faster removal. This material may only be used for short-term work zones up to 6 months to prevent the resin from strongly adhering to the pavement. Temporary tape used in work zones is produced with retroreflective material incorporated into it.
- *Temporary Raised Pavement Markers (TRPM).* TRPMs are commonly used in construction zones. Either an adhesive or a peel and stick backing are used to attach the TRPM to the pavement.
    - *Tabs.* These markers are strips of plastic which have a reflective strip built into the marker such as Figure 1. Tabs are constructed with enough flexibility to resist an impact. However, practitioners should regularly inspect and replace damaged devices as soon as possible. These devices are deployed to simulate a continuous or dashed line and can supplement flat line markings for conditions such as rain.

Figure 1. Temporary Plastic Tab

    - *Buttons.* These are rounded domes such as are shown in Figure 2 and are similar to Tabs. These can be glued to the pavement and could be used to simulate dashed lines. These devices are manufactured from plastic or ceramic materials. They are not as impact resistant as tabs and are not usually used where snow-plowing may be a possibility.

- *Epoxy and Thermoplastic.* Long-term work zones and high traffic volumes may warrant the use of these materials. These are highly durable materials that are appropriate for those areas where a visible line is needed for many months or years and subject to extreme abuse from traffic or other situation-specific conditions. Agencies considering these markings will typically apply them in the locations where permanent markings will be when the project is complete.

Figure 2. Temporary Buttons

Traffic paint is the material most commonly used for temporary pavement markings in work zones, as shown in Table 1. The advantages of traffic paint are that it's versatile, relatively inexpensive, and quickly installed. Traffic paint is formulated to dry within minutes after application, and can be applied either by hand using paint brushes or truck mounted marking system. Temporary tape is also a commonly used pavement marking in work zones due to its ease of installation and removal. Temporary buttons and raised pavement markers can be used to simulate solid lines or supplement existing flat-line pavement marking. Buttons are normally used where snow removal is not expected. Epoxy or thermoplastics materials create highly durable markings and may not be considered as "temporary" as the other markings discussed in this document are. However, high-traffic volumes or lengthy project duration may make it necessary to apply these markings to ensure that the markings are visible and adequate for traffic guidance and control. Because the characteristics of these materials vary, agencies may use several different types of temporary marking materials on a project based on project duration, traffic characteristics, and weather conditions.

Table 1. Results of 20 State Survey on Pavement Markings by the Nebraska Department of Transportation

Most Frequently Used Temporary Pavement Markings	Number of Participating States	Percentage of Participating States
Traffic Paint Only	17	85%
Traffic Paint and Temporary Tape	4	20%
Temporary Tape Only	2	10%
Raised Pavement Markers, Buttons, Tabs	1	5%
Tabs, raised pavement markings or temporary tape	1	5%
Y. Cho, K. Kabassi, Jae-Ho Pyeon, *Effectiveness Study on Temporary Pavement Marking Removals Methods*, The Charles W. Durham School of Architectural Engineering & Construction, June 2011.		

Table 1 shows the results of a Nebraska Department of Transportation study to identify the most frequently used method of applying temporary pavement markings. The purpose of the study was to evaluate different pavement marking removal techniques for various materials. As the survey indicates, while paint is the most used temporary marking, other materials may be chosen in combination or as standalone applications to satisfy specific situations related to visibility, discernment of travel path, worker protection, and traffic flow.

Material Attributes

Agencies should consider the characteristics and attributes of various temporary pavement marking material. Pavement marking materials are available with a variety of attributes. Pertinent criteria for choosing a pavement marking material include the following:

- *Material and Installation Cost*. Agencies must identify the cost of applying a treatment at a specific location. For example, traffic paint is widely used by agencies because it is readily available and relatively low cost. In other situations (e.g., low traffic volumes or short-term work zones), TRPMs are acceptable and can be installed at a lower price and in a shorter period of time than traffic paint.
- *Material Performance*. There are situations where one material will perform more effectively than others. For example, TRPMs or buttons can address situations not conducive for flat-line applications such as resurfacing projects with multiple pavement lifts. TRPMs can also be used for chip seals or other roadway surface treatments that are difficult for traffic paint to adhere to. On the other hand, agencies may choose to use traffic paint in situations with longer work zones, higher traffic volumes, and maintenance issues (e.g., snow plowing). In addition, traffic paint provides a continuous pavement marking to road users to help them navigate the work zone, especially in lane shifts and other horizontal alignment changes.
- *Maintenance*. Even in a temporary traffic control situation, the initial installation of a pavement marking material may not last the duration of the project's needs. Because of this, it is necessary to consider maintenance efforts when choosing materials. For example, the downside of traffic paint is that – even though the initial cost is low–restriping will likely be required for a long-term or high-volume work zone. The reapplication process is relatively simple, but it does increase the overall cost of the treatment. Indiana DOT requires restriping of traffic paint for active work zones expected to be in place from December through March.[1] More durable markings (e.g., epoxy, thermoplastic) are more costly up front, but they also last longer, which can be helpful if a long-term work zone has a single phase requiring the same pavement marking pattern for many months. TRPMs require regular field inspections to replace damaged units. Because TRPMs and buttons are not continuous, it is critical to replace missing or damaged TRPMs in a timely manner so road users can see and maneuver through the work zone.
- *Preparation Time*. The majority of pavement marking materials require a dry and relatively clean pavement surface for proper adhesion. Some materials require time between the time they are applied

---

[1] Indiana DOT. (2012). 2012 Standard Specifications; Section 800. Retrieved May 28, 2013, from Indiana Department of Transportation: http://www.in.gov/dot/div/contracts/standards/book/sep11/sep.htm

and when the roadway can be open to traffic. Traffic paint dries tack-free in two minutes when applied in temperatures between 50 and 75 degrees F. Traffic paint can also be applied when the surface temperatures are lower than 50 degrees, but drying time is extended. In some situations this may not be an acceptable preparation time, so other options (e.g., TRPMs) may be used instead. Some TRPMs are used with certain applications such as asphaltic chip seals; because other liquid traffic markings would not adequately adhere to the roadway.

The following situations may impact the decision to use a certain material for work zone pavement marking.

- *Short-term Work Zones* – In some cases, the roadway project requires daily or weekly adjustments, so pavement markings must be easily removed and reapplied. For example, a resurfacing project may require daily remarking of the roadway. The mobilization of stripers, truck mounted attenuators, brooms, and other equipment would be cost-prohibitive for traffic paint in this situation, so TRPMs or temporary tape could be better options.
- *Weather* – In inclement weather conditions, TRPMs are often the most appropriate option because moisture during application is not as significant an issue as it is with traffic paint. In addition, paint does not provide enough retroreflectivity during wet weather conditions unless wet reflective beads are added; TRPMs can provide better visibility during inclement weather.
- *High Traffic Volume* – High traffic volume will cause significant wearing of pavement marking and should be monitored closely. Traffic paint is likely to wear quickly under these conditions, especially if traffic is driving directly on the stripe. Other pavement marking types such as epoxy or thermoplastic may be used to provide a more durable pavement marking for high-volume work zones, reducing the need to re-mark during the project. TRPMs also are not highly-durable devices and should be monitored closely.
- *Special Situations* – One application being used is sequential lighting on channelizers. A typical example for this application is nighttime road repairs such as a concrete joint repair on a divided roadway. Using this approach, the impact to the permanent striping will likely be minimal. The sequential lighting provides a strong visual cue to the driver, guiding them to the correct path through the work zone without applying other temporary marking materials. The roadway is opened to normal traffic flow in the morning by simply moving the traffic control devices off the roadway.

Table 2 shows a sample of the temporary pavement marking commonly used in work zones. Paint is often a preferred material used in work zones, but other materials can be beneficial for specific situations. Figures 3, 4, and 5 provide examples of temporary pavement marking.

Table 2. Characteristics of Pavement Markings for Work Zones

Materials	Application	Durability	Pros	Cons
Paint	Machine	1 year or less	Low cost $0.10-0.15/foot; wet-reflective	Low durability under heavy traffic, low quality

Materials	Application	Durability	Pros	Cons
			elements can be added	under wet weather.
Thermoplastic	Machine	3 to 5 years	High durability	High cost $0.70-3.00/foot, medium wet weather recovery; difficult to remove.
Epoxy	Machine	3 to 5 years	High Durability	High cost $0.70-3.00/foot, medium wet weather recovery, and contrast hard to see on new concrete.
TRPM: Tabs	Installed by hand	Less than 1 year; less than 1 month under heavy traffic	Low cost, high visibility under wet weather, flexible installation	Possible littering, vandalism, best in warm weather application.
TRPM: Buttons	Installed by hand or by machine	1 year	Low cost, audible and tactile clue to driver	Not conducive for snow plows, small target value.

Figure 3. Use of Temporary Raised Pavement Markers on Centerline and Shoulder on I-70 in Missouri.

(Source: Leidos)

Figure 4. Use of Temporary Raised Pavement Markers on Lane Shift on I-44 in Oklahoma.
(Source: Leidos)

Figure 5. Use of Paint on Lane Shift on I-44 in Oklahoma.
(Source: Leidos)

Retroreflectivity

Guidance from the Manual on Uniform Traffic Control Devices MUTCD indicates temporary pavement markings should perform during the day and at night. The pavement marking must provide adequate visibility through the work zone. The pavement marking must also be easily removable, so that it leaves no residual line when the marking is no longer needed.

Durability

Factors such as the initial quality of the implementation, traffic volume and percentage of heavy vehicles, and weather have an impact on the durability of markings. Most basic markings used for permanent installations have a minimum life of one year, and other more durable (and more expensive) products can last three to five years. These durable markings such as thermoplastic can be used for work zones where the level of wear of the stripe is a concern, but removal of these markings during various stages of construction can often leave "ghost" markings. Ghost markings are remnants of the pavement marking due to scarring or discoloration of the pavement, and can be as prominent as a permanent pavement marking.

> The Indiana Department of Transportation reapplies temporary road markings on long-term work zones on Interstate routes prior to winter to ensure markings are adequate throughout the year.

A study performed under the Smart Work Zone Deployment Initiative (SWZDI) evaluated temporary pavement marking products: three temporary tapes and one temporary marking paint. The objective of the research project was to measure presence, retroreflectivity, and removability of these temporary markings. The marking material was installed in an active work zone using a typical crossover for a divided highway. The research team took readings at 15 days and 46 days from installation. The research team discovered that the locations of heavy wear from vehicles driving directly on the pavement marking caused significant damage (see Figure 6).[2] The tape on the right allows the previous white edge line to become visible. For some sections, this wearing worsened until reapplication of the marking became necessary.

Figure 6. Pavement Marking Damage in a Work Zone

(Source: CTRE, Evaluating the Effectiveness of Temporary Work-Zone Pavement Marking Products, 2012)

[2] Center for Transportation Research and Education (CTRE), *Evaluating the Effectiveness of Temporary Work-Zone Pavement Marking Products*, Smart Work Zone Deployment Initiative, July 2012

While the MUTCD does not have specific performance measures for temporary pavement markings, many transportation agencies use industry established guidelines or specifications for permanent markings to govern temporary pavement marking applications. Practitioners should also inspect these lines to be sure the markings are in good condition. Any condition causing a loss of reflectivity such as debris or loss of pavement marking material should be evaluated for possible repairs. For example, Figure 7 shows a well maintained line during the day. Figure 8 is showing the same work zone, but water is covering the line and reduces the retroreflectivity in the photo on the right. The line on the left in figure 8 is an all-weather paint which still shines through the water.

Figure 7. All-weather Pavement Marking (left) and Standard Pavement Marking (right) Work Zones on US-32/33/50 Eastbound in Ohio (Daytime).

(Source: FHWA, May 2013)

Figure 8. All-weather Pavement Marking (left) and Standard Pavement Marking (right) Work Zones on US-32/33/50 Eastbound in Ohio (Nighttime).

(Source: FHWA, May 2013)

Other methods to ensure adequate marking are the use of TRPM's or buttons such as in Figure 9. This depicts a work zone with a concrete barrier along a rural interstate in Oklahoma. The white edge line is showing excessive wear from traffic driving directly on the marking. An inspection of this line should include night inspection to be sure the marking guides drivers adequately.

Figure 9. Use of Tabs on Barrier and Paint Wear on Edge Line on I-44 in Oklahoma
(Source: Leidos)

Ongoing inspection and maintenance of temporary markings should be conducted on long-term work zones. Inspection can be either visual or conducted using a retroreflectometer. Temporary markings should perform similarly to permanent markings for night and day operations. Figure 9 highlights why both a night and day inspection should be made. Although the loss of material is evident, the retroreflectivity of the line may have diminished sooner than the loss of marking material. The significance of the loss of marking is important; but there are other indications being used at this location to show the travel way to the driver. If excessive wearing of the marking is a concern, practitioners may use other supplemental devices to guide drivers through the work zone, such as reflective tabs on a barrier, reflective strips on a glare screen, a rumble strip in the shoulder, and delineation on the guardrail itself, as Figure 9 illustrates. These traffic control devices all supplement and support the driver traveling through this work zone and ensure adequate guidance until restriping can be completed. As part of the inspection, all of these devices should be reviewed to be sure the drivers' path is delineated through the work zone.

While ensuring the temporary marking is adequately maintained, weather is another concern agencies should consider when choosing materials. Water over flat line marking can significantly reduce the retroreflectivity of even the best maintained line. Some agencies use TRPMs as in Figure 9 to supplement flat-line marking as the reflective panels shed water better and still reflect during a rain storm. All-weather paint is another option now available and is covered later in the section under retroreflectivity.

TRPMs are typically not made to sustain heavy traffic over extended periods. In addition, these devices are not able to withstand the rigor of snowplows. TRPMs are commonly used between asphalt courses on resurfacing projects where using traffic paint or other markings is not practical. The color of TRPMs should match the line they are trying to simulate and should be the same color at night. Damaged or missing TRPMs should be replaced as soon as possible. Minnesota DOT uses the following guidelines when TRPM's are used to simulate a line:

- Broken line - install four TRPMs at 3-1/3 feet centers and leave a 40 foot gap to the next set of four TRPMs.
- Single line – place TRPMs on 10 foot center to center on tangents; 5 foot center to center spacing on curves over 6 degrees.[3]

[3] Temporary Raised Pavement Markers (TRPMs), Minnesota DOT, March 2006, http://www.dot.state.mn.us/products/pavementmarkings/common/TRPM.pdf

Retroreflectivity

Retroreflectivity Standards

Under MUTCD Section 6F.77, pavement markings in work zones are to be seen during the day, at night, and during twilight periods. For most agencies, traffic paint is the pavement marking method used in work zones, particularly for long-term stationary work. TRPM, temporary tape, and buttons may be required for other situations not suitable for paint, such as chip sealed surfaces or short- and intermediate-term work zones.

In the MUTCD Section 6G.02 Work Duration, all temporary markings in long-term work zones are required to be retroreflective. Missing or defective devices such as TRPMs can be replaced to regain lost retroreflectivity. However, traffic paint, epoxy, and thermoplastic are in place for longer time periods, and retroreflectivity can diminish due to exposure to weather, debris, dirt, and traffic. Driving at night is very dependent on the quality of the retroreflectivity of the marking. Retroreflectivity is also usually associated with nighttime driving, but practitioners should consider impacts during the day as well. Factors to be considered when determining the type of pavement markings to use include:

- Degradation of reflectivity;
- Glare on roadway surface causing markings to become difficult to see;
- Other pavement treatments competing for the driver's attention;
- Missing or damaged temporary marking devices such as tabs, tape, or TRPM; and
- Wearing of traffic paint.

The Center for Transportation Research Excellence (CTRE) at Iowa State University recently conducted research on the connection of pavement marking retroreflectivity to roadway safety. The focus of the study was to evaluate differing segments of retroreflective markings and their impacts to roadway safety. The results are presented in

Table 3. The study did not validate specific retroreflectivity levels, but rather it compared crash data on roadway segments with various retroreflectivity levels to gauge impact. The researchers discovered that pavement marking on freeways provided a significant safety benefit to drivers. For freeways, yellow edge lines reduced nighttime crashes, and white edge lines helped reduce single-vehicle crashes. For two-lane highways, increasing retroreflectivity led to a decrease in crash frequency.

Table 3. CTRE Iowa State University Study on Roadway Safety and Maintained Pavement Markings

Facility	Retroreflectivity Marking Location	Safety Impacts
Freeway	Yellow Edge Lines	Decrease in all nighttime crashes correlated to increases in retroreflectivity

Facility	Retroreflectivity Marking Location	Safety Impacts
	White Edge Lines	Decrease in SV nighttime crashes correlated to increases in retroreflectivity.
	Lane Lines	Decrease in night time and SV Crashes when retroreflectivity increased.
Two-Lane Highways	Yellow Centerline	Decrease in all nighttime crashes correlated to increases in retroreflectivity
	White Edge Line	Decrease in crash frequency as retroreflectivity increased.

SV = Single Vehicle

Source: Center for Transportation Research and Education (CTRE), *Evaluating the Effectiveness of Temporary Work-Zone Pavement Marking Products*, Smart Work Zone Deployment Initiative, July 2012.

Measuring Retroreflectivity. A number of agencies have recognized the need to measure the performance of pavement marking. Although there are not minimum retroreflectivity levels for work zones, some agencies are using retroreflectivity to ensure installed pavement marking is adequate for the driving public. Table 4 lists a few states that have incorporated minimum retro-reflectivity values into their operations. Combining retroreflectivity with physical condition information (e.g. pavement type and condition, horizontal alignment, weather) can ensure an adequate marking throughout the work zone for most physical conditions and for the wide range of drivers.

Figure 10. Oklahoma Work Zone in Wet Weather Conditions

(Source: Leidos)

Table 4. Initial Retroreflectivity Readings of Roadway Marking (Dry Conditions)

Agency	Initial Retroreflectivity Readings (mcd/lux/m^2)	Additional Notes
Iowa [4]	Yellow 150	Initial retroreflectivity readings for temporary marking for dry, wet, and night conditions.

[4] N. Hawkins, O. Smadi, B. Aldemir-Bektas, *Evaluating the Effectiveness of Temporary Work-Zone Pavement Marking Products*, Center for Transportation Research and Education, Final Report InTrans Project 06-277, June 2012, Smart Work Zone Deployment Initiative (SWZDI)

Agency	Initial Retroreflectivity Readings (mcd/lux/m^2)	Additional Notes
	White 100	Initial retroreflectivity readings for temporary marking for dry, wet, and night conditions.
Maryland	Yellow 150	Maintain above 100 mcd/lux/m^2
	White 250	Maintain above 150 mcd/lux/m^2
Minnesota	Yellow 80	Minimum readings

Wet Retroreflectivity and Recovery

Retroreflectivity of beads on most pavement marking is greatly diminished during active rainstorms or water over the traffic paint. A research study by the Texas A&M Transportation Institute measured a 17 percent retained dry-pavement visibility of conventional pavement marking when the markings were covered with moisture.[5] Water covered pavement marking can hamper a driver's ability to safely maneuver through a work zone as shown in Figure 11.

Today, agencies can utilize wet-reflective or wet-recoverable marking materials. Wet-recoverable pavement markings consist of preformed tape or paint which recover retroreflectivity very quickly once an active rainstorm has stopped. These materials are not retroreflective while covered by water; but simply allow for the retroreflective elements to recover faster than typical pavement marking with standard bead elements.

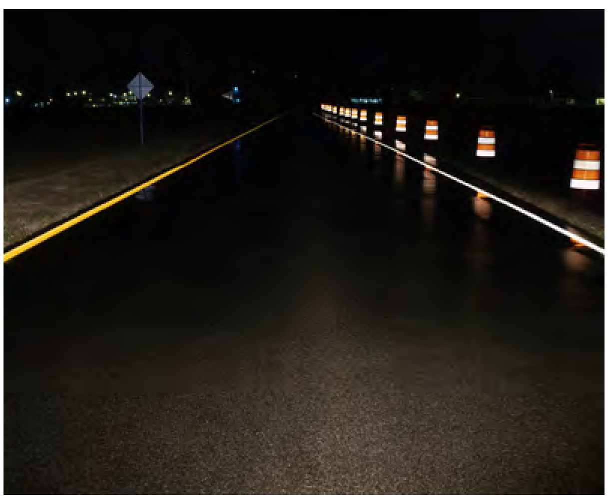

Figure 11. Wet-reflective Markings under Wet Conditions
(Source: 3M, 2012)

Wet-reflective elements allow a pavement marking to retain its retroreflectivity when covered by water, even during an active rain event. These elements are specifically designed to use the angularity of light through water to help the marking reflect back to the light source. Agencies may combine typical bead elements with wet-reflective beads to provide a cost-effective retroreflectivity for both dry and wet pavement conditions.

Under the Highways for Life technology partnerships program, researchers evaluated all-weather paint

[5] Higgins, L., J. D, Miles, P. J. Carlson, D. M. Burns, F. Aktan, M. Zender, and J. M. Kaczmarczik. *The Nighttime Visibility of Prototype Work Zone Markings Under Dry, Wet, and Raining Conditions*. Transportation Research Board, 88th Annual Meeting. 2009. Washington, DC.

(AWP) as shown in Figure 12. The evaluation was split between two phases over the years 2007 to 2009. The marking was evaluated at a closed circuit test site, where it was found to have higher retro-reflectivity than other materials under the same active wet conditions. A second phase of evaluation was conducted at five active work zones in North Carolina and Ohio.[6] Figures 7 and 8 were day and night comparison of these work zones with AWP. The evaluation was conducted by assessing the following measures of effectiveness (MOE): pavement marking retroreflectivity, rate of lane encroachments, linear lane displacement, and vehicle travel speed (as a surrogate MOE due to increased speed potentially increasing the opportunity for crashes).

Figure 12. Example of Water-Blasting to Remove Striping in Florida

(Source: FHWA, 2013)

The results of the study from the second phase of the AWP study found the AWP retroreflectivity values were confirmed to be higher than standard pavement markings. Motorists typically maintained safer lane placements when traveling along the AWP delineated lanes than in lanes with standard pavement marking within the same work zones.

[6] Federal Highway Administration, *All-Weather Pavement Marking for Work Zones: Field Evaluation in North Carolina and Ohio*, May 2013. Retrieved September 17, 2013, from FHWA Accelerating Innovation: http://www.fhwa.dot.gov/hfl/pubs/hif13004/chapt00.cfm

Pavement Marking Removal

Methods

A common issue for every work zone is the removal of permanent or temporary pavement marking as adjustments are needed for the work zone. Section 6F.77 of the MUTCD states that agencies should minimize pavement scarring and not paint over existing marking with black paint or asphalt. Preventing pavement scarring while completely removing the marking can be a difficult challenge. A number of methods can be used to remove pavement marking. Removing pavement marking with a grinder is one of the prominent methods of removal, though others are allowed by most agencies. Table 5 provides a list of available removal methods and a general description of each method.

Table 5. Pavement Marking Removal Techniques

Technique of Removal	Description	Performance
Water blasting	Water shot at 10,000 psi; relatively high cost; relatively long time for removal; standard practice by agencies.	Rated best for removal especially on concrete; slower than most other treatments; very effective for tape
Grinding	Relatively fast method; most common treatment used; scars pavement.	Grinding leaves 1/8 to 1/4 inch groove for thermoplastic; concrete pavement is bright to look like permanent marking
Shot Blasting	Uses small steel balls shot at high speed to remove markings.	Dry pavement only; effective for thinner lines; recycle shot; slower process
Sand Blasting	Similar to sand blasting; very fine materials are propelled at high speed to remove markings	Slow and can scar pavement; performance is highly tied to operator.
Hydro-blasting	Combination of water and sand; can leave scars but effective; water and sand can be recycled	Effective due to the ability to recycle sand and water, but can leave scars
Hot Compressed Air Burning (HCAB)	Mix of propane and air to vaporize material, found effective with temporary tape,	Relatively slow rate
Excess oxygen burning	Similar to HCAB; slow removal for thicker materials	Scarring may fade quickly
Dry Ice Blasting	Application of solid carbon dioxide;	Effective but costly
Chemical	Environmentally friendly – does not contain Methylene Chloride (MeCl); Still needs to be power washed at 400 psi	Best at removing stripe without scarring on concrete and asphalt

Source: Y. Cho, K. Kabassi, Jae-Ho Pyeon, *Effectiveness Study on Temporary Pavement Marking Removals Methods*, The Charles W. Durham School of Architectural Engineering & Construction, June 2011

The following information lists three examples from Indiana, Arizona and Maryland on what these states do to remove temporary markings.

- Arizona – remove temporary pavement marking by abrasive blasting, high-pressure water jet, or grinding.
- Maryland – remove adhesive from temporary tape by water blasting.
- Indiana – remove temporary pavement marking by sandblasting, steel shot blasting, water blasting, or grinding.

These agencies' guidelines highlight accepted removal methods, but the choice of method is left to the discretion of the contactor. The type and thickness of the material has impact on the performance of these removal techniques. The most important aspect of choosing the appropriate removal is minimizing damage to the pavement, leaving what is otherwise known as "ghost markings."

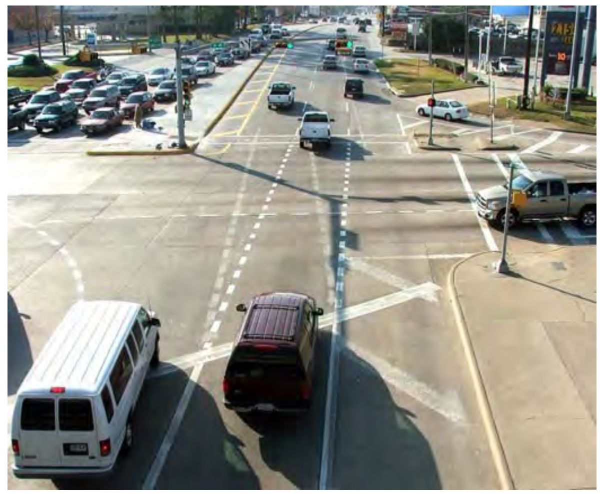

Figure 13. Removed Markings ("Ghost Markings") Compared to Existing Pavement Markings
(Source: Texas Transportation Institute, 2008)

Ghost Markings

Pavement marking removal can sometimes leave behind "ghosts" or the impressions of past markings left from scarring as shown in Figure 14. These past markings can be seen during rainstorms or reflected from sun glare. At times, these past markings can be easier to see than the existing pavement marking. Nebraska DOT initiated a study[7] to evaluate the effectiveness of the removal methods. The project evaluated each method according to speed of removal, amount of scarring, and cost. This information can help agencies and contractors determine what method of removal would best meet driver and agency expectations.

The results of the study are shown in Tables 6 and 7. One of the highest rated methods was a chemical process. The chemical process is environmentally friendly and completely removes marking with no pavement scarring.

[7] FHWA, All-Weather Pavement Marking, 2013.

Table 6. Stripe Removal Techniques, Nebraska Transportation Center

Removal Method	Type	Marking	Marking Size	Rate (Ft/min)	Completeness of Removal	Degree of Scarring
Chemicals	Concrete	Water Based	12 mils	12.58	5	1
	Concrete	Solvent Based	20 mils	10.10	5	1
	Asphalt	Water Based	20 mils	5.00	5	1
	Asphalt	Solvent Based	12 mils	8.61	5	1
Water Blasting	Concrete	Water Based	20 mils	3.11	4	1
	Concrete	Solvent Based	12 mils	1.52	4	1
	Asphalt	Water Based	12 mils	11.58	5	5
	Asphalt	Solvent Based	20 mils	1.14	3	5
	Asphalt	Tape	4 inch	74.92	5	1
Dry Ice Blasting	Concrete	Water Based	12 mils	1.48	1	1
	Concrete	Solvent Based	20 mils	0.19	1	4
	Concrete	Tape	4 inch	87.05	5	1
	Asphalt	Water Based	20 mils	22.83	4	5
	Asphalt	Solvent Based	12 mils	6.83	3	5
Shot Blasting	Concrete	Water Based	20 mils	57.73	4	4
	Concrete	Solvent Based	12 mils	26.59	3	4
	Asphalt	Water Based	12 mils	45.92	5	1
	Asphalt	Solvent Based	20 mils	22.37	4	5
	Asphalt	Tape	4 inch	28.00	5	1
Scarifier	Concrete	Water Based	12 mils	36.01	3	5
Grinding	Concrete	Solvent Based	20 mils	44.49	3	5
Heat Torch	Concrete	Tape	4 inch	63.25	5	1
Grinding	Asphalt	Water Based	12 mils	116.09	5	5
PCD	Asphalt	Solvent Based	20 mills	1.34	5	5
Scarifier	Asphalt	Tape	4 inch	2.05	5	1

Note: 5 to 1 Range from complete to no removal of paint; 5 to 1 Range high degree of to no scarring.

Source: Y. Cho, K. Kabassi, Jae-Ho Pyeon, Effectiveness Study on Temporary Pavement Marking Removals Methods, The Charles W. Durham School of Architectural Engineering & Construction, June 2011.

Table 7. Cost Data for Pavement Marking Removal Techniques

Removal	Type	Marking	Marking Size	Cost per Linear Foot
Chemicals	Concrete	Water Based	12 mils	$0.33
	Concrete	Solvent Based	20 mils	$0.41
	Asphalt	Water Based	20 mils	$0.83
	Asphalt	Solvent Based	12 mils	$0.48
Water Blasting	Concrete	Water Based	20 mils	$2.14
	Concrete	Solvent Based	12 mils	$4.39
	Asphalt	Water Based	12 mils	$0.58
	Asphalt	Solvent Based	20 mils	$5.86
	Asphalt	Tape	4 inch	$0.09
Dry Ice Blasting	Concrete	Water Based	12 mils	$3.37
	Concrete	Solvent Based	20 mils	$26.00
	Concrete	Tape	4 inch	$0.06
	Asphalt	Water Based	20 mils	$0.22
	Asphalt	Solvent Based	12 mils	$0.73
Shot Blasting	Concrete	Water Based	20 mils	$0.12
	Concrete	Solvent Based	12 mils	$15.95
	Asphalt	Water Based	12 mils	$3.47
	Asphalt	Solvent Based	20 mils	$0.55
	Asphalt	Tape	4 inch	$0.02
Scarifier	Concrete	Water Based	12 mils	$0.19
Grinding	Concrete	Solvent Based	20 mils	$0.15
Heat Torch	Concrete	Tape	4 inch	$0.11
Grinding	Asphalt	Water Based	12 mils	$0.58
PCD	Asphalt	Solvent Based	20 mills	$0.80
Scarifier	Asphalt	Tape	4 inch	$3.25

Source: Y. Cho, K. Kabassi, Jae-Ho Pyeon, Effectiveness Study on Temporary Pavement Marking Removals Methods, The Charles W. Durham School of Architectural Engineering & Construction, June 2011.

Choosing the appropriate method of removal can minimize visible scarring of the pavement, but adding contrast striping can help to increase pavement markings conspicuity. Contrast striping involves adding another material (often black paint) to a stripe. It can be used to offset ghosting impacts by differentiating the markings. Figure 14 shows a location where contrast striping is used to provide users guidance in a complex situation. First, pavement marking removal "ghosts" are very visible on the right side of the roadway. In addition, the crack sealant on this route is more prominent than the pavement marking, which can be confusing for road users and cause them to use this as their lane line. The contrast stripe – a black stripe added at the end of the typical white stripe – provides additional information to drivers about the correct lane line so they can see the appropriate path to travel.

Figure 14. Contrast Striping, Oklahoma
(Source: Leidos)

Figure 15. Example of Disallowed Black Paint Covering Temporary Pavement Markings
(Source: Leidos)

Black paint or asphalt has been used to cover up temporary markings. The MUTCD specifically prohibits the use of black paint or asphalt to cover up markings given that the paint can wear out over time revealing the old marking underneath. Figure 15 shows a project where black paint was used as a cover up, and it is as visible as the white shoulder line, which could cause a distraction. This distraction is not limited to daytime; black markings can be visible at night and during rain storms.

Sequential Lighting for Taper or Lane Transitions

As part of traffic management plan efforts in work zones, more agencies are conducting construction activities during nighttime hours to avoid the highest traffic volumes. Working at night reduces work zone impacts on the traveling public. However, traffic control plans for night-time work zones must provide additional visual cues for drivers, in particular the higher percentage of high-risk drivers at night (e.g., impaired, drowsy). To fully capitalize on nighttime construction activities, the permanent marking needs to remain in place when the work zone is moved off the roadway and all of the lanes are opened to traffic for normal operations. In most cases, temporary marking is not a viable option for these work zones. One option with similar benefits to temporary pavement marking is the use of sequential lighting at the taper and along the work zone.

In addition to temporary lighting, enhanced retroreflective sheeting, and additional traffic control devices, sequential warning work zone lighting can improve visibility and provide improved visual cues for drivers on merging tapers and lane shifts. Sequential warning work zone lights direct the driver through the merging taper and work zone. The devices are self-calibrating once installed at the work zone. For example, if one of the lights stops functioning, the devices will self-adjust the sequence to account for any outages. Additionally, if workers move the devices in a different order, the devices will adjust to the proper sequence based on their proximity to each other in the work zone.

Section 6F.63 of the MUTCD allows sequential lighting in place of steady-burn lights on channelizing devices used in a series, such as merging tapers. Specifically, paragraph 12 of Section 6F.63 of the MUTCD states, "A series of sequential flashing warning lights may be placed on channelizing devices that form a merging taper in order to increase driver detection and recognition of the merging taper." Figure 16 is an example of an installation in Missouri.

Sequential lighting systems are easy to install, and they are effective for both short-duration and long-term work zones. Sequential lighting helps improve the safety of the work zone without adjusting the striping, allowing a quick removal of the temporary traffic control to restore normal operations during the day.   The sequential lights accomplish the following goals:

- Provide positive guidance of the appropriate path at the taper and throughout the work zone.
- Provide information to motorists that they are entering an active work zone.
- Confirm that motorists are following the correct path.

The University of Missouri performed an evaluation of the effectiveness of sequential lighting deployed on Interstate 70 for the Smart Work Zone Initiative (SWZI).[8] Below are results from the evaluation based on speed and merged vehicles. The study concluded that sequential lighting devices provide a "benefit-to-cost ratio" ranging from 5:1 to 10:1, meaning road users receive from 5 to 10 times the benefit from these devices compared to the cost to deploy. Figure 17 shows results from the Missouri evaluation based on speed of approaching vehicles. The study also evaluated when drivers would merge into one lane. The researchers concluded more drivers merged sooner and the number of drivers waiting until the last moment before merging was also reduced when compared to similar work zones without sequential lighting installed.

[8] Sun, C., Edara, P., Hou, Y., & Robertson, A. (2011). Cost-Benefit Analysis of Sequential Warning Lights in Nighttime Work Zone Tapers. Columbia: Smart Work Zone Deployment Initiative.

Figure 16. Sequential Work Zone Taper Warning on US Route 54 in Missouri.
(Source: Leidos)

Missouri DOT uses sequential lighting for concrete repairs of divided U.S. highways. These operations involve joint and roadway repair on concrete pavement. Missouri DOT normally conducts these repairs at night during low-traffic volume periods, and these repairs can take most of the night-time hours. The agency may close one lane for a sufficient length to repair multiple areas. The operation requires most of the nighttime hours for the crews to prepare the roadway, pour the concrete, and wait for the concrete to gain enough strength prior to opening to traffic. The agency has the lane opened to the morning peak. This operation does not impact the existing striping on the highway. Sequential lighting has proven itself to reduces speeds through the work zone, and reduced late-merging traffic without adding temporary marking throughout the work zone eliminating removal.

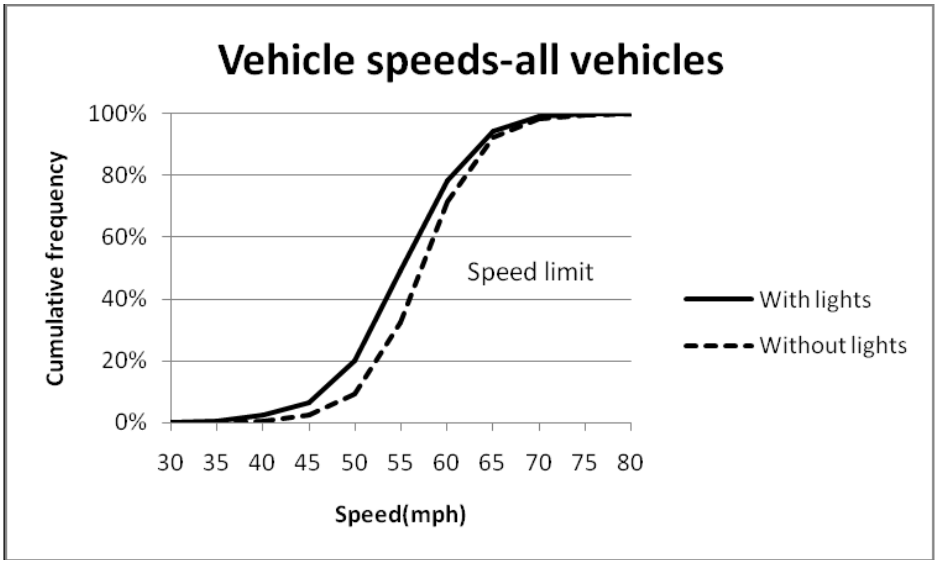

Figure 17. Impact on Speed through Work Zones with Sequential Lighting

(Source: Sun, Edara, et al., 2011.)

Summary

Temporary pavement markings are essential for motorists to guide them through work zones. Temporary markings are to be visible day or night through any type of weather. Durability, cost, ease of removal, maintenance, and implementation are all factors that contribute to the decision as to what type of temporary marking to use. Temporary marking can be created with traffic paint, temporary tape, or temporary raised pavement markers (TRPM) such as tabs or buttons. Work zones with high traffic volumes may require highly durable markings such as thermoplastic or epoxy to ensure markings last through the life of a project. TRPMs are used to supplement other temporary marking or simulate flat-line marking on surfaces not conducive to the successful application of other materials (e.g., chip seals) or for resurfacing or certain other complex projects. For example, a bridge replacement may require a combination of long-line traffic paint and TRPMs for many months.

As with permanent markings, temporary pavement marking should be retroreflective to provide the necessary guidance to drivers especially for nighttime work zones. Agencies and practitioners should have an inspection program to ensure pavement marking is kept in good condition. Even with regular inspection, weather events such as rain can reduce retroreflectivity of temporary markings. Water covering flat-line marking can significantly reduce retroreflectivity by more than 80 percent. TRPMs can supplement flat-line markings during these events, and all-weather paint, which is made with wet-reflective bead elements, is retroreflective even if covered by water and provides another option to deal with wet weather. More durable markings such as thermoplastic or epoxy may be needed to ensure the markings will last through the winter months of northern states or high-traffic volumes roadways. Some states restripe traffic paint prior to these winter months to ensure the marking can withstand damage by snowplows.

Removal of temporary markings when no longer needed is another important consideration when choosing the appropriate material. Pavement type and marking material impact the effectiveness of each method of marking removal. Temporary tape can be removed by hand or machine. TRPMs may be removed by hand or machinery. Removing traffic paint, thermoplastic, or epoxy may require special equipment such as shot-water-blasting or grinders. Other non-typical methods of removal include chemical, dry ice, or heat torch. Grinding is commonly used because of a high rate of removal and is one of the cheapest methods compared to the other methods; however, grinding is very likely to scar the pavement in order to completely remove the pavement techniques. One study found chemical removal ranks best in removal with no visible scarring of the pavement, but shot blasting had one of the highest rates of removal for all pavement surface types.

Besides AWP, sequential lighting is an innovation which leads the driver through the work zone taper and the work zone by using a number of lights that turn on and off in a successive manner, guiding the driver through the work zone. This sequence has been shown to reduce vehicular speeds through the work zone. Another benefit found was a reduction in the number of drivers waiting until the last moment to merge into the open lane. Sequential lighting accommodates night-time work zones where additional temporary marking may not be practical.

Temporary pavement marking provides the necessary guidance to drivers and other users to navigate safely through work zones. Agencies and practitioners utilizing the information from this guide will enhance the safety of both the traveling public and construction workers while providing a smooth transition to and from the work zone.

Resources

3M. (2012, April 19). *Highways for Life*. Retrieved June 11, 2013, from Federal Highway Administration: http://www.fhwa.dot.gov/hfl/partnerships/3m.cfm

Association, A. T. (n.d.). *Quality Guidelines for Work Zone Traffic Control Devices.* Retrieved May 28, 2013, from Workzonesafety: http://www.workzonesafety.org/research/record/1957

Clearinghouse, N. W. (2000). *Safety Products*. Retrieved May 23, 2013, from The National Work Zone Safety Information Clearinghouse: http://www.workzonesafety.org/safety_products/record/9016

Federal Highway Administration. (2013, May). *All-Weather Pavement Marking for Work Zones: Field Evaluation in North Carolina and Ohio.* Retrieved September 17, 2013, from FHWA Accelerating Innovation: http://www.fhwa.dot.gov/hfl/pubs/hif13004/chapt00.cfm

Hawkins, N., Smadi, O., & Aldemir-Bektas, B. (2012). *Smart Work Zone Deployment Initiative; Evaluating the Effectivenss of Temporary Work-Zone Pavement Marking Products.* Ames, Iowa: Iowa Department of Transportation; FHWA.

Indiana DOT. (2012). *2012 Standard Specifications; Section 800.* Retrieved May 28, 2013, from Indiana Department of Transportation: http://www.in.gov/dot/div/contracts/standards/book/sep11/sep.htm

Sun, C., Edara, P., Hou, Y., & Robertson, A. (2011). *Cost-Benefit Analysis of Sequential Warning Lights in Nighttime Work Zone Tapers.* Columbia: Smart Work Zone Deployment Initiative.

Texas Department of Transportation. (2012, December 6). *www.txdot.gov.* Retrieved September 16, 2013, from Texas Department of Transportation Manual on Uniform Traffic Control Devices: http://ftp.dot.state.tx.us/pub/txdot-info/trf/tmutcd/2011_rev1/6.pdf

Transportation, I. D. (2010, December 21). *www.iowadot.gov.* Retrieved September 12, 2013, from http://www.iowadot.gov/specifications/: http://www.iowadot.gov/specifications/ss/SS-09012.pdf

Transportation, I. D. (2012). *Idaho DOT Traffic Manual.* Retrieved June 10, 2013, from Idaho Department of Transportation: http://itd.idaho.gov/newsandinfo/docs/Traffic/200PavtMkgs.pdf

Transportation, M. D. (2008, July). *Standard Specifiations for Construction and Materials.* Retrieved May 21, 2013, from www.marylandroads.com: http://sha.md.gov/ohd/FrontPage.pdf

Y. Cho, K. K.-H. (2011). *Effectiveness Study on Temporary Pavement Marking Removals Methods.* Lincoln, NE: Nebraska Department of Roads.

SAFER ROADS SAVE LIVES

Developed by:

The American Traffic Safety Services Association
15 Riverside Parkway Suite 100
Fredericksburg, VA 22406-1022
800-272-8772

U.S. Department of Transportation
Federal Highway Administration