Effective Removal of Pavement Markings

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 759

Effective Removal of Pavement Markings

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FOREWORD

By David Reynaud
Staff Officer
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Traffic pattern changes can be problematic if the markings are not completely removed or the removal technique produces scarring of the roadway surface which, in darkness or rain, can be confusing to drivers and create an unsafe driving environment. *NCHRP Report 759: Effective Removal of Pavement Markings* presents field evaluation results of five removal methods applied to eight pavement marking material types on multiple pavement surfaces using a number of performance measures. These field observations, combined with results from a survey of 55 state and local agencies, yielded recommendations to aid in the selection of pavement marking removal techniques. This report will be of interest to state and local highway agency construction managers and contractors engaged in removal of pavement markings at the end their service life or to facilitate the changing of traffic patterns associated with road construction detours.

During construction projects, it is often necessary to implement lane shifts in order to detour traffic around work zones or establish a new alignment. Shifting lanes requires obscuring or removing the existing pavement markings and applying new markings along the new alignment. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires that all visible traces of the existing marking be removed or obliterated, and it does not allow for removal methods that will cause unacceptable scarring of the pavement. However, there is no specification for a level of scarring that is acceptable.

One of the primary requirements of pavement marking systems is to create a durable, strongly bonded material. Pavement markings have to be capable of withstanding several years of wear due to heavy traffic at highway speeds and resist the environment (UV exposure, freeze/thaw, chemicals, etc.). Many of the new systems are epoxy-based and adhere adamantly to the pavement. Black tapes that are applied to obscure the existing markings tend not to last long enough and/or have different reflective properties than the pavement and may confuse drivers as to the correct path to follow. The problem may be exacerbated at night and in wet weather. Chemical systems that are aggressive enough to remove epoxies and other products may raise safety and environmental concerns. As a result, removal generally requires grinding of the markings, which leaves undesirable scarring that is often mistaken for actual pavement markings under low-light or wet conditions. Consequently, the owners of public highways are faced with a very difficult problem.

The objective of this research was to determine best practices for the safe, cost-effective, and environmentally acceptable removal of work zone and permanent pavement markings with minimal damage to the underlying pavement or visible character of the surface course.

To achieve the project objective, the research team from Texas A&M Transportation Institute conducted a literature review and surveyed state and local agencies to identify

pavement marking removal processes to evaluate. They then developed a matrix of these pavement marking removal systems to be evaluated based on type of process, pavement type, and marking material. The next step was the development of criteria to measure the effectiveness of removal techniques for the systems included in this matrix. Finally, the researchers observed a field trial of each pavement marking removal process and assessed the success or failure of each trial with respect to marking removal, pavement condition, cost effectiveness, and environmental impact.

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Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Effective Removal of Pavement Markings

Introduction

While the need to remove pavement markings may occur during the end of the service life of a marking, it is also common to remove or obscure markings due to construction work that requires lane shifts or changes in the traffic pattern. Pavement markings that were previously used as guidance need to be removed or obscured so that new markings can be applied to form the new traffic pattern. Markings that are not effectively removed or obscured can be confusing to drivers and create an unsafe driving environment. Ineffective pavement marking removal results in at least two primary outcomes: (1) the marking is not completely removed and results in a marking that may suggest the original travel path is still the intended travel path, or (2) the marking is completely removed, but the removal technique has produced a scar or surface discoloration that provides a significant texture or color contrast with the surrounding pavement surface that may also suggest the original travel path is still the intended travel path.

The 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) addresses pavement marking removal in two sections as seen below.

> **Section 3A.02 Standardization of Application**
> **Standard:** Markings that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user shall be removed or obliterated to be unidentifiable as a marking as soon as practical.
> **Option:** Until they can be removed or obliterated, markings may be temporarily masked with tape that is approximately the same color as the pavement.

> **Section 6F.77 Pavement Markings**
> **Standard:** For long-term stationary operations, pavement markings in the temporary traveled way that are no longer applicable shall be removed or obliterated as soon as practical. Pavement marking obliteration shall remove the non-applicable pavement marking material, and the obliteration method shall minimize pavement scarring. Painting over existing pavement markings with black paint or spraying with asphalt shall not be accepted as a substitute for removal or obliteration.
> **Option:** Removable, non-reflective, preformed tape that is approximately the same color as the pavement surface may be used where markings need to be covered temporarily.

The MUTCD does not address how to determine if a removed marking is unidentifiable or what measures should be used to evaluate whether a removal technique is able to minimize pavement scarring. Not addressing these two issues results in a variable quality of pavement marking removal. If an agency establishes a requirement for 100 percent marking removal so that the marking is unidentifiable, the resulting removal may produce an excessive amount of pavement scarring. In contrast, if an agency establishes a policy of minimizing pavement scarring, the removal may result in insufficient pavement marking removal. A compromise

between complete removal and limiting pavement damage needs to be made in most situations. This is a difficult problem that is faced by every transportation agency. This is further compounded by the lack of sufficient guidance on the following: (a) what removal techniques are available; (b) what the trade-offs are of each technique with respect to effective removal versus the amount of scarring; and (c) whether any of these techniques could be combined to improve the percentage of material removed, reduce the scarring, and/or reduce the process time and/or cost.

The objective of this research was to determine best practices for the safe, cost-effective, and environmentally acceptable removal of work zone and permanent pavement markings with minimal damage to the underlying pavement or visible character of the surface course. The research was divided into two phases over the duration of the project. Phase I of the research focused on collecting information on pavement marking removal techniques and past experiences through a nationwide survey and a literature review. Phase II evaluated the pros and cons of the different removal techniques.

The Phase I research focused on the identification, description, and evaluation of available and emerging removal processes. Phase I was carried out through a literature review of past research that evaluated pavement marking removal techniques and a nationwide survey of transportation practitioners. The survey conducted in the Phase I research also focused on the current state of the practice of pavement marking removal. The survey was distributed to each state department of transportation (DOT), to over 100 cities nationwide, and to practitioners through many listservs and other contact lists. The survey yielded 55 responses from a combination of state and local agencies as well as contractors, equipment manufacturers, and industry groups.

The Phase II research used results from Phase I to develop a field study to evaluate various combinations of pavement marking removal. The removal combinations to be evaluated were based on combinations of the type of removal process, type of marking material, and type of road surface. The field study consisted of two different study types. The first study type was controlled pavement marking removal evaluations where the researchers controlled the marking types, road surfaces, and removal methods used. The second study type was the evaluation of pavement marking removal operations as part of planned highway maintenance or construction as they occurred or after they were recently completed. In addition to the field studies, the research team explored several other areas of pavement marking removal. These areas were the environmental and worker safety issues associated with marking removal, the removal of temporary tape pavement marking materials, and the usage of masking and blending techniques to either cover markings or help conceal removed areas.

Findings and Conclusions

The literature review, survey, controlled test deck removal, field observations, and additional research areas all yielded information used in the findings and conclusions of the research. The researchers developed a standalone table of pros and cons of the most common forms of pavement marking removal (Appendix E). This table highlights the advantages and disadvantages of each removal technique, which should aid in the selection of the most appropriate removal technique.

The survey responses indicated that grinding was the most common form of pavement marking removal and that it was preferred by many, even though most noted the drawbacks of pavement scars that are often left behind. Water blasting was also commonly used and is becoming more common as more equipment makes its way to the field. Water blasting was

the most common method that the survey respondents would like to try. Both sand and shot blasting were commonly used, but they also both received several responses that indicated they were no longer being used. Outside of those four removal techniques, the temporary masking of markings was the only other method regularly used in the field. Other removal methods, such as chemical, heat, and laser, and other forms of blasting, such as soda, dry ice, or glass, are not commonly being used.

Grinding removal is the most available removal technique and is also the least expensive type of marking removal. Water blasting systems are becoming more common, but availability is limited in some areas. Water blasting is more expensive than grinding. The survey responses and literature review indicated water blasting can average being from 10 to 40 percent more expensive than grinding. The cost of removal is highly dependent on the availability of equipment and size of the removal contract. Typically, only grinding and water blasting are used for long stretches of removal because they can remove marking at a greater rate than other techniques. Other removal techniques such as shot and sand blasting as well as grinding and water blasting are used for shorter removal sections.

There are methods of applying durable coatings over the markings to blend into the appearance of the pavement. The problem is that these coatings and the surrounding pavement may change colors at different rates over time, and the covered area will no longer blend as well as it did originally. The surface texture of the painted areas and the surrounding pavement will also be different and may be noticeable under certain driving conditions, such as the sun being low on the horizon or in wet conditions. Simply covering the markings with a durable material also leaves the possibility that the marking may later be exposed and need to be either removed or recovered with another durable material. Subsequently, the MUTCD only allows the markings to be covered for temporary conditions. Color-matching paint systems may be better suited in a light application over removed areas in the short term to help blend in color differences after removal until the removed area has time to age and blend into the surrounding pavement. Any materials placed over a marking to mask it need to be maintained so that the marking does not become exposed over time.

The survey responses indicated that after the removal of pavement markings, fog or slurry seals have been used to help blend the removed areas with the surrounding pavement surface. The use of a fog seal or slurry seal to help blend color changes, scars, or surface texture changes to the surrounding pavement would only be useful on asphalt road surfaces. The researchers propose that on concrete surfaces where a discoloration occurred after marking removal, a larger area could be washed or cleaned with a high-pressure water blasting system to help blend in the removed area to the surrounding pavement. The field studies indicated that when the sun is behind the viewer, it makes the removal area more visible by lighting up the unremoved marking and reflecting off the textured surface. When looking toward the sun, there is glare off smooth surfaces, and textured surfaces look dull. Using a technique such as a fog seal or water blasting on a larger area will reduce visibility issues associated with the sun because the area will be more uniform in appearance.

The MUTCD indicates the need to remove or obliterate markings until they are unidentifiable as markings. There are not standards for acceptable levels or criteria for how to determine a marking is no longer identifiable. The level of removal needed to make a marking no longer identifiable will differ for each situation. White markings on lighter-color road surfaces will not require the same level of removal as white markings on a dark surface. Removing a marking to the point of making the marking itself no longer identifiable may result in damage to the road surface that could be confusing to drivers. The MUTCD indicates that the removal of the marking should minimize pavement scarring. Again, there are not standards for acceptable levels or criteria for how to determine scarring. The wording in the MUTCD regarding how to minimize scarring acknowledges that when removing pavement

markings, some scarring may occur. It is the agencies' job to ensure that appropriate pavement marking removal practices are used to minimize the scarring while removing enough of the marking material to no longer be considered as guidance or be confusing to drivers.

In general, the state DOT specifications call for the complete removal of the markings while limiting damage to the road surface. Several states did call for specific levels of required removal ranging from 75 to 100 percent, with the majority indicating 90 or 95 percent removal. Several states also indicated maximum allowable depth of pavement scarring ranging from 1/16 to 1/4 inch, with the majority indicating 1/8 of an inch or less. The survey responses did acknowledge the need for a balance between the removal percentage and damage to the road surface. The thought is that to attain 100 percent removal, excessive damage to the road will occur, whereas 90 or 95 percent removal may do minimal damage to the road surface. Leaving marking material on the road surface or damaging the road surface will both be visible to drivers, so an adequate balance needs to be sought for each individual situation. The required level of pavement marking removal should vary depending on the reason for the removal and the roadway conditions where the removal takes place.

The controlled field test deck removal and field observations found many good and some bad pavement marking removal results. High-pressure water blasting provided good removal on the Portland cement concrete (PCC) surfaces with little damage to the road surface and good removal of the marking materials. On asphalt surfaces, the results were mixed. The system typically removed all of the marking, but in some test areas, the high-pressure water blasting system removed some of the surface asphalt and fines. The flailing truck had mixed results on both the PCC and asphalt surfaces. To achieve a high level of removal, the flailing truck typically left a scar on the road surface. Minimal scarring may be okay in some areas, but in critical areas such as lane-shift areas, scarring needs to be minimized as much as possible. The speed of removal depended on the marking type and the quality of the removal. The water blasting was as fast as or faster than the grinding for many of the tests. The orbital flailing system was not as aggressive as the full-size truck drum flailing system, and so it left minimal scarring on the road surface. The drawback to this was the system seemed to have difficulty removing paint and preformed thermoplastic markings that found their way into voids below the pavement surface. The orbital flailing system was not a full-size system, which resulted in much slower removal than the other full-size removal methods tested.

Recommendations

The recommendations include things to consider that relate to pavement marking removal and a set of best practices to assist in improving pavement marking removal quality. The standalone table of pros and cons of the most common forms of pavement marking removal in Appendix E should be used to help determine which type of pavement marking removal may be best suited for a given situation.

The selection of a removal system needs to take into account many factors, each of which may be more or less influential on some projects. The proper consideration of each of these factors is the best way to achieve acceptable pavement marking removal results. These factors include the following:

- What marking material is being removed.
- What road surface the material is on.
- How much of the material needs to be removed (what is the purpose of the removal).
- Whether speed of removal is important.
- What removal techniques are available and at what cost.
- Whether there are special environmental conditions that need to be considered.

- How long the removed area will be viewed by drivers (whether a new surface will be installed or markings will be restriped in the future).
- Whether the removed area will be in a location where confusion could lead to an accident.
- Whether there are other measures that can be taken to minimize confusion to the driver.

Best Practices

Pavement marking removal should be specified as a percentage of material removed based on the purpose of the removal. The percentage of material removed equates to the percentage of the road surface made visible where the marking was removed. The purpose of the removal should also play a role in the removal method selected and other measures selected to provide a roadway with delineation that is not confusing to drivers.

Changing pavement marking patterns is the most critical pavement marking removal because the old markings are no longer conveying the travel path to the drivers. Any errors in removal can lead to drivers being confused by the old markings or the removed areas. A high percentage of the material needs to be removed, but damage to the road surface also needs to be considered. Removal should be 90–95 percent, with 100 percent removal in some cases. Based on current practice, damage to the road surface should be ⅛ of an inch or less while changing the road surface texture as little as possible.

Open-graded or tined surfaces may require the material below the pavement surface to be removed with a blasting technique to minimize scarring. Depending on the road surface type and the road conditions, additional measures may need to be taken to reduce driver confusion with the removed markings. These additional measures can include fog or slurry seals over the removed area or the entire lane width on asphalt surfaces. The friction of the road surface needs to be considered, but these techniques will help blend the removed areas with the surrounding pavement. On PCC surfaces, additional light removal around the removed area or across the entire lane width can be conducted with a blasting technique such as water blasting to help blend in the removed area.

Remove and replace is the process of removing the current pavement marking material and restriping in the same location where removal occurred. This type of removal is conducted to remove a poorly bonded material so the new material can form a good bond, to reduce the overall thickness of restriped markings, or to remove an aged marking that is incompatible with the new marking that is being applied. For remove and replace with compatible markings, the whole marking does not always need to be removed, so removal can be limited to at or above the road surface. This can help limit scarring to the road surface. Removal by grinding may be the best option, but if full removal or removal of material below the surface is needed, then water blasting or another blasting technique may be a better option to minimize scarring.

Practitioners need to consider the work phasing and the final road surface. If markings are to be removed for a short duration prior to a new surface, then damage to the road surface is not as critical compared to a removed area that will be visible for a longer duration. Any removal on the final road surface needs to be accomplished with minimal damage to the road surface. It may be best to use temporary pavement markings on the final road surface until the final marking configuration so that removal will do as little damage to the road surface as possible.

The selection of the most appropriate pavement marking removal system needs to consider the amount of removal that is required and the length of time available to complete the removal. If the removal quantity is large, full-size removal trucks should be used. If the removal quantity is small, hand units and the slower removal methods can be considered.

Symbols and text should be removed in a square or rectangular pattern so that the previous shape is not left as a scar or discoloration. This requires removal of the marking and the necessary removal/cleaning around the marking to help blend in the area with the surrounding pavement by creating a larger removal area that is no longer recognized as a symbol or text.

Older road surfaces that are experiencing cracking or surfaces with joints may need special consideration when removal occurs around these areas. The use of high-pressure water blasting on these surfaces can lead to road damage if the water is allowed to penetrate into the cracks or joints. Grinding may also pose a threat to cracks and joints. Removal around these areas should be conducted carefully such that the joints are not disturbed and that the cracks are not made worse by the removal.

Initially, any pavement marking removal project should begin with testing the removal equipment in a non-critical area to evaluate the removal. This initial testing will show how well the operators can use the equipment to remove the marking material and how much damage is done to the road surface. The test area can be used to adjust the equipment to find the ideal setup for the work required. If the operator and equipment cannot provide satisfactory results, another removal system should be considered.

The quality of removal needs to be evaluated during the day, at night, and during wet conditions. Surface color changes and scarring will have a greater impact during the day than at night, whereas retroreflectivity from remaining marking material or retroreflectivity differences because of surface texture changes will be more noticeable at night. The direction of travel and the position of the sun also need to be considered. Wet conditions may fill pavement scarring, resulting in an area that looks like a wet marking and thus creating confusing delineation. Any areas with color, texture, or retroreflectivity issues should be corrected to reduce or eliminate driver confusion.

Pavement marking specifications for areas where removal has occurred should consider post-removal conditions. Wider markings and continuous markings in transition areas will provide better guidance to drivers and may reduce confusion of the removed marking areas by enhancing the new markings. Markings with high retroreflectivity levels should also be maintained in areas where previous removal could lead to confusion by drivers at night. The high retroreflectivity of the new markings will be more noticeable to drivers than removed areas of markings with lower retroreflectivity levels.

CHAPTER 1

Introduction

While the need to remove pavement markings may occur during the end of the service life of a marking, it is also common to remove or obscure markings due to construction work that requires lane shifts or changes in the traffic pattern. Pavement markings that were previously used as guidance need to be removed or obscured so that new markings can be applied to form the new traffic pattern. Markings that are not effectively removed or obscured can be confusing to drivers and create an unsafe driving environment. Ineffective pavement marking removal results in at least two primary outcomes: (1) the marking is not completely removed and results in a marking that may suggest the original travel path is still the intended travel path, or (2) the marking is completely removed, but the removal technique has produced a scar or surface discoloration that provides a significant texture or color contrast with the surrounding pavement surface that may also suggest the original travel path is still the intended travel path.

The Federal Highway Administration (FHWA) *Manual on Uniform Traffic Control Devices* (MUTCD) addresses pavement marking removal in two sections as seen below (FHWA 2009).

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> **Standard:** Markings that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user shall be removed or obliterated to be unidentifiable as a marking as soon as practical.
> **Option:** Until they can be removed or obliterated, markings may be temporarily masked with tape that is approximately the same color as the pavement.

> **Section 6F.77 Pavement Markings**
> **Standard:** For long-term stationary operations, pavement markings in the temporary traveled way that are no longer applicable shall be removed or obliterated as soon as practical. Pavement marking obliteration shall remove the non-applicable pavement marking material, and the obliteration method shall minimize pavement scarring. Painting over existing pavement markings with black paint or spraying with asphalt shall not be accepted as a substitute for removal or obliteration.
> **Option:** Removable, non-reflective, preformed tape that is approximately the same color as the pavement surface may be used where markings need to be covered temporarily.

The MUTCD does not address how to determine if a removed marking is unidentifiable or what measures should be used to evaluate whether a removal technique is able to minimize pavement scarring. Not addressing these two issues results in a variable quality of pavement marking removal. If an agency establishes a requirement for 100 percent marking removal so that the marking is unidentifiable, the resulting removal may produce an excessive amount of pavement scarring. In contrast, if an agency establishes a policy of minimizing pavement scarring, the removal may result in insufficient pavement marking removal. A compromise between complete removal and limiting pavement damage needs to be made in most situations. This is a difficult problem that is faced by every transportation agency. This is further compounded by the lack of sufficient guidance on the following: (a) what removal techniques are available; (b) what the trade-offs are of each technique with respect to effective removal versus the amount of scarring; and (c) whether any of these techniques could be combined to improve the percentage of material removed, reduce the scarring, and/or reduce the process time and/or cost.

Objectives

The objective of this research was to determine best practices for the safe, cost-effective, and environmentally acceptable removal of work zone and permanent pavement markings with minimal damage to the underlying pavement or visible character of the surface course. The research was divided into two phases over the duration of the project. Phase I of the research focused on collecting information on pavement marking removal techniques and past experiences through a nationwide survey and a literature review. Phase II evaluated the pros and cons of the different removal techniques. The

work of both phases resulted in developing recommendations of best practices for the removal of pavement markings.

The objective itself has many aspects that needed to be evaluated to determine the best practices for pavement marking removal. The most critical aspects are posed below as questions that needed to be answered by the two phases of the research.

- What are the current and emerging mechanical, chemical, and/or obscuring methods of pavement marking removal? How common are each of these techniques?
- Are there mechanical processes, such as a combination of heat and power tools that can effectively remove the markings?
- Are certain mechanical processes more effective for specific markings and/or road surface types? What are the drawbacks of the different processes?
- Are there chemical removal systems that are environmentally acceptable, and how effective are they?
- Does mechanical removal of certain marking systems pose an environmental risk?
- Is the preferred removal technique readily available and of a reasonable cost for materials, equipment, and labor?
- Are there methods of applying a durable or temporary coating over the existing pavement marking that will blend in to the appearance of the pavement, perhaps by using color-matching technology or a camouflaging technique? Or can the full width of the pavement be covered completely in a cost-effective manner without losing friction characteristics?
- Can a combination of mechanical processes and obscuring methods result in a more effective removal of the marking?
- Are there color-matching paint systems that can help obscure scars left by mechanical removal techniques?
- How much removal is adequate to meet the MUTCD requirements?
- How much tolerance is there for altering the pavement surface?
- Does the removed marking leave a ghost marking or alter the road surface as compared to the surrounding surface? Is the ghost marking or altered road surface more or less visible in different light conditions or in wet conditions?
- What are the best ways to measure the effectiveness or quality of marking removal with respect to quantifying whether a removed marking is unidentifiable, and whether the removal minimized pavement scarring?

CHAPTER 2

Literature Review

Over the years, pavement marking removal methods have evolved and new methods have been developed. In general, pavement marking removal is completed using some form of blasting, grinding, burning, laser, chemical, or masking technique (Berg and Johnson 2009, Bryden and Kenyon 1986, Ellis 2003, Ellis et al. 1999, Heydon 1997, Kilgore 1980, Migletz et al. 1994, Niessner 1979). Each of these techniques is explained in Chapter 3. The effectiveness of each of these removal methods is impacted by the type of material being removed, the material thickness, the pavement surface, the allowed duration of the work activity, and the skill of the equipment operator(s) (Berg and Johnson 2009). Some examples of inadequate pavement marking removal can be seen in Figure 1.

Past Research

Over the years, there have been several different research studies with regard to pavement marking removal methods. However, there have only been a few completed recently with some of the newer technologies, and even those studies have not captured the entire matrix of available technologies, pavement marking types, and pavement surfaces.

A recent study conducted in Utah by Berg and Johnson focused on evaluating five specific removal technologies (Berg and Johnson 2009). There were three blasting methods (i.e., high-pressure water, soda, and dry ice) and two grinding methods (i.e., carbide and diamond bit). The researchers conducted the high-pressure water blasting and the two grinding methods using large mobile truck units that provided greater productivity and ease of operation than the soda and dry ice blasting. Test removal sections consisted of waterborne paint on an asphalt chip seal pavement and waterborne paint over an existing epoxy line on a Portland cement concrete (PCC) pavement. The researchers evaluated the amount of time with respect to linear feet (lf) of line removed per minute for each method for each test section (see Table 1).

The researchers also assessed other subjective factors, such as pavement surface damage and overall impact of the removal method (i.e., pavement surface was left wet, the method reduced visibility during operations, etc.). While the grinding removal methods were faster than the high-pressure water blasting, the high-pressure water blasting resulted in the least amount of pavement damage. The high-pressure water blasting also had the least amount of complications during and post application with regard to dust and noise concerns. The only noted limitation of the high-pressure water blasting method was that it is potentially limited to above-freezing conditions.

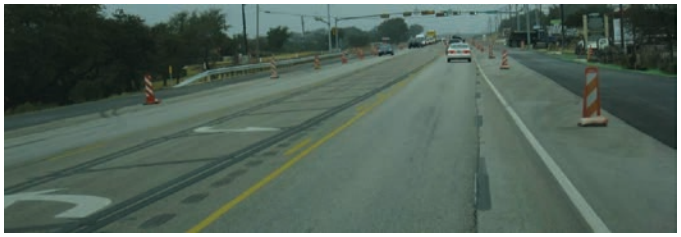
The soda and dry ice blasting were both noted to be very slow compared to the vehicle-mounted removal methods, but the removal left very little pavement degradation except for some pitting of the chip seal surface. The soda blasting generated a large amount of dust that could be a potential safety hazard by lowering visibility.

The research recommendations/implementations indicated that the two grinding technologies are still the most effective in removing lines quickly and leaving the surface ready to be restriped. It was also suggested that the soda and dry ice technologies should be investigated if space is limited or there are other special circumstances, but the speed and possible visibility issues need to be considered. Finally, the water blasting technology was the most effective at marking removal with the least amount of damage to the pavement and should be investigated for future use.

The Florida DOT sponsored two separate research efforts to investigate how to eradicate pavement markings, with one focused on the actual removal of the pavement markings (Ellis et al. 1999) and one focused on methods to mask or cover the pavement markings with an inexpensive surface treatment or black tape (Ellis 2003). In the first study, Ellis et al. investigated the removal of paint, thermoplastic, and temporary tape on asphalt concrete (AC) using high-pressure water blasting (full truck and hand-operated walk-behind systems), grinding (hand-operated walk-behind system), and a

a) Ghost markings resulting from scarring and/or surface characteristic changes and incomplete marking removal.

b) Insufficient marking removal and poor temporary markings.



c) Color contrast of markings masked with black material.

Figure 1. Examples of inadequate pavement marking removal.

combination of those two methods. The researchers focused on AC because it is the most common pavement surface in Florida, and this pavement type had the most pavement marking removal problems.

The researchers evaluated the removal methods based on the measured rate of removal, degree of removal, condition of the pavement surface after removal, and potential for scarring to confuse the motorist. The researchers based the degree of removal on subjective evaluation. They based the condition of the surface after removal on subjectively evaluated changes in color and texture from the surrounding pavement. They subjectively based the potential for the scarring to confuse a motorist on the visual appearance of any scar present after the removal. The researchers then conducted the subjective evaluations during the day as well as during the night in dry and wet conditions. The nighttime evaluations resulted in similar findings to the daytime evaluations.

While the researchers did not recommend a specific removal method, they had several useful findings. They indicated that pavement scarring is possible with both grinding and water blasting, but grinding appears to present the largest possibility for pavement scarring. Subsequently, they reported that the high-pressure water blasting method appears to be the most effective at removing pavement markings with the least amount of surface scarring. The researchers also experimented with using reflectance to evaluate quantitatively the removal. The results were promising, so the researchers recommended further study.

In the second Florida study (Ellis 2003), Ellis investigated pavement marking eradication alternatives that masked or covered pavement markings with an inexpensive surface treatment or temporary black tape, thus negating the need for actual marking removal. Both methods resulted in complete eradication; hence, the measures of effectiveness were focused on the blending of the masking material with the existing pavement, the durability of the surface, the surface friction of the seal coat material, and the associated costs with each method. The surface friction measurements and the estimated costs were objective measures, and the durability and blending were subjective measures. The estimated costs were $0.47 per linear foot and $1.83 per linear foot for the modified sand seal coat and temporary black pavement markings, respectively.

While the study period with regard to durability was short at 30 days, each method proved effective. Friction characteristics of the modified sand seal coat were deemed acceptable. The blending of the black tape to the surrounding new black asphalt road surface was deemed satisfactory but would not have been satisfactory on an aged/faded asphalt surface or PCC surface. Ellis recommended both methods to be adopted as optional methods to either remove temporary markings or temporarily remove pavement markings.

Table 1. Average Utah study removal rate.

Method	Average Speed (ft/min)	
	Paint on Chip Seal	Paint over Epoxy on PCC
Mechanical (Carbide Grinding)	132.2	81.1
Mechanical (Diamond Grinding)	116.1	57.5
High-Pressure Water Blasting (40,000 psi truck unit)	109.6	45.1
Soda Blasting	Three tests (4.8, 6.2, 8.6)	1.4
Dry Ice Blasting	1.0	0.7

Source: Data summarized from Berg and Johnson 2009 report.

Oregon DOT (ODOT) evaluated several different pavement marking removal methods and reported their results (Oregon DOT 2001). Oregon DOT had contractors remove 4-inch wide, 15-mil and 30-mil thick paint pavement markings from AC. The removal methods evaluated were soda blasting and three mechanical methods, a scarifier, a grinder, and a planar. No one method was reported to be better than another; however, the mechanical methods were all faster than the soda blasting, but the soda blasting outperformed the mechanical methods with respect to minimal pavement surface scarring. The authors noted that pavement scarring is possible with any mechanical removal method and that operator skill and experience can affect results. The removal rates and the percentage removed on the first pass are reported in Table 2.

In 2000, Pew and Thorne completed a report describing the use of lasers to remove pavement markings (Pew and Thorne 2000). The focus of the study was the further development of a prototype laser pavement marking removal system. In this study, paint was removed from an asphalt pavement. The removal was successful, and it was completed at a rate of approximately 0.42 ft/min. While this rate would be considered slow, there have been several years of improvements in laser technology that may have improved the removal time. One company that makes laser removal equipment for commercial applications other than pavement marking removal states its system can remove paint at a rate of 7.2 ft/min (Coherent 2010), so there is the potential that faster removal rates may be possible. Pew and Thorne also noted that the removal process removed the paint and some of the surface coating from the aggregate, and that it would be beneficial to add a vacuum system to collect both the debris and any unwanted gas releases from the removal process.

In 2006, Mathis and Ward completed a pavement marking removal synthesis for Washington DOT (WSDOT) (Mathis and Ward 2006). This effort did not focus on investigating new methods of pavement marking removal, but rather on the existing policies and methods that various agencies were using to provide WSDOT guidance on how to minimize ghost markings in work zone activities. The resulting recommendations emphasized the use of tape for masking unnecessary pavement markings during construction, specification revisions, preplanning, solid white lane markings in transition areas, and detailed review during project development.

The University of Tennessee conducted a research study to evaluate the removal and placement of pavement markings in work zones (Jackson et al. 2001). The researchers carried out an extensive literature review and survey covering the most promising pavement marking materials and methods. Interviewed contractors reported that for effective application of temporary tape the weather needs to be warm and dry, and preferably dry for several days after placement. It is also preferable to limit lateral movement across temporary tape to extend its service life. The researchers found that some agencies do not use paint as a temporary marking if later project phases require removal of the marking. The researchers also found that temporary or removable tape is often used on PCC surfaces due to ease of removal.

The Nebraska Department of Roads sponsored the University of Nebraska-Lincoln to conduct a research project on the effectiveness of temporary pavement marking removal methods (Cho et al. 2011). The project sought to identify effective removal methods and procedures on concrete and asphalt pavements. The research team conducted a five-question survey on which removal methods are used, which are most common, which are most satisfactory, what common problems exist, and what marking materials are used most. The survey was completed by 50 respondents including at least one representative from 25 states. Grinding was indicated for use in all responding states, with 80 percent of states stating they use water blasting, and 60 percent using sand blasting. The most commonly used removal methods by the respondents were grinding (92 percent); water blasting (56 percent); and sand blasting (24 percent). The removal method with the most satisfactory results was grinding (48 percent), water blasting (52 percent), and sand blasting (20 percent). The research team generated a list of common problems identified for each of the removal methods. Based on the comments, each technique has the ability to damage the road surface or leave a scar while removing markings. Paint (85 percent) and temporary tape (20 percent) were the most common types of temporary markings used.

In addition to the survey, the research team conducted a controlled field evaluation of several removal techniques: water blasting, dry ice blasting, grinder, scarifier, polycrystalline diamond cutter grinder, chemical removal, and heat torch (Cho et al. 2011). All removal methods were hand operated

Table 2. Average ODOT study removal rate.

Method	Average Speed (ft/min)		% Removed First Pass	
	15 mil	30 mil	15 mil	30 mil
Mechanical (Scarifier)	10.2	15.0	95	95
Mechanical (Tungsten Carbide Grinding)	23.6	16.1	99	50
Mechanical (Planar)	44.0	14.6	75	100
Soda Blasting	0.9	0.3	100	100

Source: Data summarized/modified from Oregon DOT 2001 report.

including the water blasting, which was a lower pressure setup that used a wand. A total of 40 yellow paint lines 50 ft in length were applied to a concrete and an asphalt surface. Half of the lines were 12 mil thick, and the other half 20 mil. Half of the markings of each thickness were water-based paint, whereas the other half were solvent based. In addition to the paint, foil-backed tape was also evaluated, but weather conditions likely caused the tape to not properly bond, so those results will not be discussed. Evaluation criteria consisted of rate of removal, completeness of removal, and condition of the surface after removal (degree of scarring). Completeness of removal was subjectively and objectively evaluated through the use of digital image analysis to determine the percentage of material removed.

The research results showed that the blasting and grinding techniques could remove most, if not all, of the markings. The exception was that the dry ice blasting on PCC did not remove the paint very well. The shot blasting and grinding techniques scarred the PCC surface the most, and all removal techniques scarred the asphalt surface. The chemical removal system was an off-the-shelf product that does not contain methylene chloride (MeCl). Therefore, it was determined to be environmentally safe, as the Environmental Protection Agency (EPA) only has regulations for chemical paint strippers that contain MeCl. The paint stripper was coated on the marking, allowed to sit for 30 min, and then power-washed off. The markings were completely removed on both surfaces, leaving no scar. The objective image analysis of the removal provided results similar to those of the subjective analysis as far as completeness of removal. The objective image analysis could be used to determine the change in the surface color from the removed area to the surrounding area. Overall, the researchers found that the paint was most effectively removed with the chemical stripper and that the image analysis could be a useful tool in quantifying marking removal.

Measures of Effectiveness

There have been several research studies that have evaluated the different types of pavement marking removal methods, and the researchers in these studies used several different measures of effectiveness, or metrics, to evaluate each method (Berg and Johnson 2009, Bryden and Kenyon 1986, Cho et al. 2011, Ellis 2003, Ellis et al. 1999, Kilgore 1980, Niessner 1979, Pew and Thorne 2000). The majority of the studies focused on some form of subjective assessment with respect to pavement marking removal. Factors such as surface scarring and other changes in the pavement surface characteristics that create a contrast were still subjectively rated/ranked.

A few studies included objective, quantifiable data. Some studies avoided the subjective assessment and focused first on 100 percent pavement marking removal, then the depth of any surface scarring, and finally the duration and/or cost with respect to linear feet removed as the metrics. Berg and Johnson measured the depth of any resulting surface scarring and calculated an average removal rate in feet per minute (Berg and Johnson 2009). Ellis et al. developed a prototype device to assess the pavement diffuse reflectance and then used those values to generate a ratio of the removed region versus the surrounding pavement (Ellis et al. 1999). This ratio indicated the extent to which the surface characteristics of the removed area differed from those of the surrounding pavement. Cho et al. used digital image analysis to determine the percentage of material remaining and found favorable agreement with their subjective ratings (Cho et al. 2011).

CHAPTER 3

Identification, Description, and Evaluation of Removal Processes

This chapter identifies, describes, and evaluates different forms of pavement marking removal as to their ability to remove work zone and permanent pavement markings effectively with minimal damage to the underlying pavement or visible character of the surface course. The removal methods discussed are blasting, grinding, burning, laser, chemical, and masking. Each of these methods and the variants thereof are described in detail herein. Several of the methods are only seeing limited use and do not show much promise for expanded use, whereas other methods are showing increased interest and use. The advantages and disadvantages of the methods based on the literature and survey (Chapter 4) are also described herein.

Blasting

There are several different forms of blasting removal techniques, such as high-pressure water blasting, sand blasting, hydroblasting, dry ice blasting, shot blasting, crushed glass blasting, and soda blasting. With the advent of large truck-mounted mobile high-pressure water blasting systems that reach or exceed 30,000 pounds per square inch (psi), water blasting systems appear to have made vast improvements over their predecessors, which ranged from 1,000 to 10,000 psi. This method is more mobile, and not only is the marking removed, but the current systems have vacuum heads that suction up the water and the majority of the debris produced during the removal operation, which can average 2 mph. As a result, for sections of roadway requiring restripe in the same area, the pavement surface is already cleaned for restriping once the remaining residual water evaporates.

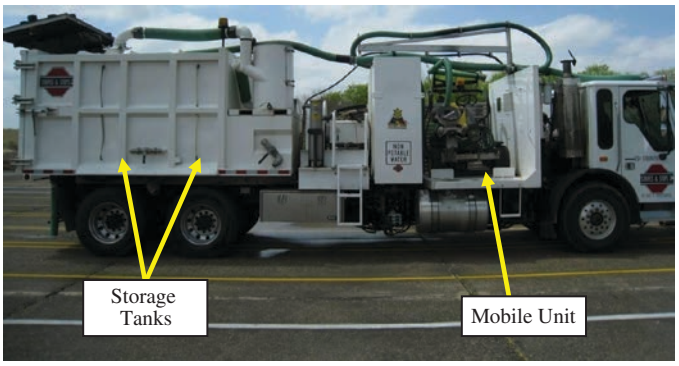
Several pictures of pavement marking removal by the newer, larger truck-mounted mobile high-pressure (40,000 psi) water blasting system are shown in Figure 2. Figure 2a shows the bars that contain the nozzles and rotate while spraying the high-pressure water. The nozzles, bar rotation speed, water pressure, and forward velocity of the vehicle can all be adjusted for more or less aggressive removal. Figure 2b shows the high-pressure water blaster removing markings. The smaller hoses are for the supply water, whereas the larger hoses are for the vacuum suction system. Figure 2c shows the entire truck, the location of the supply water tank and return waste storage tank, and the smaller mobile utility cart that can be used for special removal applications, such as transverse pavement markings.

Based on experience and findings in the literature (Berg and Johnson 2009, Ellis et al. 1999, Niessner 1979), the potential drawbacks to high-pressure water blasting are low temperature (e.g., freezing conditions); residual surface moisture; and removal complications with open-graded asphalt surfaces. The low temperature and surface moisture concerns are really more of an operation consideration than a problem, whereby contractors would need to plan for the water evaporation prior to marking installation, and low temperature freezing situations would need to be considered. As for the open-graded asphalt and surface treatments, other blasting methods and even the most common removal method of grinding may also have similar difficulties on these surfaces. The high-pressure water blasting may also remove the surface layer of asphalt binders, which could lead to water infiltration, and the surface of the aggregate may become polished, which could lead to a ghost marking. The high-pressure water blasting also has the highest potential to do damage to pavement joints on asphalt or concrete.

Sand blasting is another removal method that utilizes high-pressure air and a nozzle to blast sand aggregate against pavement markings to break up the pavement marking surface. The sand blasting technique is effective at removal, but it produces byproduct/debris consisting of sand, pavement marking materials, and pavement aggregate. While this method may not cause a large amount of surface scarring, this method may actually polish the surface of the pavement, which could result in a ghost marking from pavement surface contrast between the existing pavement and the polished pavement. A working pavement marking removal convoy

a) Rotating heads

b) Removing marking



c) Full-size truck with smaller mobile unit

Figure 2. High-pressure water blasting removal truck example.

would require a supply vehicle with the aggregate sand, a vehicle with the blasting equipment, and a vehicle with an aggregate and debris collection system. There have been several other aggregate-based blasting methods developed similar to sand blasting. Health issues from silica in the sand have affected the use of sand blasting. Sand blasting is more effective at removing thin pavement marking systems such as paint compared to thicker systems such as thermoplastic.

Soda and dry ice blasting also utilize high-pressure air and a nozzle. Both methods are effective at removing pavement markings with minimal surface effects with respect to either scarring or leaving a ghost marking; however, both methods are very slow (0.3 to 8.6 ft/sec), and the soda blasting produces a considerable amount of dust that can greatly hamper visibility (Berg and Johnson 2009, Oregon DOT 2001). One of the primary advantages of dry ice blasting is that the only byproduct is the removed pavement marking material and loose pavement aggregate. The actual dry ice sublimates into a gas, and so only the dislodged material is the byproduct. Some additional drawbacks of both of these methods are that the working convoys require multiple vehicles and staff personnel must conduct the removal on foot. These types of blasting are only effective on non-durable marking materials.

Shot blasting is similar to sand blasting in the use of aggregate, but shot blasting accelerates with a conveyor rather than compressed air at velocities around 175 mph. There are truck-mounted mobile systems, and the blasting aggregate can be recycled, which adds to the speed of the operations while reducing the waste generated in the removal process. Shot blasting can use several different types of blast material, such as aluminum oxide, ground glass, or silicon carbide. Shot blasting can only be used in dry conditions, and typically only on a smooth surface. Undulations in the surface will lead to a loss of blasting media. Shot blasting is more effective at removing non-durable pavement marking systems compared to durable systems.

Hydroblasting is a combination of sand and water blasting. High-pressure water blasting is often referred to as hydroblasting, which can be confusing because they are technically not the same since hydroblasting combines sand and water to abrasively remove pavement markings, and in general, the operating pressures range from 5,000 to 10,000 psi (Migletz et al. 1994). While hydroblasting is effective, it has similar drawbacks to sand blasting with regard to the generation of larger quantities of debris versus water blasting, and it has a tendency to scar the surface of the pavement, although the scarring appears to wear away under traffic. Hydroblasting also appears to remove the asphalt binder coating the surface aggregate in AC, and it does poorly at removing thermoplastic pavement markings (Niessner 1979). It also appears that the advent of high-pressure water blasting in a mobile truck platform may have replaced this removal method, at least for large-scale pavement marking removal.

Grinding

The term grinding is being used to describe grinding, milling, flailing, and scarifying, as each of these methods is often referred to as just grinding, even though the reference is often incorrect or at least lacking in description. Grinding can be used on any marking type, but scarring of the road surface is typical. Regardless of the design, all removal equipment utilizing grinding methods rotates an abrasive surface against the pavement marking. One method is to rotate abrasive disks or spindles fitted with teeth within the horizontal plane about a vertical axis similar to an orbital sander (Heydon 1997). Figure 3 shows an example of one orbital style removal system and its triple flailing style head.

Another grinding method uses a drum setup of multiple blades/disks stacked side by side (see Figure 4), a drum with teeth, or a drum with a combination of smaller drums with teeth or disks stacked together. The disks will be made of metal or a composite material and have abrasive edges like a saw blade that may consist of teeth, or an abrasive surface, such as diamonds that are adhered over the outer edge of the disk. Cutting heads that utilize teeth are either steel tip, carbide tip, or diamond tip. Regardless of the design of the cutting head, the head is rotated along the cylindrical axis. The cylindrical

Figure 3. Orbital flailing style system mounted on track steer.

Figure 5. Full-size flailing drum-style removal truck.

axis will be placed perpendicular to the travel direction of the removal process and rotated in or against the direction of travel. Figure 5 displays a full-size flailing truck fitted with six drums with flailing heads, as pictured in Figure 4b. This truck system also has an incorporated vacuum system.

Burning

There are several different methods of removing pavement markings using burning, such as hot compressed air and excess oxygen (Bryden and Kenyon 1986, Kilgore 1980, Migletz et al. 1994, Niessner 1979). With the hot compressed-air method, high-velocity air is mixed with propane into a combustion chamber that vents out high-velocity heated gas at around 2,400 °F. The flame from the combustion is actually contained within the combustion chamber. The excess-oxygen system also utilizes propane, except the combustion is external and the flame makes direct contact with the pavement marking (Kilgore 1980). Propane and oxygen are mixed and ejected out of a nozzle, and the mixture is ignited. Then, additional pure oxygen is fed into the flame and applied over the marking. This method reaches temperatures in excess of 4,500 °F. Burning methods are typically only used for specific temporary tapes, typically foil, and for thin paint markings. Care

a) Walk-behind flailing unit drum

b) Replacement flailing drum for truck

Figure 4. Drum-style mechanical removal.

needs to be taken, especially on asphalt, to ensure the burning heads are not left in one place too long or pavement damage may occur. Typically, a second form of removal, vacuum or sweeper, is necessary to remove the burned debris from the roadway.

Laser

The laser removal method is still in the experimental phase. Innovations Deserving Exploratory Analysis (IDEA) Project 16 was one such research effort to evaluate and further develop a laser removal method (Pew and Thorne 2000). While the system developed on the project did not deliver comparable productivity with respect to pavement marking removal, it did show promise, though slow, for paint pavement markings.

Chemical

The chemical method consists of applying a remover over the pavement markings to be removed and allowing it to react prior to pressure washing off the line (Bryden and Kenyon 1986, Migletz et al. 1994, Niessner 1979). This method is effective on thin lines of paint around 0.010 to 0.020 inches (10–20 mil) in thickness, and so for thicker lines, multiple applications may be required. While it is effective, the method requires 10 or more minutes and at least two passes of equipment between the initial application and the pressure washing. Furthermore, the water and residue should be removed from the pavement, which may either be completed with additional water or vacuum removal. While this method works on both PCC and AC, the method's effectiveness is hampered by the porosity of the pavement surface, so open-graded AC may require multiple passes to remove the pavement markings. There were no systems found that would work on anything besides paint pavement markings. Also, depending on the chemical removal system, the asphalt may be damaged if left on too long, though newer chemical systems seem to have corrected this issue.

Masking

The masking of pavement markings is not necessarily removal of the marking itself but rather covering the marking with something else to hide its presence. Markings can be masked with a new road surface across the entire road, a small area of surface treatment, or material just over the marking itself. The covering material needs to be similar to that of the surrounding road surface so that the covered area blends into the surrounding pavement and cannot be confused as a form of delineation.

Other than a full or partial resurface, masking is a method whereby a material of similar color and surface characteristics to the roadway is applied over the pavement markings that need to be removed. Masking with removable, non-reflective, preformed tape that is approximately the same color as the pavement surface may be used where markings need to be covered temporarily (FHWA 2009). In the case of masking with temporary tape, the tape itself would need to match the road surface color and be applied directly over the marking. The tape would be used (temporarily) to preserve the marking underneath to be reused later instead of removing the marking just to apply another one in a short time frame. The tape can also be used to cover markings that are in need of removal but have yet to be removed. The MUTCD prohibits masking using other marking materials or for long-term use because of concerns that the marking being covered may become exposed in the future.

Resurfacing is generally the most expensive method of pavement marking removal because the roadway requires an entire overlay. As a result, it is used the least, and when used, it is typically the final surface of the construction project. Resurfacing that is not planned for the entire roadway is typically limited to lane-shift areas where markings cross lanes and removing them could lead to very confusing ghost markings. Another method is to cover the marking and the surrounding area (1 or 2 ft on either side) with a surface treatment similar to that of the surrounding road surface. Surface treatment refers to fog seal, slurry seal, microsurfacing, bituminous surface treatment, and other treatments, usually involving asphalt. They are primarily used for maintenance or interim roadway surface treatments. These types of surface treatments are described in Chapter 6.

Summary

Each of the removal methods are summarized in Table 3. Table 3 lists the reported advantages and disadvantages of each removal method. The advantages and disadvantages were gathered from the literature and the pavement marking removal survey (discussed in the next chapter). Table 4 is a re-creation of a table presented in the *Roadway Delineation Practices Handbook* that provides a previous perspective on the effectiveness of each removal method with respect to the pavement marking material being removed (Migletz et al. 1994).

Table 4 has been updated with additional information gathered from literature and the pavement marking removal survey. The specific literature references are indicated where the research has either filled in gaps or improved upon the original research with new information. Where *good* is referenced in the table, it is an indication that the removal type can adequately remove the pavement marking. Where *slow* is referenced in the table, it indicates the marking can be adequately removed but at a slower speed than other removal techniques. A notable change is that high-pressure water blasting has significantly improved in that the operating removal pressures now range

Table 3. Advantages and disadvantages of pavement marking removal methods.

Removal Method	Advantages	Disadvantages
High-Pressure Water	• Byproduct does not create dust and is contained within the equipment. • Little to no scarring on PCC. • With the exception of drying time, the pavement surface is prepped for pavement marking reinstallation. • Relatively fast for a blasting method. • Large vehicle mobile systems available with additional utility carts for smaller nearby areas.	• Limited to above-freezing conditions. • May polish surface aggregate and/or clean the surrounding pavement, creating a color contrast. • May remove some surface asphalt and fines that could lead to water penetration. • Potential for damage to pavement joints. • Currently not widely available, higher costs. • Proper equipment operation critical to achieve good results.
Grinding	• Fast and economical. • Depending on the system configuration (effective vacuum system installed to remove dust), dust created by removal can be contained. • High availability.	• Damage to pavement surface. • Scarring with full marking removal, minimizing damage to roadway may leave marking material behind. Orbital flailing may result in less noticeable scarring than drum flailing due to tapered edges. • Non-vacuum systems can create dust clouds and be hazardous.
Sand Blasting	• Minimal pavement degradation. • Little to no scarring. • Hand-operated precision.	• Creates considerable byproduct. • Creates considerable dust. • No current large vehicle mobile system, therefore slower than mobile methods. • Health hazards depending on blast media.
Shot Blasting	• Minimal byproduct. • Byproduct does not create dust and is contained within the equipment. • Minimal pavement degradation. • Little to no scarring.	• Shot recovery can be problematic especially on uneven surfaces. • Cannot be used in wet conditions. • Can be slow especially for thicker markings. • Can cause pavement damage on non-smooth surfaces. • Limited availability of equipment.
Soda Blasting	• Minimal pavement degradation. • Little to no scarring. • Hand-operated precision.	• Creates a moderate amount of byproduct. • Creates considerable dust. • No current large vehicle mobile system. • Can be slow especially for thick markings. • Only useful on some markings.
Dry Ice Blasting	• Minimal environmental concerns with respect to debris generated. • Minimal pavement degradation. • Marking can be completely removed. • Hand-operated precision.	• Dry ice is a difficult medium to handle and store. • Very noisy. • Slow. • No current large vehicle mobile system. • Only useful on some markings.
Hydroblasting	• Similar advantages to high-pressure water and sand blasting. • Minimal pavement degradation. • Limited scarring.	• Similar disadvantages to high-pressure water and sand blasting. • Creates considerable byproduct. • No current large vehicle mobile system. • Limited to above-freezing conditions.
Excess-Oxygen Burning	• Minimal pavement degradation.	• Requires at least one additional pass to remove residue. • Slow. • No current large vehicle mobile system. • Only useful on some markings.
Laser	• Non-contact and should have little to no wear, which reduces maintenance costs. • Minimal pavement degradation. • Minimal environmental concerns.	• Slow. • Requires at least one additional pass to remove residue. • No current large vehicle mobile system. • Only useful on some markings.

(continued on next page)

Table 3. (Continued).

Removal Method	Advantages	Disadvantages
Chemical	• Byproduct does not create dust. Can get complete removal without scarring.	• Potential to damage pavement surface if incorrect removing agents are used. • Requires at least one additional pass to remove residue. • Slow, need to wait for chemical to react then proceed with removal. • No current large vehicle mobile system. • Only useful on some markings.
Hand Removal	• Detailed removal.	• Slow. • Typically only for removable tapes.
Masking	• No damage to road surface. • Existing markings can be temporarily covered with tape that matches the road surface color and texture, and later reused when the tape is removed. • Removed areas can be masked to help blend in scarring or surface color changes. • Can be used in lane-shift areas to reduce driver confusion due to ghost markings or scarring.	• Can be expensive. • Material may wear away exposing the markings being covered. • Difficult to match color and texture with tape. • Tape is for temporary purposes only. • Cannot use marking materials other than tape to cover a marking.

Table 4. Effectiveness with respect to pavement marking material.[a]

Removal Method	Paint	Thermoplastic	Epoxy	Tape	Foil Tape
High-Pressure Water	Good (Berg and Johnson 2009; Ellis et al. 1999)	Good (Ellis et al. 1999)	Good (Berg and Johnson 2009)	Good	Ineffective
Sand Blasting	Good	Slow	Good	Ineffective	Very Slow
Hydroblasting	Good	Slow	Good	Ineffective	Ineffective
Soda Blasting	Slow (Berg and Johnson 2009, Cho et al. 2011, Oregon DOT 2001)		Slow (Berg and Johnson 2009, Cho et al. 2011)		
Dry Ice Blasting	Slow (Berg and Johnson 2009, Cho et al. 2011)		Slow (Berg and Johnson 2009)		Slow (Cho et al. 2011)
Shot Blasting	Good (13)				
Grinding	Good (Berg and Johnson 2009, Cho et al. 2011, Ellis et al. 1999, Oregon DOT 2001)[c]	Good (Ellis et al. 1999, Oregon DOT 2001)[c]	Good (Berg and Johnson 2009, Ellis et al. 1999)[c]	Ineffective	Ineffective
Hot Compressed-Air Burning	Slow (Niessner 1979)				
Excess-Oxygen Burning[b]	Thin Only	Ineffective	Ineffective	Ineffective	Good
Laser[b]	Slow (Pew and Thorne 2000)				
Chemicals[b]	Slow (Cho et al. 2011)	Ineffective	Ineffective	Ineffective	Ineffective
Hand Removal		Very Slow		Very Slow	Ineffective

[a] Table modified from original table presented in the *Roadway Delineation Practices Handbook* (Migletz et al. 1994) based on more recent research.
[b] Method requires a second pass to remove debris/residue, which could be another method such as high-pressure water.
[c] Removal can be successful but typically results in pavement scarring.

in excess of 40,000 psi and all of the equipment can be loaded on a mobile platform. These changes have made high-pressure water blasting more competitive with respect to effectiveness and cost versus grinding methods.

In general, blasting systems tend to be able to remove all of the markings without leaving a deep scar but still may result in shadow lines from the removal process, whereas grinding tends to leave a scar in order to remove all of the markings. Grinding and blasting can both create dust and debris that need to be cleaned or vacuumed while marking removal is conducted to allow for a safe driving and work environment. Wet grinding and water blasting do not have issues with dust. Grinding tends to be faster and cheaper than the blasting techniques.

CHAPTER 4

Pavement Marking Removal Survey

The pavement marking removal survey was one of the main sources of information for the research. The overall goal of the survey was to get as many quality responses as possible from a variety of sources to answer as many questions as possible about pavement marking removal.

Survey Development and Distribution

Initially, three separate surveys were developed for the following: (a) DOT and local agencies, (b) contractors, and (c) manufacturers. The surveys were later consolidated and revised to simplify the process and hopefully increase the response rate. The original state DOT and local agency survey can be found in Appendix A. The revised survey that was also distributed can be found in Appendix B. In addition to the survey, telephone and e-mail scripts were developed to allow the survey to be conducted in a consistent and professional manner.

The survey was distributed in two ways. The first was directly to individuals who were known to be involved in pavement marking removal, i.e., contractors and manufacturers. The second method was via related listservs. E-mails were sent out to numerous listservs seeking participation in the survey. People wanting to take part in the survey would reply to the listserv request and would be contacted directly about the survey. Respondents were given the option of completing the survey via e-mail or a phone interview. The listservs contacted were the following:

- American Traffic Safety Services Association (ATSSA) Temporary Traffic Control Committee.
- ATSSA Pavement Markings Committee.
- ATSSA Operating Committee.
- American Association of State Highway Transportation Officials (AASHTO) Highway Traffic Safety Committee.
- AASHTO Maintenance Committee.
- AASHTO Construction Committee.
- National Committee on Uniform Traffic Control Devices (NCUTCD) Pavement Marking Technical Committee.
- NCUTCD Temporary Traffic Control Technical Committee.
- Work Zone Clearing House.
- ITE Traffic Engineering Council.
- Transportation Research Board (TRB) Signing and Marking Material Committee.
- National Transportation Product Evaluation Program (NTPEP) Pavement Marking Materials Committee.
- NTPEP Temporary Traffic Control Devices Committee.
- American Public Works Association (APWA) Transportation Committee.
- National Association of County Engineers (NACE).
- Local Technical Assistance Program (LTAP).
- National League of Cities.

The two methods of distribution were thought to be able to reach the intended audiences of state DOTs, local agencies, pavement marking removal contractors, pavement marking removal equipment manufacturers, and international agencies. The research team also worked with ATSSA to include the request for survey participation in its bi-weekly newsletter, The Flash. The request was included in the 8/30/10 and 9/13/10 versions of the newsletter, which is distributed to over 1,600 ATSSA members.

Survey Response Summary and Discussion

Response to the listserv request for participation and direct contact with contractors and manufacturers resulted in a total of 25 states, 19 contractors, and 18 manufacturers being directly contacted. Response from local agencies was limited, with only three indicating they would like to take part and subsequently were directly contacted. Several other local agencies were directly contacted, but they indicated a limited use of pavement marking removal and did not feel they

could provide beneficial information to the survey. The international response was limited to two manufacturers, one industry representative, and one ministry of transportation. In addition, three other industry groups expressed interest in taking part in the survey and were subsequently contacted directly by the research team. After over 3 months of calls and e-mails to those expressing a willingness to participate, only 22 of the 72 individuals contacted had completed the survey, and 17 of the 22 were from state DOTs. This low response rate led to the revision of the survey to hopefully increase the response rate yet still provide as much quality detailed information as possible.

The research team sought to increase survey participation by contacting the remaining states that had not yet been contacted. In addition to the remaining states, the research team also contacted the 100 most populous cites in the United States (see Table 5). Appropriate individuals at each city and state were found and were contacted by either phone or e-mail to take part in the survey. The revised survey was also redistributed to those who had yet to complete the original survey.

In total, the research team received 55 responses to the survey. This includes 30 different state DOTs, 17 city or county agencies, 4 contractors, 3 manufacturers, and 1 industry group. In addition to these 55 responses, the research team also received several responses from the city and county agencies indicating that they did not do enough removal to be able to provide beneficial information to the study. Figure 6 provides a map indicating the responding states shaded in gray. Figure 6 also provides the location of the cities contacted (black dots) and the responding cities or other local agencies (larger gray dot with a black border).

The summaries of the responses to the survey are indicated in the following subsections in Table 6 through Table 50. The five subsections are as follows: general pavement marking removal practices, removal quality evaluation, costs and removal rates, environmental and worker safety concerns, and past removal experiences. The responses are separated by three different response groups, state DOTs, local agencies (cities and counties), and other respondents (contractors, manufacturers, industry groups), so that the responses can be seen from the separate groups. A discussion of the results is provided with the groups of tables representing similar questions in the surveys. It should be noted that each respondent did not respond to all questions, and some respondents only partially answered some questions.

General Pavement Marking Removal Practices

The researchers' first question on the original surveys was a general question to get the respondents thinking about pavement marking removal and why they do it. The question and responses can be seen in Table 6. The responses were as expected, centering on construction work zones, removal of existing markings prior to applying new ones, and changes to marking configuration.

Table 5. Local agencies directly contacted.

City, State Contacted				
New York, NY	El Paso, TX	Mesa, AZ	Riverside, CA	Norfolk, VA
Los Angeles, CA	Milwaukee, WI	Virginia Beach, VA	Lexington, KY	Birmingham, AL
Chicago, IL	Seattle, WA	Omaha, NE	Stockton, CA	Winston-Salem, NC
Houston, TX	Boston, MA	Oakland, CA	Corpus Christi, TX	Durham, NC
Philadelphia, PA	Denver, CO	Miami, FL	Anchorage, AK	Laredo, TX
Phoenix, AZ	Louisville, KY	Tulsa, OK	St. Paul, MN	Lubbock, TX
San Antonio, TX	Washington, DC	Honolulu, HI	Newark, NJ	Baton Rouge, LA
San Diego, CA	Nashville, TN	Minneapolis, MN	Plano, TX	N. Las Vegas, NV
Dallas, TX	Las Vegas, NV	Colorado Springs, CO	Buffalo, NY	Chula Vista, CA
San Jose, CA	Portland, OR	Arlington, TX	Henderson, NV	Chesapeake, VA
Detroit, MI	Oklahoma City, OK	Wichita, KS	Ft. Wayne, IN	Gilbert, AZ
Indianapolis, IN	Tucson, AZ	St. Louis, MO	Greensboro, NC	Garland, TX
Jacksonville, FL	Albuquerque, NM	Tampa, FL	Lincoln, NE	Reno, NV
San Francisco, CA	Long Beach, CA	Santa Ana, CA	Glendale, AZ	Hialeah, FL
Columbus, OH	Atlanta, GA	Anaheim, CA	Chandler, AZ	Arlington, VA
Austin, TX	Fresno, CA	Cincinnati, OH	St. Petersburg, FL	Irvine, CA
Memphis, TN	Sacramento, CA	Bakersfield, CA	Jersey City, NJ	Rochester, NY
Baltimore, MD	New Orleans, LA	Aurora, CO	Scottsdale, AZ	Akron, OH
Fort Worth, TX	Cleveland, OH	Toledo, OH	Orlando, FL	Boise, ID
Charlotte, NC	Kansas City, MO	Pittsburgh, PA	Madison, WI	San Bernardino, CA

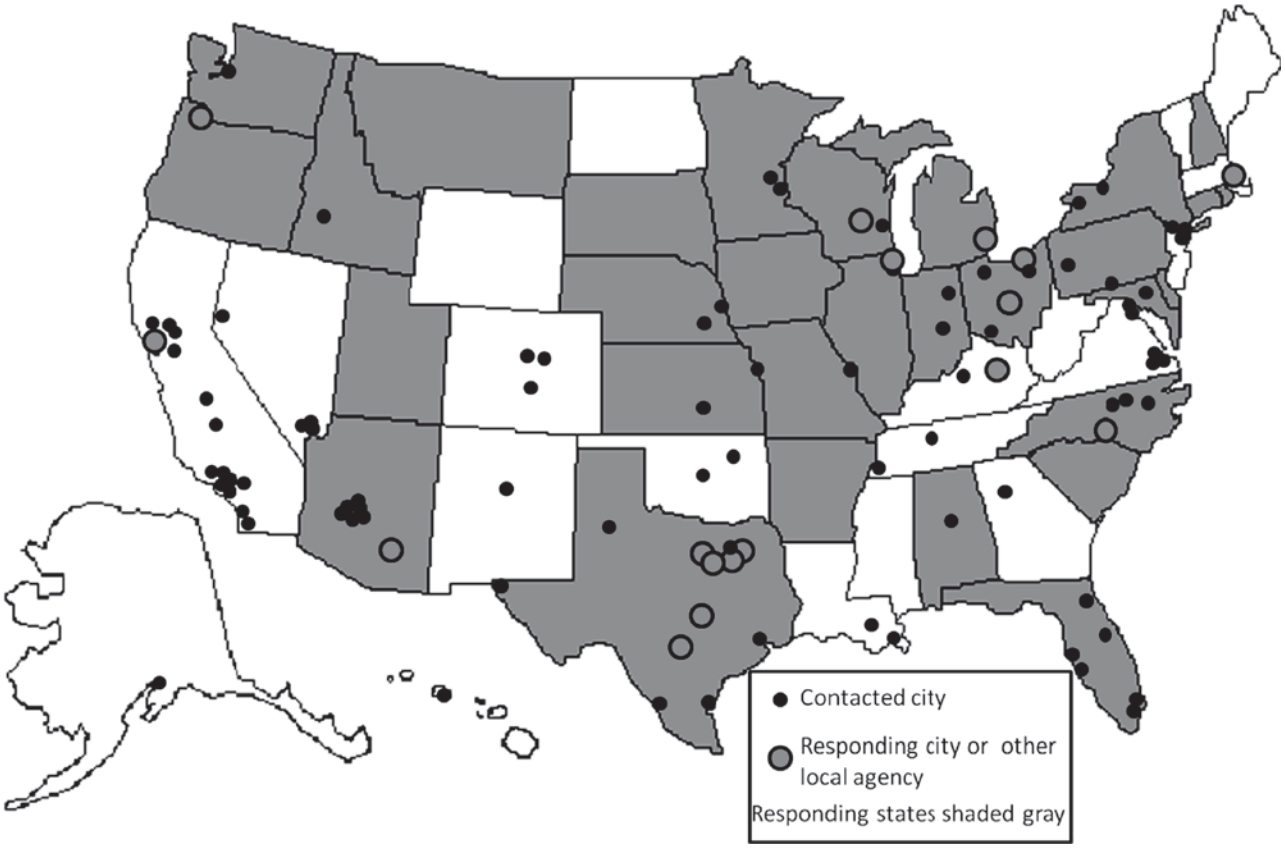


Figure 6. Map indicating responding states and local agencies.

In the original survey, the researchers sought to determine the typical source of pavement marking removal that the DOTs use: either contract out the work, or do it themselves. Table 7 shows that approximately half the respondents contracted out all of their removal work, whereas the other half contracted out some work while also using in-house forces to conduct a portion of their own removal work. No one reported completing all of their removal work in-house. The comments received were all similar in that larger jobs were contracted out and smaller jobs were done in-house. Typical in-house marking removal was conducted with a hand grinder.

The source of standard pavement marking removal practices for each organization was a major point of interest. These standard specifications are what govern a contractor's ability to use a certain removal type and how the quality of their work is to be evaluated. The differences in specifications are also of interest, because some areas may be doing things differently than others and seeing better results. All but two state DOTs responded that they have a standard practice or specification, and approximately half the remaining respondents indicated they have standard practices (see Table 8).

The research team acquired the standard specification from the 28 responding states as well as the rest of the 50 states. The part pertaining to marking removal in the standard specifications for every state is included in Appendix C. Also included in the appendix is a link to the full specification for each state.

Table 6. DOT—most common reasons for pavement marking removal.

What are the most common reasons for pavement marking removal?	Number of Responses
New pavement marking configurations	14
Construction work zone	13
Remove old pavement marking prior to new pavement marking installation	11
Correct pavement marking application errors	4
Various small pavement marking changes	1
Ensure proper adhesion of new pavement surface	1
Ensure compatibility with manufacturer warranty	1

Table 7. DOT—contract vs. in-house pavement marking removal.

Does your agency contract out for pavement marking removal or use in-house crews and equipment? Please explain the conditions of each.	Number of Responses
Contract Out	8
In-House	0
Both	10
Comments:	
Both. Contractor is responsible for marking removal on construction and maintenance contracts, while small quantities of removal for maintenance projects are done in-house.	
Both. Contract out for construction projects. In-house for traffic control changes.	
Both. Contract out for construction lane shifts on major construction projects. In-house for re-channelization of intersections or other operational low-cost improvements.	
Both. Contract out water blasting primarily for large removal jobs. In-house for grinding (hand machines) primarily for small jobs.	
Both. Depends on the type of project. For example, if a project is a minor restriping project, it could be done in-house. If it's widening or new construction, the project may be contracted out.	
Both. Contract out can use grinding and sand or water blasting. In-house uses grinding only.	
Contract out. This work falls under the epoxy items in our statewide contracts at no cost.	
Contract out. We have some in-house, but usually done in projects.	
Both. Majority is by contract. Some in-house work in maintenance on a case-by-case basis.	
Both. On-call for obliteration. Have hand grinder. Will black-out markings (in-house only).	
Both. Contract out for construction projects and durable pavement marking contracts. In-house for small paint sites and agility program locations.	
Both. Most removal for construction is contracted out; in-house crews are used for some traffic configuration changes.	

These specifications will be further examined when discussing various questions throughout the survey.

In the survey, the researchers asked what types of pavement marking removal methods are used or have been used, as well as the road surface and pavement marking material types on which they were used. Table 9 and Table 10 display the responses. Both the water blasting and grinding methods were very common among the state DOT responses, with zero responses indicating that these methods are no longer used. Grinding was by far the most commonly used method by the local agencies. The use of shot blasting and sand blasting were also indicated in many of the responses, but it was also indicated in several responses that these methods are no longer used. Masking of the markings was indicated about as frequently as shot or sand blasting but not as frequently as grinding or water blasting. A combination of grinding and blasting was indicated by only a few responses, but this method may offer an effective means of marking removal. Based on the DOT responses, there does not appear to be a pattern of a specific removal method associated with a specific road surface or marking type.

There was little consensus among states on removal methods. From the state specifications, 17 states specified a removal type, 13 indicated some methods but allowed for any other approved method, and 20 states did not indicate a method to use. Of the methods indicated, grinding was the highest with 22 references, sand blasting had 20 references, water blasting had 18 references, and other methods were referenced fewer than 10 times each.

The masking of markings was indicated by several respondents, and those using masking were also asked whether masking was used for temporary, permanent, or both pavement

Table 8. Standard pavement marking removal practices.

Does your organization have any standard practices or specifications for pavement marking removal?	State DOT	Local Agency	Other
Yes	28	10	3
No	2	7	4
Comments:			
See Appendix D for links to all state DOT standards.	☑		
Yes. We use a pavement marking grinder.		☑	
Yes. Grinding. Coordinate with public works and do spot seal coats. City spec for contractors can sandblast or grind.		☑	
Yes. For in-house projects, we only grind.		☑	
Yes, but it's not in writing.		☑	
No. We only do small projects in-house. Larger projects are contracted out.		☑	
Yes. State DOT standards.		☑	
Yes, we use the standards of the agencies for which we work.			☑
We do not have in-house standards. We use the DOT's.			☑

Table 9. DOT—current/past pavement marking removal practices.

Type of Removal	Status	Number of Responses	Pavement Type	Number of Responses	Pavement Marking Type							
					All	Paint	Thermo	Tape	Epoxy	Polyurea	Urethane	MMA
Water Blasting	Yes	23	All	10	9							
			Asphalt	8		6	4	3	3	2	1	
			Concrete	10		9	5	6	5	4	2	
			Surface Treatment	1		1		1	1			
	Never	3										
	No Longer	0										
Grinding	Yes	29	All	11	11	1			2			
			Asphalt	12		9	10	7	5	4	3	1
			Concrete	13		10	10	8	6	4	3	1
			Surface Treatment	3		2	1	2	2	1	1	
	Never	0										
	No Longer	0										
Sand Blasting	Yes	17	All	9	6	3			2			
			Asphalt	3		2	2	1	2	2		
			Concrete	3		3	2	1	2	2		
			Surface Treatment	2		2	2		1	1		
	Never	2										
	No Longer	5										
Combination Blasting + Grinding	Yes	8	All	3	2							
			Asphalt	2		2	2	2	1	1	1	
			Concrete	5		5	4	5	3	3	1	
			Surface Treatment									
	Never	5										
	No Longer	1										
Shot Blasting	Yes	14	All	7	6							
			Asphalt	5		5	5	1	2	3	3	1
			Concrete	6		5	6	1	3	3	3	1
			Surface Treatment	1		1	1		1	1		
	Never	3										
	No Longer	2										
Masking	Yes	16	All	9	6			3				
			Asphalt	5		4	4	4	3	2	1	
			Concrete	5		4	3	5	3	2	1	
			Surface Treatment									
	Never	5										
	No Longer	1										
CO_2 Blasting	Experimental	1	All	1		1			1			
Soda Blasting	Experimental	1	All	1		1			1			

Table 10. Non-DOT pavement marking removal practices.

What types of pavement marking removal methods are used or have been used by your organization?	Local Agencies	Other
Water Blasting	4	5
Grinding	17	6
Sand Blasting	5	3
Shot Blasting	3	3
Masking	1	1
Glass Blasting	0	1
Mixed Media Dry Ice Blasting	0	1

Table 11. DOT—masking technologies.

If your organization uses any masking technologies (black pavement markings, slurry or black tape) to cover existing markings, are they covered for temporary applications, permanent application, or a combination of both?	Number of Responses
Temporary Only	11
Permanent Only	1
Both	0
Comments:	
Temporary. To cover conflicting markings in construction or maintenance projects.	
Black tape is used to cover permanent tape markings on a temporary basis.	
Black tape used to cover expensive permanent markings for short time periods.	
Not used.	
Rarely used.	
Temporary removable black tape only.	
Non-reflective tape is used over durable pavement marking that will be retained.	
Slurry, microsurface, paint over (in-house only).	

marking conditions. All but one respondent indicated that markings were masked only temporarily (see Table 11). Temporary black tape was indicated as the typical method of masking the markings. Several responses indicated that durable markings to be retained were masked. The state specifications indicated that 20 states allowed markings to be painted over.

Several responses indicated that a removal method was no longer used, so those respondents were also asked why a method was no longer used. Table 12 indicates the responses on why the removal methods were no longer used. The table contains a number of different reasons. One of the main reasons indicated is the environmental impact of open sand and shot blasting. Masking of markings was indicated as no longer being used due to not sufficiently masking the markings. One response indicated the respondent's opinion that grinding, due to the scarring it leaves, should be a candidate to be abandoned. The state specifications indicated that 19 states did not allow markings to be painted over. Burning (three references), chemicals (three references), and grinding (five references) were addressed as not being allowable. Grinding was typically not allowable on the final surface.

Participants were asked if they were aware of any emerging technologies in the field of pavement marking material removal. Table 13 presents the responses to the question. The majority of the yes responses referred to a paint and chemical system. The opinion seemed to be that it was not a great system. Two responses indicated high-pressure water blasting, and another three indicated the use of orbital grinding/mechanical erasing. Blasting using materials other than water, sand, or shot were also mentioned; these responses came from the manufacturer of this type of removal technology.

Table 14 and Table 15 indicate the responses to the question asking if there were any removal technologies that the respondent would like to try that were not currently being used. The vast majority of the responses indicated that participants wanted to see water blasting used more. Reasons stated for not as much water blasting being used currently were typically due to the cost of removal or availability of the equipment. Several responses indicated blasting techniques such as glass, shot, sand, or water as methods participants would like to try. Two local agencies wanted to try long-line grinding trucks instead of the walk-behind units.

The researchers asked in the survey what the agencies' preferred pavement marking removal technique was. Table 16 through Table 18 provide the responses. The DOT respondents indicated that their preferred removal techniques seemed to be either water blasting or grinding. The local agencies' preferred removal technique was grinding. This preference by the local agencies was likely due to the availability of the equipment

Table 12. DOT—abandoned removal methods.

If your organization no longer uses or has not used a type of removal, please explain why they are not used.
Comments:
Sand and shot blasting have a lot of environmental concerns with the collection of the used sand/shot blast.
Per our spec book, no slurry or black markings can be used to obliterate existing markings.
Shot blasting and sand blasting are too messy.
Open sand blasting is a hazard.
Would like to see grinding abolished . . . too much pavement scarring even on PCC.
Sand blasting—not safe, produces hazardous silica.
Black pavement markings did not cover traffic markings enough to effectively redirect traffic.

Table 13. Emerging technologies.

Are you aware of any emerging technologies in the field of pavement marking removal such as chemical systems or a combination of mechanical processes? If yes, please describe and/or provide a website link for more information.	State DOT	Local Agency	Other
Yes	8	4	3
No	17	11	5
Comments:			
Paint marking material with chemical solution to make removal easier.	☑		
We did a small application of removable paint but it was not successful.	☑		
We are aware of removable paint. We have not used it and believe the manufacturer has reduced their marketing effort. We are not aware of any other emerging technologies.	☑		
Heard of some chemical systems. Just started using water blasting.	☑		
Removable paint/compatible solvent system. It's been around for many years but very expensive.	☑		
Rotary grinding.	☑		
Heating. It can create a mess, and it's not that great. Orbital grinder sander following a regular grinder.	☑		
Chemical removal systems used in combination with formulated temporary markings. Issues with application and removal of the chemicals.	☑		
Rotary grinding.		☑	
We are kept up to date through vendors.		☑	
High-pressure water jet, have seen at airport on paint only.		☑	
We've heard of chemical removal but haven't seen any results.		☑	
Mechanical erasing.			☑
Glass blasting.			☑
Mixed media with dry ice blasting.			☑

Table 14. DOT—removal technologies desired to try.

Are there any removal technologies that you would like to try that you are not currently using due to environmental impact, cost, unavailability, or some other factor? If yes, please describe which types you would like to use.	Number of Responses
Yes	11
No	7
Comments:	
Yes. I'd be interested in water blasting. It has been used for surface preparation but not line removal that I'm aware of.	
Yes. We would love to find something that does not scar pavement besides temporary tape.	
Yes. Sand blasting and/or hydro-sanding, if for no other reason than to keep water blasting costs down through competitive pricing.	
Yes. Currently testing black cover-up markings with ok from MUTCD group.	
Yes. Possibly other abrasive techniques.	
Water blasting has really just come around in the last two years, but there was definitely a time where we wanted it and the closest was 12 hours away and mobilization was very high.	
The cost of water blasting is kind of high, making it impractical for small removal jobs.	
We would like to do more water blasting, but not all contractors are properly equipped.	
Yes. Water blasting is starting to emerge, but only one contractor has it, so cost and availability are issues. Seasonal use with water blasting may be an issue. Environmental issues are not a concern.	
Water blasting seems like a good option but has a dry time issue. Water blasting can also be costly, as it is new equipment.	
Not that we know of. We might choose to do more water blasting if it were cheaper.	
Yes. Water blasting would be interesting to see done.	
We prefer tape, but it costs too much. Nothing on the market that we know of is as quick, inexpensive, and does not scar.	
Hydroblasting is limited due to cost.	
Cost may keep water blasting from being used as much.	
We don't have our own equipment for water blasting. So, we're dependent on contractors. Mobilization fees are very high, so it's definitely not cost effective to bring them in on small jobs.	

Table 15. Local agency and other respondents—removal technologies desired to try.

Are there any removal technologies that you would like to try that you are not currently using due to environmental impact, cost, unavailability, or some other factor? If yes, please describe which types you would like to use.	Local Agency	Other
Yes	11	3
No	2	5
Comments:		
Possibly other abrasive techniques.	☑	
No. Water blasting causes a big mess, hard to clean up.	☑	
Yes. Water blasting then fog seal.	☑	
Since early 1980s we were told not to sand blast because of silica in the sand.	☑	
Long-line grinding trucks with vacuums on it, expensive in the short term.	☑	
Try long-line grinding truck for thermo. Not currently used due to lack of research on effects of it vs. water blasting on asphalt.	☑	
We have not tried anything else, but we would be open to trying something different.	☑	
Water blasting. It is quicker and creates less damage.	☑	
Water blasting, but we don't use due to cost of equipment. We are also looking into purchasing an attachment for a Bobcat, a grinding machine for long distance use.	☑	
Wet sand blasting, if the contractor is directed to block out the area because the old shadow of the past markings will not show.	☑	
No. Based on knowledge of existing equipment.	☑	
Masking on some special locations. We just have not tried it yet.	☑	
Currently we would like to try water blasting, but as of yet, no contractor has come forward to use the method.	☑	
Would like to try chemical systems.		☑
Would like to try shot blasting.		☑
Working on developing new technologies.		☑

and their typical use of only hand grinding units, which are less expensive than large grinding trucks or water blasting. The other respondents favored water blasting over grinding.

When asked if temporary work zone markings are removed in a manner similar to that of a permanent marking, all but one respondent answered yes. Table 19 provides the results and comments. Some comments did specifically state removal or pavement marking practices used on the final surface. The respondents indicated that some projects will specify either water blasting or sand blasting as a removal technique so there is less scarring, or temporary/removable tape being used as the temporary marking so that it can be removed by hand.

Table 20 indicates the responses to the question asking if the selection of pavement markings in work zones takes into consideration having to remove those markings later. Most responses indicated that the removal of the marking was considered for work zone markings. A major concern was the impact the removal would have on the final surface of the roadway. Another concern was the duration of the work zone. Markings that are more durable are more expensive and more difficult to remove, but the markings need to be present over the duration of the project. Tape was the preferred choice on the final surface to limit scarring from marking removal; paint was the second choice because it is cheap and the easiest marking to remove.

Similar to the last question about pavement scarring concerns, Table 21 indicates the responses to concerns about ghost markings and means of preventing them. Typically, ghost markings are areas where a marking was removed but may still be perceived to be acting as delineation. This can be the result of scarring, material remaining on the surface, or changes to the surface texture. The responses were similar to that of the specific concerns for pavement scarring. Responses indicated using tape in areas where scarring was expected to be a problem on the final surface. Blending removed areas with pigmented sealer or using a sealer to mask shine from polished rock to mask the surface characteristics changes were methods used. Using water blasting on the final surface and keeping grinding to a minimum were ways indicated to prevent ghost markings.

Removal Quality Evaluation

The damage to the surface of the roadway from marking removal is one of the most important areas of concern, as scarring can be confusing to drivers and may also negatively affect the durability of the road surface. Removing all the pavement marking material is also an important area of concern because marking material left behind may be mistaken for an actual marking, resulting in confusion to drivers. Finding the optimal removal technique for a given situation that removes all of the marking and does not damage the road surface is the ultimate goal.

Table 16. DOT—preferred pavement marking removal technique.

Describe your organization's preferred removal technique and indicate whether this varies by marking or road surface type?	Number of Responses
None	4
Water Blasting	9
Grinding	10
Sand Blasting	1
Masking	1
Hydroblasting	2
Comments:	
Different district offices have different preferences on how to remove markings. There is no one preferred removal technique.	
Grinding is the preferred removal technique used by contractors and our forces.	
Temporary tape. Water blasting on concrete.	
We do not have a favorite. We try to control damage in all removal methods. Hydroblasting is favored for most removal for all flat lines on all surfaces.	
Hydroblasting for all markings and surfaces.	
Prefer water blasting, but spec leaves it open to the contractor. Have had a project or two where design personnel have required water blasting.	
Truck-mounted hydro (water) blasting is preferred for both road surface types.	
We don't specify any specific removal technique over others irrespective of marking or road surface types. However, we would like to see more use of water blasting in the future.	
Our preferred method of removal is grinding.	
Grinding and water blasting (concrete only).	
Grinding, but it does vary by road surface type.	
Grinding and water blasting.	
Only grinding and water blasting are allowed.	
Our preferred removal technique is grinding due to cost effectiveness. Grinding is usually adequate on all marking and road surface types.	
1) Water Blasting 2) Shot/Sand Blasting 3) Grinding.	
Plan notes allow the contractors to use any method of removal as long as they do not do any damage to the pavement surface.	
Most safe and cost-effective method possible.	
We prefer water blasting for edgelines and temporary markings. We are currently grinding markings to specified groove where permanent markings will be replaced at the same location.	
We contract out, and contractors typically use grinding to remove all pavement markings.	
Hand grinding for maintenance projects. For larger projects contract out sand blasting.	
No, mostly shot blasting since this is the most readily available equipment.	
No preference, depends on-site conditions.	
Specifications allow the contractors to pick the type of removal.	
Grinding is the most effective at a reasonable cost.	

Table 17. Local agency—preferred pavement marking removal technique.

Describe your organization's preferred removal technique and indicate whether this varies by marking or road surface type?	Number of Responses
Water Blasting	2
Grinding	14
Sand Blasting	1
Masking	1
Comments:	
Water blast, then fog seal.	
We use a grinder for concrete/asphalt for paint/thermo removal.	
Grinding for all markings.	
Polymer tape can be removed by torching the tape till it's black. Afterward the tape scrapes off easily. Grinding is the preferred method for removing thermoplastic lines. Buttons (raised pavement markings) are removed with a chisel and hammer or front loader scraped off.	
Preferred method is grinding—used for all surfaces.	
We only use grinding.	
Grinding for in-house projects. For pavements less than 6 months old, we prefer water blasting.	
Grinding on all types of surfaces and markings.	
Past experience is sand blasting gives the best results.	
Mobile line removal hand grinders. No variation based on markings of road surface. We use the same type of grinder for all surfaces.	
Currently, the contractors grind pavement markings and we use grinding for paint, thermoplastic, and polyurea markings.	

Table 18. Other respondents—preferred pavement marking removal technique.

Describe your organization's preferred removal technique and indicate whether this varies by marking or road surface type?	Number of Responses
Water Blasting	4
Grinding	2
Mixed Media Blasting	1
Comments:	
Water blasting for less scarring.	
Water blasting, everything varies according to materials, thickness and substrate.	
Grinding (flailing).	
Water blasting.	
Water blasting for large jobs that require complete removal. Grinding on small projects that require partial removal or transverse marking.	
Orbital flailer referred to as mechanical eraser.	
Mixed media blasting with dry ice and walnut shells.	

In the survey, the researchers sought comments on whether or not there were acceptable threshold levels of scarring depth to completely remove a marking. The responses to this question can be found in Table 22 through Table 24. Most DOT responses indicated that there were not any specific measuring techniques, nor were there specific threshold levels. Examining the state specifications revealed that seven states did indicate a maximum allowable scarring depth. Three states indicated allowable depth of less than ⅛ inch, and one state each indicated less than 1/16, less than 1/32, less than ¼, and typical scarring depths of ⅛ to ¼ inch. Three local agencies indicated a maximum allowable scarring depth of ⅛ inch, and another indicated approximately ⅕ inch. The remaining responses indicated that there were no stated thresholds and that minimal scarring was preferred and was left to the inspector's judgment.

One state has worked on developing a specification to measure the depth of scarring using a plate of known thickness. This plate is placed in the scarred area, and a straight edge is placed over the plate and across the groove so that it rests on the pavement. The straight edge is held in place and the plate is pulled on to see if it comes out from under the straight edge. If the plate slides out, then the scar is too deep and not acceptable; if it stays in place, the removal is acceptable from a scarring standpoint. In the same specification, the state is also trying to measure the smoothness of the removal by using a digital dial gauge to measure the depth of the removal across the marking. The average of the depth measurements needs to remain below a threshold value in order to be considered acceptable.

The researchers asked in the survey if traces of marking on the road surface were acceptable if the majority of the marking was gone, and if there were any acceptable thresholds. Tables 25 through 27 provide the responses. Of the DOT respondents, 17 indicated that traces of the marking were acceptable, whereas 9 said they were not. Of the local agency respondents, 6 indicated traces of the marking were acceptable,

Table 19. DOT—temporary work zone marking removal.

Are temporary work zone markings removed in a similar manner as permanent markings? Please explain.	Number of Responses
Yes	16
No	1
Comments:	
Yes. However, some temporary markings are glued-down tape and scraped off. Temporary markings placed on a final surface course generally are water blasted to protect pavement. Most other temporary markings would be removed in a similar fashion as permanent.	
Yes. Footage dependent. Most commonly grinding.	
May completely mill the whole surface to reduce ghost markings.	
Yes. Do not distinguish a difference.	
No. Temporary markings are often paved over, in which case they don't need to be removed. If temporary markings are needed on the final layer of pavement, then only removable tape is used.	
In addition to the methods mentioned in Question 4, sandblasting is also permitted to remove temporary work zone markings.	
Yes. May choose a particular method.	
Yes. Water or sand blasting can be used.	
Yes. Black-out for temporary work. Regret it (had to reapply, did not pull up).	
Yes. Our specification covers permanent and temporary marking removals.	
Yes. The same pay item and spec is used. Some projects will specify either water blasting as a removal technique so there is less scarring, or temporary tape as the temporary marking so that it does not need to be removed by grinding.	

Table 20. DOT—work zone scarring concerns.

When selecting markings for a work zone is the quality and cost effectiveness of removal (and subsequent remnants/scarring) taken into consideration? Please explain.	Number of Responses
Yes	12
No	4
Comments:	
Yes. Glued-down tape for low ADT and rolled-in tape for high ADT and long duration sites. Water blasting for temp markings on final surface.	
Yes. Depending on the duration of the temporary markings, removable tapes or other easily removable markings should be used. Painting of temp work zone markings is only done if the duration is expected to be over one month.	
Yes. FHWA prefers we use type R tape on permanent surface. Our spec book says not to scar pavement excessively, but it's not quantified.	
Yes. On selected projects we believe removal or scarring will be a problem.	
No. We only use grinding and water blasting. Water blasting is preferred but not as available as grinding.	
No. Work zone markings across pavement are tape. Other lines are standard pavement markings.	
Yes. 1) Highest emphasis is placed on not damaging pavement. 2) Next most important consideration is thorough removal. 3) Third would be keeping costs within reason.	
Yes, but in most cases it is left to the discretion of the contractor.	
Yes. Easily removable and the least evasive.	
Yes. Tape is used where the surface will not be resurfaced at the end of the project.	
Conflicting pavement markings should be removed by a method that will not damage the surface texture of the pavement.	
Yes. Scarring from hydroblasting. Temporary tape (not locally, just the DOT) may be willing to try.	
Yes. Waterborne is typically used in work zones because it is cheaper and easier to remove. Some cold weather epoxy materials have been used on projects when the project covers multiple construction seasons.	
Yes. If we want to preserve a high quality marking such as tape skips, we will use temporary tape striping and black mask to cover existing markings.	

Table 21. DOT—ghost marking concerns.

In areas where construction or maintenance has occurred and the markings will not go back to their previous pattern, are there any steps taken to ensure the areas of removed marking are not still perceived to be acting as delineation (i.e., ghost markings)?	Number of Responses
Yes	10
No	5
Comments:	
Yes. Generally use water blasting on final surface. Some districts use black tape, but there is some concern about east-west roads because of sunlight reflection on black tape.	
Yes. (1) Try to minimize pavement damage. (2) Tried blending with pigmented sealer without success. (3) On a project in 2009 the contractor hydroblasted concrete without leaving a scar. We directed the contractor to install contrast markings to improve contrast.	
Possibly go back with sealer to mask shine from polished rock.	
Spec says to make sure markings are removed to not have ghost markings, put down tape primer, diamond grind surface, and to try to do most shifts prior to final surface.	
Yes. This is why only removable tape is used on final surfaces. It's also why we try to keep grinding to a minimum—too much potential for damage.	
If we are not going to overlay the pavement after grinding markings, we would only allow a removable tape to be used.	
Yes. Most work zone markings are removed by grinding the old marking.	
Yes. 85% to 100% removal required. The best method is to phase construction for the markings that are to be placed in the final pattern with temporary tape.	
We take steps to ensure that the removed markings are removed by the contractor in accordance with our specifications.	
Yes. Black-out (more of a blob than a line), fog seal, and microsurface.	
Yes. As much as possible, these conditions are typically avoided and discouraged. If they do occur, additional signing is placed to alert the travel motorist of the "new" traffic patterns ahead.	
No. Pavement scarring is a big problem, for which we do not have a solution. One thing that was done when a freeway was converted from 3 lanes in one direction to 4 was to make all new markings 8" wide instead of 4".	

Table 22. DOT—acceptable damage thresholds.

Discuss how much pavement damage (surface scarring) is acceptable to completely remove a marking. Are there acceptable threshold levels?
Comments:
District offices can elect to not allow grinders to be used on new surface courses.
We do not have threshold levels other than that the removal should be limited to the marking itself.
No. Up to engineer.
0.06 inch maximum. My opinion based on other states.
Some is inevitable. No quantitative levels. Subjective evaluation only.
None really for restripe situations. Minimal for remove and replace.
Tough to measure. Previous spec says 90% of road should be visible.
Prefer no damage at all. Surface texture or color may be altered slightly. Unfortunately, the spec isn't always enforced properly.
Both durable and non-durable pavement markings, markings should be removed in such a way that the pavement surface is not damaged below a depth of 1/8 in.
Currently grinding beyond the top of the pavement surface is not accepted.
Do not do any structural damage.
No. Minimum scarring is acceptable. However, grooving, rutting, or other significant damage is not acceptable.
No set measurement. As little as possible.
Expect some level of scarring.
We require 100% removal with minimal to no damage to the pavement. We review the job prior to it being let for proper removal, and if there are any issues a note is added to the plans to call the style of removal out.
Repair the damage pavement that results in the removal of pavement more than 1/8 in. thickness.
Preference is minimal damage as possible to the pavement.
We have no standard. We try to leave minimal scarring, but it's up to the inspector. It depends on pavement quality as well.
No established threshold levels.
Minor limited amount, however will not confuse motorists.
We don't have a standardized level. We mostly rely on visual inspection.
There are no thresholds. Damage pavement as little as possible.
There are no threshold levels. It's just a given that scarring is going to happen.
No, would be difficult to put into a spec or to measure. Do not allow too much scarring, may impose a financial penalty.
Depends on-site conditions.
Subjective and usually the project inspector's decision. There is a balance between a complete removal and not structurally damaging the pavement and reducing its remaining life.

Table 23. Local agency—acceptable damage thresholds.

Discuss how much pavement damage (surface scarring) is acceptable to completely remove a marking. Are there acceptable threshold levels?
Comments:
We accept some level of scarring.
We have three levels, Good, OK, and Bad. Bad levels are removed by priority area. OK levels are removed if needed such as in a school crosswalk.
Yes. Employees that care about what they are doing cause less damage to the roadway surface.
On asphalt streets with new asphalt, we apply an asphalt emulsion after grinding.
Try to limit damage, minimal damage should result.
Expect some pavement damage, but keep as light as possible. Feather in the edges to reduce the impacts of scarring.
No more than 1/8 in.
1/8 in. or less (subjective eyeballing).
1/8 in. depth is acceptable to completely remove markings unless the product is inlaid/ recessed into the pavement, then whatever it takes to remove the markings we will do. Scars should not be any deeper than 1/8 in. per our standards. We use carbide and steel fine tooth cutters that leave the surface smooth with very little scarring.
If the removal is done correctly the pavement should have minimal scarring.
~ 2/10 in. 2.5/10 in. would be considered damage to the road. Goal = less than 1/10 in.
There are no thresholds. Scarring is just a part of the removal.
There are no written threshold levels. It's up to supervisor to ensure reasonableness.
We attempt to remove only the markings without scarring the road surface. Yes, as long as the remainder does not confuse or conflict with the revised markings or result in an unsafe condition.
Yes, as long as it is not taking up very much of the pavement. Judged on a case-by-case basis.
We try to have the contractor remove the marking as precisely as they can to reduce surface scarring. We try to have the contractor immediately replace the removed marking.

Table 24. Other respondents—acceptable damage thresholds.

Discuss how much pavement damage (surface scarring) is acceptable to completely remove a marking. Are there acceptable threshold levels?
Comments:
Depends on the inspector.
No damage is acceptable.
Small surface scarring by flailing can benefit longevity of new striping by improving cohesion.
As little as possible, set by the agency.
As long as the removed stripe does not confuse the walking or driving public and the removed area will not collect water, then the removal should be acceptable.
Keep scarring to a minimum.

whereas 10 said they were not. Of the other respondents, five indicated traces were acceptable, whereas one said they were not.

The DOT response to the threshold level of remaining marking was based on a balance between removal and road damage. The main concern was that 100 percent removal would cause added damage to the road and that leaving some material behind would spare road damage and not be confusing to drivers. Based on the state specifications, 13 states indicated required levels of removal, all based on subjective evaluations. One state specifically stated 100 percent removal, five indicated 95 percent removal, five indicated 90 percent removal, one indicated 85 percent removal, and one indicated 75 percent removal. Two local agencies indicated they strive for 100 percent removal, whereas two others indicated at least 90 percent removal, all evaluated subjectively. In general, the specifications follow the MUTCD calling for complete removal with limited pavement damage.

Table 28 provides the responses to the question of whether or not there were any measures of effectiveness to determine the quality of a marking removal. Most responses indicated that there were no measures used and that only a subjective evaluation was conducted. One manufacturer stated that if water were able to pool in the area where a marking was removed, then it should not be accepted, due to being too deep of a scar.

In the original survey, the researchers sought to get a subjective estimate as to the quality of pavement marking removal of various marking types on various road surfaces with various removal techniques. Table 29 represents the average subjective rating of the quality of the marking removal for the listed removal type, road surface, and marking type combinations.

Table 25. DOT—acceptable traces of marking remaining.

Are traces of marking on the road surface acceptable if the majority of the marking is gone? Are there acceptable threshold levels?	**Number of Responses**	
	Yes	**No**
Are traces of marking remaining ok?	**17**	**9**
Are there acceptable threshold levels?	**7**	**13**
Comments:		
No specific MOEs. Specs allow very small particles of tightly adhering markings to remain.		
There are no thresholds, but we expect full removal of the markings.		
No. Up to engineer.		
Up to 10%. No standardized test. Usually objective.		
Complete removal is preferred.		
Depends on the project. It is subjective. There is no acceptable threshold level.		
Our spec is to completely remove the marking.		
Yes. Looking at least 90% line removal (by observation).		
Minimum of 85% of the existing must be removed.		
Yes. See attached spec 90%.		
We prefer that the removal is complete removal without damaging the surface.		
Traces of markings are acceptable as long as it does not conflict with the existing markings.		
Some. Acceptance is based on visual inspection of the removal.		
100% removal will tear up the road, so some marking still being visible is alright as long as the majority is gone and it does not convey the message any longer and it does not cause confusion.		
No traces allowed for removal. Traces ok for remove and restripe.		
Yes, with satisfactory visual inspection.		
We prefer removal of 90% or more of the marking.		
No. We have no specified threshold, but remove the whole marking.		
95% removal, trying to get it all may result in deep scars.		
Depends on-site conditions.		
Subjective and usually the project inspector's decision. There is a balance between a complete removal and not structurally damaging the pavement and reducing its remaining life.		

Table 26. Local agency—acceptable traces of marking remaining.

Are traces of marking on the road surface acceptable if the majority of the marking is gone? Are there acceptable threshold levels?	Number of Responses	
	Yes	No
Are traces of marking remaining ok?	6	10
Are there acceptable threshold levels?	3	1
Comments:		
We take all of it off and then re-mark as needed. We don't ever leave trace amounts.		
Yes. It's hard to get it all with grinding without causing a lot of damage to the surface.		
Try to remove it all.		
Strive for 100% removal. Have used black paint in some cases to cover marking that is deep to prevent scarring.		
For restriping, material can be left. For removal, all should be removed. Have used preformed thermo sealant to help blend scarred area with surrounding pavement.		
Our goal is to remove all of the marking.		
We require 90% removal (subjectively viewed).		
No. We try to remove 100% of the material from the road surface so that it does not create confusion to vehicular or pedestrian traffic. We use a crisscross grinding patter to prevent leaving remnants of past markings. We must remove 90-100% of the marking material.		
No, all markings should be removed.		
Yes. Our concern is noticeability or new marking adhesion and evenness.		
No. We must completely remove the marking.		
We should remove at least 90% of the marking.		
Yes. No threshold levels. It would be hard to measure, becomes a judgment issue.		
We currently like all markings to be completely gone if possible.		
Yes, the threshold is the majority of the marking is removed.		

In general, it was difficult to differentiate between the different road surfaces and marking types for a single removal technique. This was likely due to there being no actual quantifiable data to determine the quality of the removal, thus leaving the respondents to estimate based on experience.

High-pressure water blasting received favorable scores across the board except for cost effectiveness. The low cost-effectiveness scores were likely due to the equipment not being as readily available as other forms of marking removal and the relative newness of the higher-pressure systems. The general grinding category received good scores for extent of removal, cost effectiveness, and production rate but had lower scores for level of scarring and environmental impact. Grinding's major disadvantage is that to be able to remove all of the marking, it needs to be able to get to the marking, which typically requires removing some of the road surface to get to where the marking has seeped into pores. The lower environmental impact scores can be due to the noise and dust created by the removal. Vacuum systems should be able to help reduce the amount of dust, but these systems are for larger grinding vehicles and not the hand units. Sand blasting received good scores across the board other than with production rate. The production rate likely received lower scores due to the non-mobilized nature of this blasting method. The sand blasting environmental impact ratings were higher than expected due to the presence of particulates in the air and the debris that is created. Masking received good scores other than on cost effectiveness and production rate. Similarly, CO_2 and soda blasting received very low cost-effectiveness and production rate scores.

In the revised survey, the researchers sought comments on removal satisfaction instead of subjective scores like in the original survey. Tables 30 through 32 provide the responses to

Table 27. Other respondents—acceptable traces of marking remaining.

Are traces of marking on the road surface acceptable if the majority of the marking is gone? Are there acceptable threshold levels?	Number of Responses	
	Yes	No
Are traces of marking remaining ok?	5	1
Are there acceptable threshold levels?	1	0
Comments:		
Yes, some marking can remain.		
Yes, there are acceptable levels. Depends on the project manager/engineer.		
If there is remaining color on the surface where it is not confusing, then it is acceptable. Removing extra material may damage the road surface unnecessarily.		
Yes, if not noticeable as a marking. Leaving a little on some surfaces helps reduce scarring.		
All of the marking should be removed.		

Table 28. Measures of effectiveness.

Are you aware of any emerging technologies in the field of pavement marking removal such as chemical systems or a combination of mechanical processes? If yes, please describe and/or provide a website link for more information.	**State DOT**	**Local Agency**	**Other**
Yes	5	2	2
No	21	15	4
Comments:			
Visual observation.	☑		
No. Purely subjective—must satisfy the administration's on-site engineer.	☑		
No. Visual.	☑		
Yes. Subjective to engineer's inspection.	☑		
Yes. See attached spec (visual judgment).	☑		
Yes. We review damage to the joints and material in the joints, amount of marking remaining, as well as what the permanent damage to the roadway that's left is uncovered.	☑		
Yes. Visual as determined by the engineer.	☑		
No, visual judgment.	☑		
Yes. It needs to be 100% removed. Nothing less is acceptable at all times.		☑	
Yes. This is usually determined by the supervisor in charge; they will do an on-site visit and drive through the zone. We do not have any instruments to determine a fair job to a great job.		☑	
Yes, does the removed area collect water or not.			☑
Yes, no damage to road surface.			☑

Table 29. DOT—pavement marking removal methods evaluation.

On a scale of 1-10 (1=poor, 10=excellent), rate the quality of the following pavement marking removal methods for each of the listed criteria.							
Type of Removal	**Pavement Type**	**Marking Type**	**Extent of Removal**	**Level of Scarring**	**Environmental Impact**	**Cost Effectiveness**	**Production Rate**
Water Blasting	All	All	9.2	7.7	8.7	6.0	6.3
		Flat	9.0	2.0	2.0	7.0	
		Profiled	9.0	10.0	2.0	1.0	
	HMA	All	10.0	5.0	7.0	7.0	7.0
		Paint	10.0	10.0	9.0		10.0
		Thermo	10.0	9.0	9.0		9.0
		Tape	10.0	9.0	9.0		9.0
	PCC	All	9.0	5.0	7.0	7.0	7.0
		Paint	10.0	9.5	9.5	4.0	9.5
		Thermo	10.0	10.0	10.0		9.0
		Tape	8.5	10.0	10.0		9.0
		Epoxy	10.0	9.0	9.0	4.0	7.0
		Polyurea	10.0	9.0	9.0	4.0	7.0
	Surface Treatment	All	9.0	1.0	2.0	9.0	
Grinding	All	All	7.4	5.3	6.8	5.7	5.5
		Flat	9.0	4.0	1.0	10.0	
		Profiled	9.0	4.0	2.0	10.0	
	HMA	All	6.5	1.0	7.0	8.0	8.0
		Paint	10.0	2.0	5.0		7.0
		Thermo	10.0	2.0	5.5	6.0	6.5
		Tape	10.0	1.0	3.0		6.0
		Epoxy	8.0	5.0	1.0	10.0	10.0
		Polyurea	10.0	3.0	8.0	6.0	7.0
	PCC	All	6.5	1.0	7.0	8.0	8.0
		Paint	10.0	2.0	5.0		7.0
		Thermo	10.0	1.0	3.0		6.0
		Tape	10.0	1.0	3.0		6.0
		Epoxy	8.0	5.0	1.0	9.0	10.0
	Surface Treatment	All	6.0	10.0	2.0	10.0	
		Epoxy	7.7	7.0			8.0

Table 29. (Continued).

On a scale of 1-10 (1=poor, 10=excellent), rate the quality of the following pavement marking removal methods for each of the listed criteria.							
Type of Removal	**Pavement Type**	**Marking Type**	**Extent of Removal**	**Level of Scarring**	**Environment Impact**	**Cost Effectiveness**	**Production Rate**
Sand Blasting	All	All	7.0	6.0	2.5	5.5	5.0
		Flat	9.0	3.0	4.0	7.0	
		Profiled	9.0	10.0	4.0	1.0	
	PCC	All	8.0	2.0	1.0	5.0	1.0
		Paint	10.0	10.0	8.0		5.0
		Thermo	10.0	9.0	8.0		4.0
		Tape	10.0	9.0	8.0		4.0
	HMA	All	8.0	3.0	1.0	5.0	1.0
		Paint	10.0	10.0	9.0		5.0
		Thermo	10.0	10.0	9.0		4.0
		Tape	10.0	10.0	9.0		4.0
	Surface Treatment	All	9.0	1.0	4.0	9.0	
Shot Blasting	All	All	5.8				
		Flat	9.0	3.0	3.0	7.0	
		Profiled	9.0	10.0	3.0	1.0	
	Surface Treatment	All	9.0	1.0	4.0	9.0	
Combination of Blasting and Grinding	All	Flat	10.0	2.0	3.0	5.0	
		Profiled	9.0	2.0	3.0	9.0	
	PCC	All	6.0				
	Surface Treatment	All	9.0	1.0	4.0	9.0	
Masking	All	All	9.0	9.7	10.0	6.0	7.0
	HMA	All	8.0	9.0		6.0	7.0
	PCC	All	10.0				
	Surface Treatment	All	10.0				
CO_2 Blasting	All	All	9.0	6.0	8.0	1.0	1.0
Soda Blasting	All	All	9.0	9.0	2.0	1.0	1.0

the question seeking comments on removal satisfaction. It was again difficult to see any specific trends for a particular removal type on a specific surface or for a specific marking type. Some of the general comments for the specific removal types are summarized here. Grinding was noted to be fast but also the most damaging to the road surface, and because of this, its use was limited on final road surfaces unless the removed area was to be restriped. Water blasting was considered to be the most expensive but also caused the least damage to the road surface. It was indicated that water blasting is not as good on asphalt or surface treatments as it is on concrete, as it may remove some aggregate or fines. Shot and sand blasting were both noted as being slow and still may damage the road surface. The use of masking was limited, but when it was used, it was used to cover removed areas to blend them in with the surrounding pavement or as a temporary measure in work zones.

Costs and Removal Rates

A key factor to a pavement marking removal method being effective is that it is able to be conducted at a competitive cost as compared to the other methods. If the method is too expensive, it will be limited in use and thus will not be an effective technique. Table 33 provides the DOT responses to what are the typical pavement marking removal costs for the various methods, on various road surfaces, and for various marking types. Table 34 and Table 35 provide the local agency and other respondents' typical removal costs. One of the problems with removal cost information is that oftentimes, it is a single line item that does not take into consideration the type of removal, the road surface, or the marking being removed. This results in a single average for all types of removal. Another key factor is the size of the project; larger projects tend to have much lower unit costs than smaller projects.

The general removal costs that did not specify a removal type given in the DOT responses averaged approximately $1,900/line-mi. Looking at responses that specified removal types and gave an estimated removal cost resulted in the following. In general, the grinding was the least expensive, with a DOT average of approximately $2,000/line-mi. Water blasting was approximately 40 percent more expensive, at $2,750/line-mi. Though a much smaller sample size, shot and sand blasting were similar in price to grinding and water blasting at $2,050/line-mi and $3,150/line-mi, respectively. In addition

Table 30. DOT—comments on removal satisfaction.

Type of Removal	Status of Removal	Types of Pavements or Road Surfaces	Types of Marking Material Removed	Comments on Satisfaction with Results (Pros and Cons of the Removal Method)
Grinding	current	hot mix asphalt (HMA), PCC	paint, thermo, tape	Used on maintenance and construction projects.
Grinding	current	all	all	Fast, good removal, most damage. Hand grinders for short lines, trucks for long lines. Can be done well.
Grinding	current	PCC	paint, tape, epoxy	Causes additional damage to pavement, can cause grooving, creates dust.
Grinding			durable pavement markings	Permitted when another course of material is to be placed on the existing course.
Grinding	current			Leaves a scar, primarily use handheld units.
Grinding	used			Flailing style units only.
Grinding	used some			Don't care much if road is going to be resurfaced.
Grinding	used	all		Used only for grinding a slot for in-laid markings.
Grinding and Blasting	current	HMA, PCC	paint, thermo, tape	Used mainly on construction projects.
Grinding and Blasting	current	PCC	paint, tape, epoxy	Causes additional damage to pavement, can cause grooving, creates dust.
Water Blasting	new	all	epoxy	Expensive, leaves nicest, cleanest finish.
Water Blasting	current	PCC	paint, tape, epoxy	Concentrated water slurry can pose problems for trout streams.
Water Blasting	current	AC/PCCP		Least damage to pavement; more environmentally friendly than sand blasting.
Water Blasting	new			Messy results from using a system that did not have a vacuum recovery.
Water Blasting	never used			Takes too long for pavement to dry.
Sand Blasting	new	all	epoxy	Slow, too long in one place can damage surface.
Sand Blasting	current	PCC	paint, tape, epoxy	Creates dust.
Sand Blasting	current			Leaves a scar.
Sand Blasting	used	all	epoxy, paint	Adequate for removal without ruining the pavement surface.
Shot Blasting	current	HMA, PCC	paint, thermo, tape	Used mainly on construction projects.
Shot Blasting	new	all	epoxy	Slow, too long in one place can damage surface.
Shot Blasting	current			Used frequently.
Masking	infrequent			Not allowed for permanent applications. Can use black tape on asphalt for temporary lane shifts, not generally recommended. Can use after removal to help hide scar and discoloration. Lots of complaints from grind markings, helps to black-out after.
Masking	allowed			Good for use in work zones.
Masking	limited use			Allowed for temporary purposes only.
Other: Burning				Burn temp tape off asphalt.
Other: Burning	current	PCC	paint, tape, epoxy	Poor aesthetics, dangerous.

Table 31. Local agency—comments on removal satisfaction.

Type of Removal	Status of Removal	Types of Pavements or Road Surfaces	Types of Marking Material Removed	Comments on Satisfaction with Results (Pros and Cons of the Removal Method)
Grinding	used by city and contractors	asphalt and concrete	paint and thermo	Time consuming with hand grinders, messy. Use both rotary and drum grinders.
Grinding				Can be damaging, rotary systems have better results.
Grinding	most common	older pavements		Does scar the road, depends on experience.
Grinding Only	current	concrete, asphalt	thermo, paint	Pro—little debris issue, swept up. Con—breakdown, maintenance of grinders.
Grinding	currently used	all	all	Does not work well on micro or slurry seals. Not all employees are good at operating the equipment. Dust can be a problem, as can the removed material and road surface material. Slow.
Grinding		asphalt and concrete	paint, epoxy, plastic	With walk behinds it is a slow process but is a better way to make sure all the product is removed.
Grinding	currently used	PCC	Thermoplastic	Although this seems to be the fastest and most cost-effective way to remove markings, I do not like the nighttime and wet condition appearance.
Grinding	current	concrete, asphalt	polyurea and plastic tape	Uneven and rough surfaces after removal, trouble removing glues.
Grinding	current	asphalt, concrete	thermo, paint, MMA	Tough to remove on concrete.
Grinding	current	concrete, asphalt	paint, thermo and tape	Pros—mobile units with easy access to different locations. Cons—scarring to the existing pavement.
Grinding	current	concrete, asphalt	thermo, paint, preformed thermo	Great results on all except asphalt, hard to grind without taking chunks up. Can be done but have to be really easy with it.
Grinding	current	concrete, asphalt	thermo, polyurea, paint	Contractor is told to keep removal as precise as he can to eliminate grind "sheen."
Water Blasting	have used		mostly thermo	Left some scarring on asphalt causing damage to the road surface.
Water Blasting	experimental	asphalt and concrete	thermo	Great on concrete, chipped away some asphalt. Removed a lot of aggregate on surface treatment. Great on PCC, good on HMA.
Water Blasting	have requested its use	new pavements		New surfaces only, best results so far. Does not scar and can be faster than grinding.
Sand Blasting	contractors only	asphalt and concrete	paint and thermo	Contract out only, results seem good.
Sand Blasting	used in the past			Had issues and stopped using, slow, EPA issues.
Shot Blasting	not used often	concrete, asphalt	tape and paint	Trouble with thick layers and glue.
Masking Using Black Paint	rarely used	asphalt		Used as a temporary fix.
Masking	current	asphalt		Permanent black tape to cover some lines. Black paint used to cover remnants from some line removal as to not cause scarring of the road surface.
Masking				Used temporarily, 3 months or less using black tape.
Masking	experimental	concrete, asphalt	tape and paint	Inconsistent with other markings, wears off.
Masking Using a Slurry Seal	sometimes used	asphalt		Have tried 3-foot seal on lane lines when moving them over, results are good so far.

Table 32. Other respondents—comments on removal satisfaction.

Type of Removal	Status of Removal	Types of Pavements or Road Surfaces	Types of Marking Material Removed	Comments on Satisfaction with Results (Pros and Cons of the Removal Method)
Grinding	current	HMA, PCC	paint, epoxy	Depends on the thickness of material and substrate.
Grinding	current	HMA, PCC	paint, epoxy	Slightly faster and more cost effective than water blasting.
Grinding	current	HMA, PCC	all	Typically will result in a grooved pattern in the roadway where the marking was removed.
Mechanical Erasing	current	HMA, PCC	all	The circular rotation of the cutting head leaves a finish that does not have sharp edges like grinding.
Water Blasting	current	HMA, PCC	paint, epoxy	Depends on the thickness of material and substrate.
Water Blasting	current	all	all	Best removal and finish. Equipment is expensive to maintain. Can change spray head configuration to be more or less aggressive depending on the removal needs.
Water Blasting	current	HMA, PCC	tape, thermoplastic	Less scarring than grinding.
Water Blasting	current	HMA, PCC	all	Performs best on concrete, will remove fines from asphalt. Removes non-durable markings best, thermo and tapes are more difficult to remove.
Water Blasting	current	HMA, PCC	paint, epoxy	Less scarring than grinding, cleaner operation than grinding.
Sand Blasting	current	HMA, PCC	paint	Slow, containment of blasting material is expensive, only works well on paint.
Shot Blasting	current	HMA, PCC	paint	Only works well on flat surfaces, only works well on paint.
Mixed Media Blasting with Dry Ice	experimental	all	paint, thermoplastic, tape	Pros: small machines, pull behind compressor needed, very little secondary waste, easy to contain and clean up, limited damage to road surface, no moisture added. Cons: road needs to be dry, not useable in rain or snow when it's wet.
Masking	experimental	HMA, PCC		Temporary purposes.

to the survey responses, the research team looked at available DOT bid price sheets to try to get an estimate of the various removal costs. The research team found 17 states with a general pavement marking removal average bid price of $2,194/line-mi, and 2 states with a water/hydroblasting removal average bid price of $2,467/line-mi. These bid items are in agreement with the average responses from the survey.

Another key factor to a pavement marking removal method being effective is that it is able to be conducted at a reasonable speed as compared to the other methods. If the method is too slow, it will be limited in use and thus will not be an effective technique. Table 36 through Table 38 provide the responses to what the typical pavement marking removal rates are for the various methods, on various road surfaces, and for various marking types. In general, grinding is faster than the blasting methods. Thinner, less durable markings can typically be removed faster than thicker, more durable markings. Using multiple removal devices in a series may increase the removal rate when removing thicker markings.

The researchers wanted to know if a specific production rate was necessary to meet state pavement marking removal specifications, see Table 39. Only one of the responding states indicated a specified removal rate, and it was the only state specification of all 50 that specified a rate. This rate was 80,000 lf per night of work, which is approximately 15 line-mi. This rate seems quite high, which may limit which techniques can be used to remove the markings. One manufacturer indicated it had a specified removal rate but did not indicate a value.

Table 33. DOT—typical removal costs.

What are the typical removal costs, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Cost**
			Prices vary due to the construction quantities
All	All	All	$1.50/sq ft
Weighted average for all types of PM removal			$0.60/sq ft
All			Avg $1267.2/line-mi ($0.24/lf)
All	All		Approx $1206/line-mi ($0.2285/lf)
Any	PCC	Any	$3850/line-mi
All			$1214.4/line-mi ($0.23/lf)
Bid item for marking removal	All	All	$1953.6/line-mi
All	All	All	$1108.8/line-mi ($0.21/lf)
Overall avg.			$1800/line-mi
General removal of permanent marking (all removal and markings combined)			$1742.4/line-mi ($0.33/lf)
Removal of temporary markings (paint removal)			$1214.4/line-mi ($0.23/lf)
	All	Paint	$2112/line-mi
	All	Thermo, Tape, MMA	$2851/line-mi
	All	All	$2376/line-mi ($0.45/lf)
Hand grinder			$4.15/sq ft
Truck-mounted grinder			$2376/line-mi ($0.45/lf)
Grinding			$634-$792/line-mi ($0.12-$0.15/lf)
Grinding	Concrete, Bituminous		$1848/line-mi ($0.35/lf)
Grinding	HMA	Paint, Thermo	$2060/line-mi for 4-inch line
Grinding	Concrete, Asphalt	Paint, Polyurea, Tape, Thermo	$1584/line-mi ($0.30/lf)
Grinding	All	All	$1425.6/line-mi
Grinding	Chip Seal, Class I-1, Modified Friction Course	Epoxy	$158.4/line-mi or $0.03/lf
Grinding	Concrete or Asphalt	Paint, Thermo, Tape Epoxy, Polyurea, MMA, Multi-Component	$1320/line-mi
Grinding		Solid Paint	$958-$2192/line-mi
Grinding		Broken Tape	$3300/line-mi
Grinding		Solid Tape	$6700-$7200/line-mi
Grinding or Shot Blasting	HMA, PCC	Paint, Thermo, Tape	$3960/line-mi ($0.75/lf)
Shot Blasting	Concrete, Bituminous		$2376/line-mi ($0.45/lf)
Sand Blasting	Concrete, Bituminous		$2376/line-mi ($0.45/lf)
Sand Blasting	All	Liquid Marking	$1742.4/line-mi
Water Blasting			as low as $264/line-mi ($0.05/lf) for very large district-wide contract, not cost effective for small jobs due to mobilization fees
Water Blasting	Concrete	Paint, Polyurea, Tape	$2640/line-mi ($0.50/lf)
Water Blasting	Concrete, Bituminous		$2376/line-mi ($0.45/lf)
Water Blasting			up to $5280/line-mi ($1.00/lf)
Water Blasting	Concrete or Asphalt	Paint, Thermo, Tape Epoxy, Polyurea, MMA, Multi-Component	$1636/line-mi
Water Blasting	HMA, PCC	Thermo, Tape	$1850/line-mi

Table 34. Local agency—typical removal costs.

What are the typical removal costs, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Cost**
Grinding	Concrete/ Asphalt	Thermo/Paint	We own the grinders and estimated grinder cost per job based on the employee working. These rates vary based on the pay rate of the employee.
Grinding	All	All	$5280/line-mi ($1.00/lf)
Grinding	Asphalt, Concrete	Thermo	$3960/line-mi ($0.75/lf)
Sand Blasting			$23,760/line-mi ($4.50/lf) not including lane closure and mobilization fees, smaller project and change order (not a project put out for bid).
Water Blasting			$4752/line-mi ($0.90/lf). Larger quantity and bid out compared to sand blasting. Contractor incurred additional fee for water disposal and indicated future cost would be slightly higher.
Grinding	All		$11,510/line-mi ($2.18/lf 4 inches)
Lane Lines, Traffic Arrows, Crosswalks	Asphalt, Concrete	Waterborne Paint, Oil-Based Paint, Epoxy, Thermo	($0.75/lf) in-house projects. Epoxy and plastics $1.10/lf including labor and equipment.
Grinding	Asphalt	Thermoplastic	$2.00/sq ft (symbol or word $5 each)
Grinding	HMA, PCC	Polyurea, Tape	$5280/line-mi ($1.00/lf)
Grinding	HMA, PCC	Paint, Thermo, Tape	$5280/line-mi ($1.00/lf)

Environmental and Worker Safety Concerns

The environmental impact of pavement marking removal is something that should be considered when determining the most effective method. Removal can generate dust, limiting visibility for nearby drivers, or produce waste that may require special containment and disposal. Table 40 through Table 42 indicate some of the environmental concerns from different pavement marking removal processes as well as techniques used to reduce the impacts. Sweeping and vacuuming as well as wet removal are methods used to combat dust and collect the removal debris. Wet removal may be limited in colder weather due to the chance of freezing. All materials are required to be properly disposed of. The state specifications indicate that 19 states require equipment to contain dust and debris especially when conducting removal within 10 ft of an occupied lane. An additional 14 states require the prompt removal of dust and debris as the work progresses.

The safety of workers conducting pavement marking removal is another aspect that should be considered when determining the most effective method. Table 43 through Table 45 indicate some of the worker safety concerns from different pavement marking removal processes as well as techniques used to reduce the impacts. Removal can generate dust that may be inhaled. The removal equipment may generate flying debris that could strike a worker or vehicles/pedestrians passing by. The removal of certain markings may produce hazardous material. Removal can also be noisy for the operators and the general public. Wet removal may be limited in colder weather due to the chance of freezing causing areas where ice could form. Traffic hazards and

Table 35. Other respondents—typical removal costs.

What are the typical removal costs, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Cost**
Water Blasting	HMA	paint	$1850/line-mi
Water Blasting	PCC	epoxy	$2375/line-mi
Grinding	HMA	epoxy	$2150/line-mi
Grinding (Flailing)	HMA or PCC	thermo, paint, epoxy	$792-5280/line-mi
Water Blasting	HMA or PCC	thermo, tape	$5280/line-mi
Mixed Media Blasting with Dry Ice	all	paint	$6494/line-mi

Table 36. DOT—typical removal rates.

What are the typical removal rates, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Rate**
All	All	Paint, Urethane, Polyurea	4 line-mi/day
All	All	Thermo, Tape	5 line-mi/day
Any	PCC	Any	1-3 mi/day
			Rates vary and technology is improving constantly
			Aware of grinding trucks at 4 mph
Grinding	Concrete, Asphalt	Thermo	40-50,000 lf/day
Grinding	Concrete, Asphalt	Paint	50-70,000 lf/day
Grinding			2-4 mph, 1 truck goes slow, multiple trucks go faster. Profiled lines are slower due to their thickness.
Walk grinder	HMA & PCC	Tape, Paint, and Thermo	0.5 mi/shift (6-8 hr)
Vehicle grinder	HMA & PCC	Tape, Paint, and Thermo	1.5 mi/shift (6-8 hr)
Water Blasting	Concrete, Asphalt	Tape, Paint, Polyurea, Epoxy, Thermo	10,000 linear ft/day
Water Blasting	HMA, PCC	Thermo, Tape	Line miles of 10 ft skips in one 8 hr shift

Table 37. Local agency—typical removal rates.

What are the typical removal rates, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Rate**
Grinding	Concrete/Asphalt	Thermo/Paint	500 lf/day
Grinding	Asphalt, Concrete	Thermo	5 min/ft
Grinding	All	Paint, Thermo	123 lf/hr
Grinding	Asphalt, Concrete	Paint	1-5 mi per day. Walk-behind machine only 10 ft every 6 min.
Grinding	Asphalt	Thermoplastic	15 min/sq ft
Grinding	HMA, PCC	Polyurea, Tape, Paint	5 min/100 ft
Grinding	HMA, PCC	Paint, Thermo, Tape	2000 ft/day for 4 inch line
Shot Blasting	HMA, PCC	Polyurea, Tape, Paint	8 min/100 ft or less

Table 38. Other respondents—typical removal rates.

What are the typical removal rates, listed by removal technique/road surface type/marking material?			
Type of Removal	**Type of Pavement**	**Types of Marking Materials Removed**	**Estimated Removal Rate**
Water Blasting	HMA or PCC	epoxy	2-3 mi per day
Water Blasting	HMA or PCC	paint	3-5 mi per day
Grinding (Flailing)	HMA or PCC	thermo, paint, epoxy	0.5-2 mi per day
Mixed Media Blasting with Dry Ice	All	paint	720 ft per 8 hr day

Table 39. DOT—specified removal rate.

Does your organization specify a production rate for pavement marking removal? If yes, please explain.	**Number of Responses**
Yes	1
No	15
Comments:	
Yes. 80,000 lf/night.	

Table 40. DOT—environmental concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Environmental Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process
All	All	All	Dust for workers and drivers	Vacuum dust control.
All	All	All	The removal of these materials is always a concern.	The disposal of these materials is always a concern.
All	All	All	Waste disposal	May require vacuum or debris removal systems. Proper waste disposal technique.
Grinding	All	All	Dust problems, lead pigment	Require wet removal or vacuum for dry, cannot create dust, contain all waste, HEPA methods.
Grind	HMA, PCC	Epoxy	Solid waste	Waste material becomes the property of the contractor. Dispose of waste material according to current applicable solid waste laws and regulations.
Grinding	Concrete, Asphalt	Tape, Paint, Polyurea, Epoxy, Thermo	Lead or heavy materials in the beads	We require a truck vacuum to be used in the removal operation.
Grinding	Chip Seal, Class I-1, Modified Friction Course	Epoxy		Sweeping behind grinding truck. Vacuum and dust collector must be 99.99% dust free and removed particle no bigger than 0.5 microns.
Grinding	All	All	Dust control mitigation, water quality issues when crossing waterways, disposal of grindings	Dust control and proper landfill.
Grind	HMA, PCC	Epoxy	Solid waste	Waste material becomes the property of the contractor. Dispose of waste material according to current applicable solid waste laws and regulations.
Grinding		Thermo		Sediment control/turbidity type barrier to prevent water quality or other environmental concerns.
Grinding			Noise	
Grinding and Sand Blasting			Debris runoff, particularly near water	
Grinding and Sand Blasting	PCC	All	Fugitive dust is an issue when working in areas with limestone aggregates in the pavements.	
Grinding and Sand Blasting	All	Liquid Markings	Air quality	Connection of removal equipment to an airbag vacuum system or use of a power pickup broom to collect material to be disposed of.
Sand Blasting		Paint, Thermo		Lead is not used in traffic marking material.
Sand Blasting	All	All	Dust problems, lead pigment	Require wet removal or vacuum for dry, cannot create dust, contain all waste, HEPA methods.
Shot Blasting			Noise	
Water Blasting		Paint, Thermo		Accumulated piles of debris should be removed and disposed of in accordance with applicable federal, state, and local regulations.
Water Blasting	PCC	All	Concentrated slurry must not be allowed to reach trout streams and other sensitive water bodies.	

Table 40. (Continued).

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Environmental Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process
Water Blasting	HMA, PCC	Thermo, Tape	Older thermoplastic may contain lead.	Contractors sometimes required to arrange for environmental assessment of old thermoplastic.
Chemical			May have issues if not EPA compliant.	
			We call for removed solid material to be disposed of appropriately.	
				Try to collect as much material as possible with vacuum and sweeper trucks.
				We use all lead-free pavement markings.
				Chemicals are not used to remove traffic markings.
				General waste needs to be removed and properly disposed of. Broom sweep up debris with a truck. All lead-free markings.
			Only environmentally friendly pavement marking materials are used. So our primary concern would be with cleanup of removal debris, particularly along closed (curbed) sections of roadway.	Our eradication specification requires that the contractor collect and properly dispose of all debris associated with the removal process.

Table 41. Local agency—environmental concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Environmental Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process
Grinding	Concrete/Asphalt	Thermo/Paint	Debris left behind	We sweep up 100% of debris.
Grinding	All	All	Air quality	Vacuums do not work.
Grinding	Asphalt, Concrete	Thermo	Lots of dust	Gas blower.
Torch	Asphalt, Concrete	Tape	Lots of smoke	Prefer to do this work on a windy day.
Water Blasting			Where they were going to dump in the water?	They ended up dumping water at an airport facility, not sure about where solids went.
Grinding	All	Paint, Thermo	Contain grinding spoils and prevent from entering storm/sewer systems.	Protect catch basins and sweep and dispose of spoils.
Sand Blasting			Debris entering bridge drainage. Need to remove debris before getting into drainage system. Lead chromate exposure found to not be high enough level during removal of thermo, so we do not think removal will be bad.	
Grinding	Asphalt, Concrete	Epoxy, Plastics	Bad fumes and dust, employee safety	
Grinding	HMA, PCC	Polyurea, Tape, Paint	Dust and debris	Vacuum and masks.
Grinding	HMA, PCC	Paint, Thermo, Tape	Dust and stormwater contamination	Sweeping and vacuuming.
	HMA/PCC	Letters, Symbols, Lines		We have the contractor sweep or blow grindings to gutter to keep vehicles from slipping on grindings.

Table 42. Other respondents—environmental concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Environmental Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process
Water Blasting	PCC	Epoxy	Debris run off.	Use vacuum assist.
Grinding	PCC	Epoxy	Airborne silica.	Use vacuum assist.
Water Blasting	All	All	Debris or dust.	Using water for removal results in no dust, and the high-powered vacuum system collects the excess water and debris leaving the surface clean.
Sand Blasting	All	Durable	Sand is hazardous to breath and difficult to contain.	
Shot Blasting	All	Durable	Difficulty to contain shot on uneven surfaces, and a liability on air fields.	
Grinding	All	All	Dust and debris generated from removal.	Use a dust containment system to reclaim removed materials.
Glass Blasting	All	All	Dust and debris generated from removal.	Vacuum up glass and debris. Glass is separated and reused multiple times. Glass can be recycled and the debris is sent for proper disposal.
Water Blasting	All	All	Large amounts of water needed, freezing water on road surface.	
Grinding	All	All	Road scarring.	

Table 43. DOT—worker safety concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process
All	All	All	Proper work zone traffic control is to be maintained. The removal waste must be contained and properly disposed. Workers must be properly protected according to the department's policies or their company's safety plan.	Proper protection (i.e., clothing, footwear, ear, eye, and breathing) is always a must when any type of removal operation is performed.
All	All	All	Work zone exposure.	Proper work zone safety practices.
Grinding	All	All	Noise.	Hearing protection.
Grinding	All	All	Dust is a concern for both traffic and worker safety.	Wear respirators unless proper dust control system.
Grinding	HMA, PCC	Epoxy	N/A	Reduction of airborne dust.
Grinding	All	All	General public concerns are noise of grinding operation.	Attempt to schedule grinding work in residential areas such that inconveniences to public is minimized (i.e., no removal during bedtime hours).
Grinding and Sand Blasting	All	Liquid Markings	Traffic hazard from dust.	Connection of removal equipment to an airbag vacuum system.
Grinding or Shot Blasting	HMA, PCC	Paint, Thermo, Tape	Inhalation of dust from marking removal.	Workers wear personal protection equipment (PPE) to reduce inhalation of dust.
Water Blasting, Sand Blasting, Grinding			Traffic hazards, noise, use of equipment.	Proper maintenance of traffic (MOT) set up. Use personal safety equipment.
Sand Blasting	All	All	Reduced visibility and noise.	Hearing protection.

Table 43. (Continued).

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process
Pulling Type R Tape, Grinding, Blasting			Noise, heavy equipment, traffic hazards.	
				Limit worker exposure to traffic. Use TMAs. Keep workers behind barrier if possible.
			All methods related to typical noise, equipment and work zone hazards.	Typical to all organizations.
			Dust control, especially at night.	Use water sprayers to reduce dust. Some use rain days to remove pavement markings.
			Flying debris from the eradication process must be contained to avoid injury or damage to pedestrians or vehicles.	Good MOT and PPE.
			Worker safety is always a concern, particularly when hand machines are used in close proximity to heavy traffic.	Good MOT and PPE.
			Water blasting during winter months has potential to cause freezing road surfaces.	
			Dust.	Water to keep dust down.
			Exposure to traffic.	Faster is better to get off road and complete traffic shifts.

Table 44. Local agency—worker safety concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process
Grinding	HMA, PCC	Thermo/ Paint	Working in traffic, noise, eye damage, dust, air quality	Set up safe work zones, ear/eye protection, dust masks.
Grinding	All	All	Dust in air causes driver confusion	Blow dust off road.
Grinding			Air quality	Masks.
Sand Blasting			Overspray	Require vacuum.
Grinding	All	All	Traffic control, safe work zones	We use our vehicles for added safety, blocking inside of zones. Use lights and arrow boards and traffic cones. Use safety gear, glasses, ear plugs, gloves, vests, and hardhats.
Grinding	HMA, PCC	Polyurea, Tape, Paint	Dust breathing	Masks, boots/pants.
Grinding	HMA, PCC	Paint, Thermo, Tape	Employees are exposed to moving traffic and weather	Safety equipment (sign boards, cones, PPE).
Grinding	HMA, PCC	Thermo, Polyurea	Vehicles entering work area, vehicles or peds slipping on grindings	Sweep or blow grinding off pavement.

Table 45. Other respondents—worker safety concerns.

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process
Shot Blasting	PCC	Paint	Shot being projectiles	Ensure equipment is properly maintained with good seals
Water Blasting	Asphalt	Durable	Water and freezing temperatures may have issues	
Mixed Media Dry Ice Blasting	All	Paint	Noise, breathing residue	PPE: safety glasses, mask, hearing protection

the operation of equipment are always safety concerns. Sweeping and vacuuming as well as wet removal are methods used to combat dust and collect the removal debris. If dust is present, respirators should be worn. Limit worker exposure to traffic by following proper traffic control, wearing appropriate safety gear, and using techniques that get the job done faster.

Past Removal Experiences

Table 46 and Table 47 display general feedback that the respondents had received from public comments. Scarring of the pavement and inadequate removal leading to driver confusion are major concerns expressed by the public. Typically, the comments were received only when the removal was not very good. The noise of the removal and the dust and debris generated were also included in the negative comments received. Several comments also mentioned that public complaints had been received suggesting poor pavement marking removal is evident under certain conditions, such as low sun angles on east-west roads and wet-night conditions.

Table 48 through Table 50 provide comments on past pavement marking removal experiences. The comments bring up several points that need to be considered in this research. Factors such as reflection of sunlight off black masking may result

Table 46. DOT—public comments.

Have you received any public comments about the removal of markings? If yes, please describe the types of comments (indicate whether the comments were positive, negative, or mixed).	**Number of Responses**
Yes	13
No	14
Comments:	
Yes. We recently had a significant project on an east-west interstate where we were changing the lane configuration significantly. There was a lot of public concern about confusing lines and scars until the resurfacing was completed.	
Yes. All comments are negative.	
Only negative when removal scars are confusing.	
Not many complaints. Interstate work done at night mostly.	
I-235 traffic shifts created lots of ghost markings. Diamond ground to correct.	
Yes. Perfect jobs generally go unnoticed. Poorly applied work sticks out like a sore thumb, and that's when the complaints start rolling in.	
Comments vary, but usually are negative and related to noise or unclear guidance/delineation through construction zones.	
Yes. Only when the markings are confusing. Usually due to poor pavement marking removal.	
No. Just hear about finished product, not actual removal on the project.	
Yes. Comments usually occur when markings are not adequately removed and delineation of vehicle path is not clear. If this occurs, corrections are promptly made.	
Yes. Ghost marking issues with scarring confusing drivers. Scarring issues depend on the time of day due to sun angle. We've started grinding wider to help reduce confusion. We've also covered scars with black slurry or paint on asphalt roads.	
Yes. We have received some negative comments regarding removal marks, which can cause driver confusion due to glare of sunlight at dawn/dusk.	
Field offices would be the ones to receive comments from the public, and I haven't heard of any from them.	
Removal of markings in a lane shift resulted in confusion to drivers heading eastbound when the sun was low on the horizon. Likely due to a deeper than ideal depth of removal.	
Occasionally we will receive complaints from drivers who mistake the removed markings for existing markings. This seems to be a particular problem after traffic switches during construction staging, particularly during wet-night conditions.	

Table 47. Local agency and other respondents—public comments.

Have you received any public comments about the removal of markings? If yes, please describe the types of comments (indicate whether the comments were positive, negative, or mixed).	Local Agency	Other
Yes	7	1
No	9	5
Comments:		
Yes. Most comments are positive; never an issue with removal, but most citizen concerns deal with "why" markings are gone, not "how."	☑	
Yes. Complaint on heavy scarring from a project. Positive remarks from bike lanes shifts using slurry seal.	☑	
Yes. Citizen felt we should do this at night time.	☑	
Yes. However, we rarely receive any public comment.	☑	
Yes. Drivers confused by poor removal.	☑	
Yes. We regularly get positive feedback from citizens or local contractors. They always say, "Wow, that's how that is done," and how they think it is so amazing that we can remove the markings in a very short time and leave very little damage to the roadway.	☑	
No. The Streets Operations Division does not like the scarring caused by the removal, as it compromises the integrity of the street.	☑	
Yes. Dust and debris are messy and unpleasant.	☑	
Yes. Water blasting—positive. Grinding—negative.		☑

Table 48. DOT—past pavement marking removal experiences.

Please describe past pavement marking removal experiences (either good or bad) that may be of benefit to this research.
Comments:
The DOT is still looking at black tape to cover conflict markings. There are concerns with sunlight reflecting off the black tape and with the tape unraveling under traffic exposing the conflict marking underneath.
Some type R tape does not peel, and then it has to be ground off. Too much exposure of workers to traffic and vice versa.
We like water and grinding. Shot blasting and sand blasting are too messy. CO_2 and soda blasting are too slow.
Ghost lines 4 years later on PCC. Motorists have followed ghost lines on that part. Water blasting can make aggregate shine.
I-235 project was bad. Best technique = water blasting with good operator. Cannot use water blasting in freezing weather.
Somewhat limited. We've only done water blasting with contractor-owned, truck-mounted equipment, and we've only done sand blasting and grinding with hand machines.
We have done a trial on in-laid grinding and have found that in those areas the life cycle of the line was longer. However, we have yet to adopt some sort of specification for that type of grind.
Water blasting on asphalt damages the asphalt when removing the surface lines.
Deep scarring from water blasting (operator error or equipment issue). Cracking of black-out techniques. Rotary grinding method seemed good.
When properly performed, water blasting is the quickest (less exposure time) method, and costs have been competitive with the other approved methods of removal.
Good—in the summer, water blasting works for one pass ready to install, where grinding you have to sweep and high-pressure air the area to install. Bad—we had multiple issues with grinding too deep, but training the contractor of what we expect is something we have been working on.
A few years back, a contractor grinding away a pavement marking went too deep (approx. 1 in.).
Good experience with hydroblasting. Some good experiences with long-line truck grinding.
Painting over existing pavement markings to obliterate them will not be permitted.
We are using grooving for temporary removal of permanent skip lines so that when skip lines are returned to permanent condition, the removal groove provides a good location for permanent durable tape. For temporary lane lines, we are using temporary preformed tape.
Place a lot of markings recessed in grooves so most removal will leave grooves.
Removal near joints can be problemsome. Need to avoid being near the joints to avoid unraveling the asphalt joint or breaking off of concrete.
Just a general feeling that scarring is a reality for which there isn't a solution.

Table 49. Local agency—past pavement marking removal experiences.

Please describe past pavement marking removal experiences (either good or bad) that may be of benefit to this research.
Comments:
Deep scarring from water blasting (operator error or equipment issue). Cracking of black-out techniques. Rotary grinding method seemed good.
We don't use water blasting—too messy. Water mixed with material has to flow somewhere, and this is not environmentally safe. We've always used the grinder method of removal.
Blacking out marking with black paint is a temporary fix.
It's preferred to not have to remove markings. If markings are removed it should be done in a way that is the least noticeable and the least intrusive.
Like doing removal in the rain to keep dust down.
Water blasting impacted the asphalt.
Deep scarring can cause rumble effect. Sand blasting on a bridge was expensive, messy, and slow.
We do all of our surface removal with walk-behind scarifier machines. Up to 10-inch wide paths with carbide and steel grinding teeth, we erase approximately 1-20 miles per year. This varies from year to year.
After 25 years of being in the business of pavement markings, I have found there to be no better way to remove markings than sand blasting.
Shot blasting can be dangerous sometimes because beads become projectiles.
Sand blasting was way too messy. We did not like it.
Not grinding the marking completely allows the buildup of thermoplastic, which during snow season the plow trucks are able to remove markings with plow blades.

Table 50. Other respondents—past pavement marking removal experiences.

Please describe past pavement marking removal experiences (either good or bad) that may be of benefit to this research.
Comments:
For water blasting, the fastest removal is on PCC; since the surface is hard, the system can be set aggressively. On asphalt surfaces some surface fines will be removed. The thicker the marking, the more fines that will be removed. Conducting removal in hot temperatures will increase fines loss as well since the surface is softer. Staggering the removal heads slightly can reduce some scarring.
Water blasting has issues on asphalt surfaces. Using the incorrect cutter on grinders (scarifier or mechanical eraser) will create the wrong type of surface texture. Operators that are not properly trained on the equipment will cause pavement problems.

in a contrast difference with the surrounding pavement. Similarly, water blasting may cause the tops of aggregate to shine. The skill of an operator and the types of heads used on grinding equipment can be major factors in the quality of marking removal and the resulting surface characteristics. One comment considers sand blasting the best method, whereas others consider it too messy. Several respondents commented on scarring damage caused by grinding. Positive and negative comments were also received with respect to water blasting. The biggest issue with water blasting seems to be that on asphalt surfaces, some asphalt binder and aggregate may be removed along with the marking material.

The researchers' final question on the survey was to find out if any of the respondents had any knowledge of any other research projects that have evaluated pavement marking removal. In total, four respondents indicated that they were aware of other pavement marking removal research, whereas 40 indicated they were not. The respondents provided the material or a link to the material so that the research team could review the research. The information provided was included in the literature review.

That concludes the summary of the responses to the survey. The survey allowed the research team to gather information on the current state of the practice across the United States and to use the collected information to further the research effort. The information gathered from the survey and the review of literature was used in developing the field removal portion of the study as well as in developing the findings and recommendations.

CHAPTER 5

Field Study Design and Evaluation

As part of this research project, the removal of pavement markings was studied in the field. The field study consisted of two different study types. The first study type was controlled pavement marking removal evaluations where the researchers controlled the marking types, road surfaces, and removal methods used. The second study type was the evaluation of pavement marking removal operations as part of planned highway maintenance or construction as they occurred or after they were recently completed. The field study design and resulting field evaluations are described in this chapter.

Removal Combinations to Evaluate

The removal combinations that were evaluated were based on combinations of the type of removal process, type of marking material, and type of road surface. The general idea was to test some of the most commonly removed marking materials on the most typical road surfaces. The removal processes that were tested were some of the most commonly used methods and those that show the most promise to be an effective means of marking removal. It was not feasible to evaluate every type of pavement marking removal, on every road surface, for every type of pavement marking during this research project. The survey and various pieces of literature that were reviewed served as the sources of information on marking materials, road surfaces, and removal types that should be considered for evaluation. The survey and literature also supplemented the results of the field study for removal types, road surface types, and material types that were not evaluated. The project panel also provided guidance on what pavement marking removal techniques to evaluate.

Responses from the survey indicated the most common forms of marking removal and on what types of markings. Both the water blasting and grinding methods were very common among the responses, with no responses indicating that these methods were no longer used. The use of shot blasting and sand blasting were also indicated in some of the responses, but it was also indicated in several other responses that these methods are no longer used. A combination of grinding and blasting was indicated by only a few survey responses, but this method may offer an effective means of marking removal. From the survey, the respondents indicated that their preferred removal techniques seemed to be either water blasting or grinding. Some survey respondents also indicated that their preferred method, which sees limited use due to other factors (typically cost), was water blasting.

The survey responses also indicated the combinations of road surfaces and pavement markings where removal occurred. Asphalt and PCC road surfaces had many more responses than did surface treatments. Paint and thermoplastic were the two marking materials with the highest frequency of removal, which makes sense since they are by far the two most common marking materials. Tape and several plural component markings (epoxy, polyurea, and urethane) were also indicated by several responses.

Ideally, all road surface types would be evaluated for some of the marking types that are typical on each. The most common pavement marking types were evaluated, as was temporary tape since it is often used in work zones. The temporary tape evaluation was based on a review of data from the NTPEP. The data and discussion are included in Chapter 6. Table 51 presents the combinations of marking materials and road surfaces used to conduct the field study. The Y in the table indicates that the listed combination of road surface type and pavement marking type was evaluated. The areas with a dash were not evaluated because these situations are less common. The marking removal methods that were evaluated are as follows:

- Grinding:
  - Carbide tipped drum, flailing, full-size truck-mounted system.
  - Carbide tipped drum, flailing, hand-operated system.
  - Carbide tipped rotary/orbital flailing system, mounted to skid steer.

Table 51. Combinations of marking materials and road surfaces to evaluate.

Road Surface Type	Pavement Marking Material Type				
	Paint	Thermoplastic	Plural Component	Permanent Tape	Temporary Tape
Asphalt	Y	Y	-	-	Y
PCC	Y	Y	Y	Y	Y

- High-pressure water blasting, current state-of-the-art full-size truck system.
- Combination testing.

The combination testing was a light pass from the full-size flailing truck followed by the high-pressure water blasting. This combination system was intended to take advantage of the pros of the two systems while minimizing the cons.

Criteria to Measure the Effectiveness of Removal Techniques

The effectiveness of pavement marking removal can be established in several ways, and thus a compromise of the various measures will be needed to determine which method is truly the most effective removal technique for a given situation. Based on various factors for each given situation, the impact of each of the measures that affect the effectiveness of a removal technique may vary. The measures for which the effectiveness of pavement marking removal can be established are the following:

- Quality of the actual marking removal itself:
  - Scarring depth.
  - Changes to the roadway surface characteristics.
  - Percentage of marking material removed.
  - Retroreflectivity characteristics.
- Speed at which the marking is removed.
- Cost of the marking removal.
- Environmental impact.
- Availability of the removal equipment.
- Required skill of the operator and room for operator error.

In the survey, respondents were asked if they had any measures of effectiveness to determine the quality of marking removal, such as amount of scarring to the pavement, amount of marking material remaining, and damage to joints or sealer. Most responses indicated that there were no measures used and that only a subjective evaluation was conducted. Subjective evaluation of the removal quality is not ideal compared to a quantitative measure since a quantitative measure should be equitable and repeatable. Developing a quantitative measure of the removal quality was brought up in the survey responses as something that would be beneficial.

Depth of scarring is one of the factors that will affect the quality of the removal and thus the effectiveness of the removal technique. Depth of scarring was indicated as a criterion for quality of marking removal in several state specifications and also in several responses to the survey. Several states call out a maximum allowable scarring depth, but survey respondents did not indicate how well this is enforced if at all. As shown in Figure 7, an electronic depth gauge, or an accurate depth measuring device, can be used to quantify the depth of scarring. An issue with measuring scar depth is that the scar is not typically uniform across the removal width, resulting in an undulating surface that makes measurement more difficult. In addition to the depth of scarring, the quantity of the removed marking is also a key component to effective marking removal. The percentage of marking material removed may be quantified with analysis of photos taken from directly over the marking or subjectively evaluated from over the marking or from a driver's perspective. Photo analysis of the removal percentage can be difficult due to the removal processes polishing the roadway surface, resulting in the surface aggregate being of similar color to the removed marking. This was especially true for the grinding removal techniques on the surfaces that were evaluated.

In addition to the electronic depth gauge, the research team used retroreflectometers, a colorimeter, a laser texture scanner

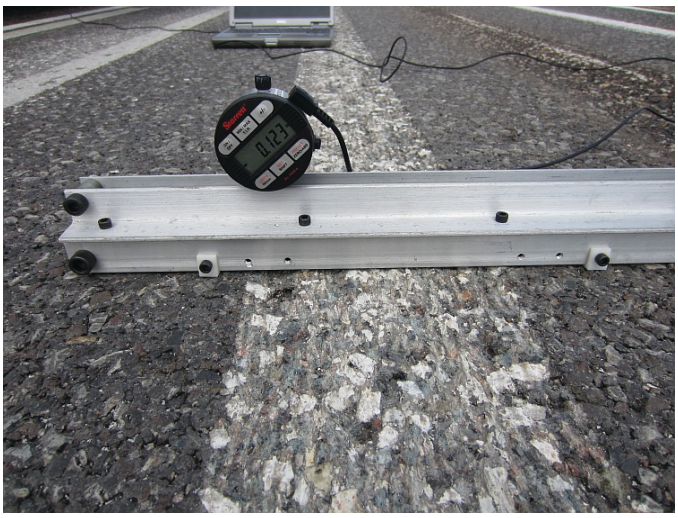


Figure 7. Electronic depth indicator.

Figure 8. Laser texture scanner.

(see Figure 8), and a charge-coupled device (CCD) photometer to capture data at the pavement marking removal sites. The researchers collected data on the removed area and the adjacent road surface area. The goal of the measurements was to determine if it is possible to quantify the changes to the roadway surface characteristics and the retroreflectivity characteristics of the removed marking area. The retroreflectometers were used to measure retroreflectivity in mcd/m^2/lux. The colorimeter was used to measure surface brightness (Y) using illuminant D65. The laser texture scanner was used to estimate the texture depth of the surface. The CCD photometer captured luminance images during both the day and night (see Figure 9). The camera was positioned at driver eye height in a vehicle 32 m away from the markings. The 32-m data collection distance was selected to achieve a similar geometry to that of standard retroreflectivity measurement while allowing all of the markings across the lane width to be captured in a single image. At night, the markings were only illuminated with the vehicle's headlights. During the day, a combination of CCD luminance measurements were taken with the sun in various positions to see its impact on the visibility of the removed areas. The researchers also explored taking CCD luminance images in wet conditions, but the natural weather did not cooperate. Water was brought to the

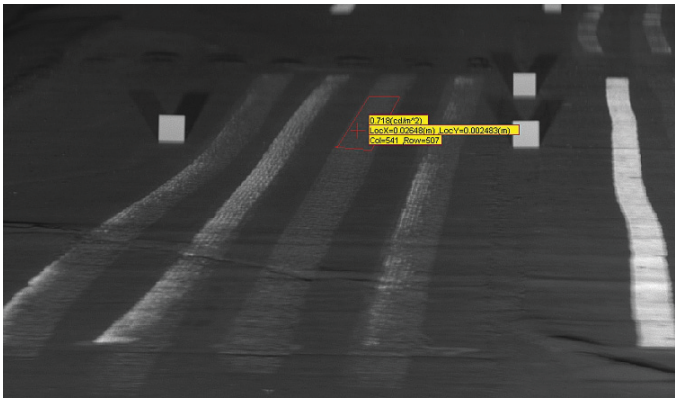


Figure 9. CCD image analysis of flailing removal of paint on asphalt.

removal sites, but the artificial wetting of the removed areas did not seem realistic, so the data were not analyzed.

Beyond the quality of the removal itself, there are also the factors of speed at which the marking is removed, cost of the marking removal, availability of the removal equipment, required skill of the operator and room for operator error, and environmental impact. Each of these factors also plays a role in determining the effectiveness of a removal technique. Obviously, the quality of the marking removal is one of the major factors, but each of these additional factors can limit the effectiveness of a removal technique. As indicated, the impact of each of these different measures may vary for different situations. If cost or speeds are more important than some of the other factors, then those measures should be weighted more heavily in the decision as to which removal method is most effective for a given situation. The researchers collected removal speed information during the testing. The other factors are discussed in other sections of this report.

Field Removal Operations

The research team felt a multifaceted field research plan would take advantage of facilities and research areas available to help cover the desired pavement marking, road surface, and removal type combinations. There were three key areas where the field removal operations occurred: (1) pavement marking test decks on open highways, (2) the closed-course at Texas A&M University Riverside Campus, and (3) construction or maintenance projects that have pavement marking removal occurring on them. The pavement marking test deck areas and closed-course Riverside Campus were controlled field studies where the research team controlled what removal methods were used, and on what markings and what surface. The evaluations at construction or maintenance areas were not controlled. The research team observed what was occurring or had occurred at these locations.

Pavement Marking Test Deck Removal

The first area where field evaluations of pavement marking removal took place was at pavement marking field test decks that had previously been studied by the Texas A&M Transportation Institute (TTI). These test decks had various marking materials installed on them for 3 years, which would better represent in-service marking compared to a newly applied marking material. The test decks were on both asphalt and PCC surfaces. The test markings were placed longitudinally in the lane in 20-ft long sections. Each removal method at each test deck was used to remove two of the pavement marking sections. The removal operators were instructed to remove the markings in two different ways. The first marking was to be removed as well as possible without damaging the

Figure 10. Pavement marking test deck on PCC surface.

road surface (light removal). The second marking was to be removed to the point that little material remained while trying to minimize damage to the road surface (heavy removal). These pavement marking test decks provide an area where direct comparisons between removal methods could occur. Figure 10 is an image of one of the pavement marking test areas on the PCC test deck. The PCC test deck had modified urethane, thermoplastic, methyl methacrylate (MMA), polyurea, preformed thermoplastic, and permanent tape pavement markings. The PCC test deck had a transverse diamond-grooved surface finish, with the depth of the grooves varying between the different marking sections. Figure 11 is an image of one of the pavement marking test areas on the asphalt test deck. The asphalt test deck had high-build paint, preformed thermoplastic, thermoplastic, and waterborne paint pavement markings.

Figure 11. Pavement markings test deck on asphalt surface.

Closed-Course Pavement Marking Removal

The second area where field evaluations of pavement marking removal took place was at the Texas A&M University Riverside Campus (see Figure 12). The Riverside Campus already had numerous thermoplastic markings applied to its concrete runways that were removed as part of this project. These thermoplastic markings were typically applied in 0.4-mi long sections. This allowed the researchers to get a better measurement of the speed of removal compared to the 20-ft long sections at the pavement marking test decks. The Riverside Campus also had sections of side-by-side waterborne paint on both concrete and asphalt surfaces similar to the field test decks, except the markings were each 45 ft long. Each removal method removed several of the paint markings from each surface and one of the long thermoplastic markings. When removing the thermoplastic markings, the first 0.1 mi was used to get the removal system optimally setup for removal and speed. The speed of removal was measured over the last 0.3 mi.

Construction and Maintenance Project Pavement Marking Removal

The third area where field observations of pavement marking removal occurred was at construction and maintenance projects that were having or recently had pavement marking removal occur on them. The research team only acted as an observer at these field locations to note pros and cons of the removal techniques, to speak with the removal crews, and to see where improvements could be made. These field observations provided supplemental information to the removal that the research team conducted on the pavement marking test areas. The researchers' goal was to evaluate each of the removal techniques that were used for the test area removal in actual field removal operations. Unfortunately, only the

Figure 12. Closed-course Texas A&M University Riverside Campus old PCC surface.

full-size flailing truck and high-pressure water blasting techniques were observed in the field. There were no operations occurring where a dual removal technique (e.g., grinding followed by high-pressure water blasting) was used, nor could arrangements be made to observe the orbital flailing method.

Controlled Test Deck Marking Removal Evaluation

During and after each field trial, whether it was on the closed-course Riverside Campus or the highway test decks, the effectiveness of each marking removal technique was evaluated. The effectiveness of the removal was based on how well the marking was removed, the condition of the pavement where the removal occurred, the cost effectiveness of the removal, and the environmental impact of the removal. The criteria to measure the effectiveness of removal techniques included the means of acquiring quantitative values for assessing the success or failure of each trial. The evaluation criteria that were necessary to collect during the field evaluations were factors associated with the quality of the removal itself, such as scar depth; changes to the roadway surface characteristics; and retroreflectivity characteristics. The speed at which the marking was removed was also collected. In addition to the quantitative data, the removal of the markings was also rated based on visual appearance. The visual ratings were removal degree and removal rating. The degree of removal was based on the percentage of pavement marking material removed and used a 0 to 10 scale, with the rating value equating to the amount of material removed, e.g., 9 = 90 percent of material removed. The removal rating was a rating based on the overall appearance of the removed area compared to the surrounding road surface. The removal rating considered the amount of material left, the scar depth, the changes to surface characteristics, and the change in color of the removed area. The removal rating was based on a 1 to 5 scale, with 5 being the least noticeable difference from the surrounding pavement and 1 being the most noticeable. The data were collected and analyzed to determine the feasibility of using the criteria to assess the quality of pavement marking removal and to compare the removal techniques. The pros and cons of each removal technique for each marking type removed on each pavement surface were also documented.

The removal at each test area was documented with video and pictures and assessed with the evaluation criteria. Figure 13 provides an example of the high-pressure water blasting removal on the PCC test deck. This was a full-size water blasting truck with a high-powered vacuum recovery system. The system typically ran around 32,000 psi, and the nozzles in the two removal heads were in an aggressive removal setup. The nozzles can be adjusted to increase or decrease removal capabilities. This is where operator experience and removal

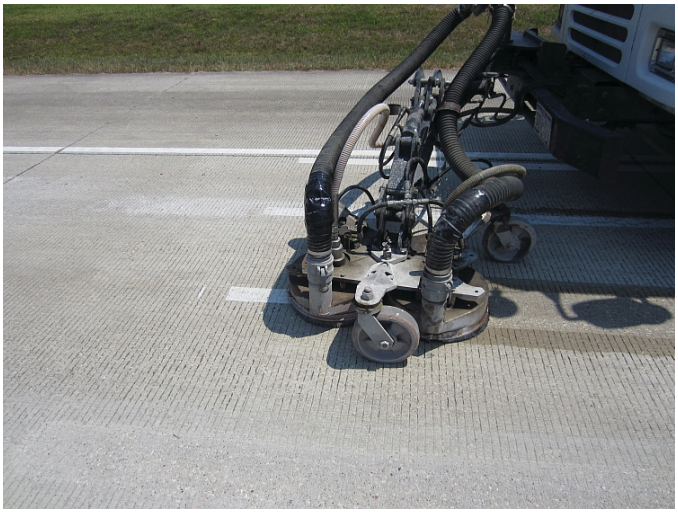


Figure 13. High-pressure water blasting on PCC test deck.

testing at the start of a project are necessary to achieve the best setup possible. The operators indicated they typically use this setup, so the researchers chose it for testing since they did not have the ability to remove numerous markings while testing different head configurations. It would have been ideal to test different configurations at the field test sites, but it was just not feasible. The operators also indicated that the rotational speed of the removal heads and the forward speed of the truck were two other variables for the high-pressure water blasting removal.

Figure 14 provides an example of the orbital flailing removal on the asphalt test deck. This was a skid steer-mounted unit with a vacuum system to control dust. The system had three removal heads. Being a skid steer-mounted unit, it was at an inherent disadvantage to the two other full-size truck-mounted removal systems when considering the speed of the removal, but all other factors should be considered equal.

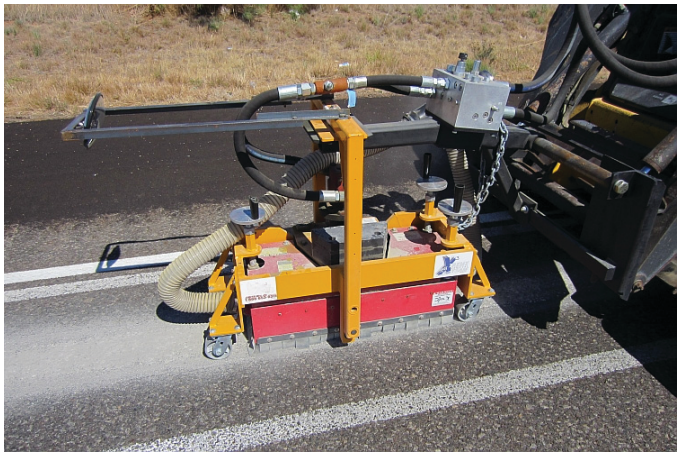


Figure 14. Orbital flailing on asphalt test deck.

The height position and downward force of the removal unit, the forward velocity of the vehicle, and the condition of the removal heads were the major variables for the orbital flailing removal. Figure 15 provides an example of the flailing removal method on the closed-course PCC test deck. The flailing truck was a full-sized truck with a vacuum system to control dust. The system had three removal units that each contained two removal drums of flailing teeth. Similar to the orbital removal method, the height position and downward force of the removal unit, the forward velocity of the vehicle, and the condition of the removal heads were variables in the flailing system's removal.

The combination testing was a pass from the full-size flailing truck followed by the high-pressure water blasting. This technique was only used on the pavement marking materials that were considered thicker materials, such as thermoplastic, preformed thermoplastic, MMA, and tape. The combination testing used the flailing truck to remove the bulk of the material without damaging the road at a higher-than-normal removal speed. After the flailing truck removed the bulk of the material, the high-pressure water blasting truck was used to remove the remnants at a higher-than-normal removal speed. The research team felt it would be difficult to remove much of the thinner materials, such as paint, high-build paint, polyurea, or modified urethane, without possibly doing damage to the road surface, so this technique was not used on those marking types. The hand-operated flailing unit was only used on the closed-course test deck. The hand-operated units are very common units but are typically only used for small removal projects. The focus of this research was for larger-scale removal projects, so the small hand-operated units were not included at all field locations. The following subsections of this report document the removal evaluations at each of the controlled test decks. The summary of all data collected can be found in Appendix D.

Figure 15. Flailing on PCC closed-course test deck.

PCC Test Deck

Six different pavement marking materials were removed using the four removal techniques on the PCC pavement marking test deck. The transverse diamond-grooved surface allowed some of the marking materials to get down into the grooved areas, increasing the difficulty of the removal on this particular surface. Two of the removed materials on the PCC deck are highlighted here in the body of the report, with general comments about the other removed materials. The summary data from all of the markings removed can be found in Appendix D, Table D-1.

The results of the pavement marking removal on the PCC deck were documented photographically. Figure 16 and Figure 17 provide images of the removal results of the modified urethane and thermoplastic pavement markings. The pictures of the four removal methods show the mark-

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing

Figure 16. Modified urethane removal on PCC images.

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing

d) Combined Removal Flailing and High-Pressure Water Blasting

Figure 17. Thermoplastic removal on PCC images.

ing closely from a low angle and from directly above. These figures provide a visual look at the quality of the removal from the perspectives of the percentage of material removed and how the pavement surface was impacted. The pictures provided are of the heavy removal where the goal of the removal was to remove the marking to the point that little material remained while trying to minimize damage to the road surface.

For both pavement marking material types on the PCC surface, the high-pressure water blasting removed nearly all of the material while doing little damage to the road surface. The high-pressure water blasting resulted in a slight removal of the very top of the surface, but the resulting surface texture change was not as apparent compared to the other removal types. The orbital flailing method removed most of the material except that which was in the grooves of the road surface. The orbital flailing impact to the road surface was limited to surface discoloration caused by polishing the top of the surface, making it appear lighter in color than the surrounding surface. The flailing method removed the majority of both marking materials but resulted in the most noticeable change to the surface texture. The flailing removal left a visible groove that removed some of the road surface and resulted in a much lighter surface color that was easily discernible from the surrounding surface. The combined removal was only used on the thermoplastic and removed all of the marking. The combined removal did result in a greater change to the surface texture than expected. The first pass using the flailing removal removed most of the marking while doing little damage to the road surface. The second pass using the high-pressure water blasting removed the little remaining material but also removed more of the road surface material than when the water blasting was used by itself, even though the speed was about twice as fast. It is likely that the uneven surface resulting from the flailing method, combined with the flailing method doing some unintended damage to the road surface, allowed the high-pressure water blasting to damage the surface further.

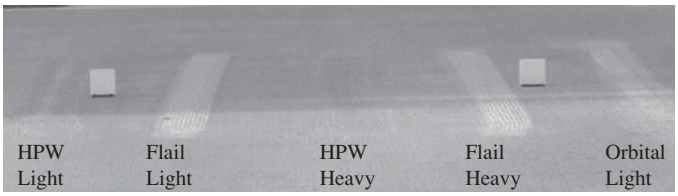
The PCC test deck had an MMA pavement marking that is noted for its hardness and durability. Figure 18 is a close-up of the end of the high-pressure water blasting removal area where some marking material remained. The picture

Figure 18. Close-up of high-pressure water blasting removal of MMA on PCC.

shows the etching of the surface that the water caused. At the edge of the removal area, the individual water jet paths can be seen, but in the center area, the removed area is smooth except for the slight indentations that were left from the diamond grooving.

The removal of the other four materials on the PCC deck had similar visual results to the modified urethane and thermoplastic markings. The high-pressure water blasting typically removed all of the marking while leaving a minimal scar and little difference in the surface texture. The orbital flailing was able to remove most of the markings, except that which was in the grooves, and did little damage to the surface, but it did result in some surface discoloration. The flailing removal damaged the PCC surface the most when it removed all of the marking; if material was left behind, the damage was less. The combined removal resulted in slightly more surface damage than the high-pressure water by itself but resulted in a smoother surface and less discoloration than the flailing removal by itself.

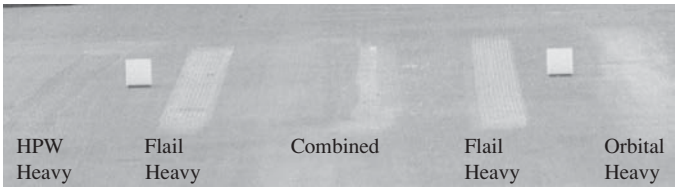
Figure 19 and Figure 20 provide a sample of the CCD images for the modified urethane and thermoplastic removal on the PCC test deck. The CCD images were taken during the day, looking away from the sun, and at night. The CCD images provide a driver's perspective of the visibility of the marking removal. The modified urethane remaining in the grooves is apparent in the night image. The visibility of the flailing removal area is also very apparent compared to the other removal methods. The remnants of the thermoplastic removal that were not adequately swept up are also very apparent in the night image, indicating the need for proper cleanup of removed materials (see Figure 20). The high-pressure water blasting removed most if not all of the marking with minimal surface damage, and the removal area appeared to show minimal contrast with the surrounding pavement both day and night and thus received high removal ratings.



a) Day Image

b) Night Image

Figure 19. CCD images of modified urethane removal on PCC.



a) Day Image

b) Night Image

Figure 20. CCD images of thermoplastic removal on PCC.

Table 52 summarizes the data collected at the removal of the modified urethane and thermoplastic markings on the PCC deck. The data include the removal with each method and whether it was light or heavy removal. The data also include the measures of the adjacent road surface for comparison purposes. Included with the measured quantitative data are the qualitative values of degree of removal and removal rating. The summary data can be viewed and evaluated in many different ways. The ability of the different removal techniques to remove a marking can be compared to each other, or the ability of the removal technique to remove different markings can be compared. Evaluating the data across the different road surfaces should also be done.

When comparing the removal speeds, the full-size removal trucks were faster than the skid steer-mounted orbital flailer, but it is expected that if multiple orbital flailers were used in sequence, like the flailing truck, comparable speeds could be maintained. The removal speeds of the flailing truck and high-pressure water blasting truck were close for most material types, with the flailing truck typically being a little faster. The flailing was a little slower than the high-pressure water blasting on the preformed thermoplastic material. The combined removal was able to yield high-pressure water blasting speeds that were typically twice as fast as when the water blasting was used alone.

When evaluating the data, comparing the removed area values to the road surface values will give a representation of how much the surface texture and reflectance characteristics differ. The bigger the difference between the values, the more noticeable the removed area will be from the surrounding pavement. On the PCC surface, the high-pressure water blasting results in the smallest difference from the surrounding road surface with regard to the reflectance measures of retroreflectivity, luminance day and night, and measured brightness for all markings except for the MMA. In general, the orbital flailing and high-pressure water blasting resulted

Table 52. PCC test deck evaluation summary.

Marking Type	Removal Method	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L (mcd/m²/lux)	CCD Luminance (cd/m²) Day	CCD Luminance (cd/m²) Night	Measured Brightness (Y)	Scar Depth (in.)	Estimated Texture Depth (mm)
Modified Urethane	Road Surface				26	1434	0.696	28.34		0.457
	Orbital Flailing Light	1980	7	3	78	1829	1.733	39.17	0.03	0.478
	Orbital Flailing Heavy	1020	9	4	66	1520	1.617	47.72	0.04	0.597
	High-Pressure Water Light	6000	9	5	47	1289	1.076	31.41	0.02	0.761
	High-Pressure Water Heavy	4020	10	5	31	1417	0.806	28.23	0.04	0.657
	Flailing Light	4500	8	3	66	1657	1.545	40.78	0.05	0.706
	Flailing Heavy	4200	8	2	64	1795	1.555	40.09	0.09	0.66
Thermoplastic	Road Surface				30	548	0.74	30.37		0.655
	Orbital Flailing Light	3600	7	4	51	683	1.339	49.56	0.01	0.594
	Orbital Flailing Heavy	3000	9	5	46	687	1.179	41.72	0.02	0.506
	High-Pressure Water Light	5160	9	4	36	586	0.927	30.23	0.01	0.753
	High-Pressure Water Heavy	4020	10	5	37	542	0.982	30.83	0.02	0.853
	Flailing Heavy	5160	10	3	50	658	1.349	39.39	0.04	0.731
	Combined	4800 grind, 7980 HPW	10	4	41	618	1.058	34.64	0.01	0.908

in similar scar depths that were less than those of the flailing method. The estimated texture depths were more variable across the removal types. Even though the high-pressure water blasting surface looked relatively smooth, the estimated texture depth numbers increased over that of the road surface, indicating a more highly textured surface. The flailing and high-pressure water blasting estimated texture depth values were higher than those of the orbital flailing. The orbital flailing appeared to smooth the surface out with some texture numbers that were lower than the surrounding pavement.

Asphalt Test Deck

Four different pavement marking materials were removed using the four removal techniques on the asphalt pavement marking test deck. The asphalt surface was slightly open, allowing some material to get down below the surface and thus increasing the difficulty of the removal on this particular surface. In addition, the gradation of stone in the asphalt mix resulted in a large variety of aggregate sizes near the surface including a large quantity of smaller aggregate and fines. Two of the removed materials on the asphalt deck are highlighted here in the body of the report with general comments about the other removed materials. The summary data from all of the markings removed can be found in Appendix D, Table D-2.

The results of the pavement marking removal on the asphalt deck were documented photographically. Figure 21 and Figure 22 provide images of the removal results of the high-build paint and thermoplastic pavement markings. The pictures of the four removal methods display the marking closely from

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing

Figure 21. High-build paint removal on asphalt.

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing

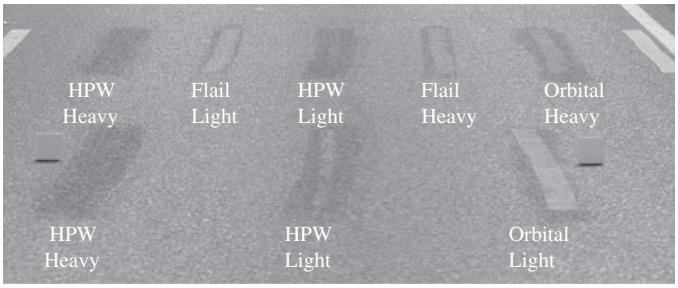
d) Combined Removal—Flailing and High-Pressure Water Blasting

Figure 22. Thermoplastic removal on asphalt.

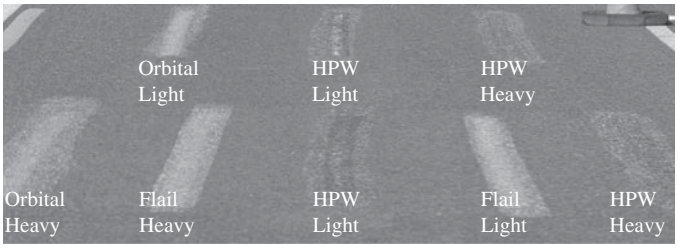
a low angle and from directly above. These figures provide a visual look at the quality of the removal from the perspectives of the percentage of material removed and how the pavement surface was impacted. The pictures provided are of the heavy removal, where the goal of the removal was to remove the marking to the point that little pavement marking material remained while trying to minimize damage to the road surface.

For both pavement marking material types on the asphalt surface, the high-pressure water blasting removed most of the marking material, but unlike the PCC, there was some damage to the road surface. The high-pressure water blasting resulted in the removal of some asphalt, small aggregate, and fines from the top of the surface. The larger aggregate was not removed, nor was a dug-out groove formed, but the asphalt and fines around the larger aggregate were removed, resulting in an easily visible change in the surface texture. The removal of the asphalt and fines may lead to the eventual loss of the larger rock and future pavement degradation in the removed area. The orbital flailing method removed all the material except that which was in the grooves of the road surface. The orbital flailing impact to the road surface was not as great as the high-pressure water blasting, with the only damage being a polishing of the aggregate, but the removal was not 100 percent. If the marking material was removed at 100 percent, the pavement would have inevitably received some damage. The flailing method removed the majority of both marking materials but also resulted in a noticeable change to the surface texture. The flailing removal left a visible groove that removed some of the road surface and resulted in a much lighter surface color that was easily discernible from the surrounding surface. The combined removal was only used on the preformed thermoplastic and removed most of the marking but left some in the voids. Not all of the material was removed because the high-pressure water blasting truck was going at a speed to minimize damage to the road surface. The combined removal did result in a much greater change to the surface texture than expected. The first pass using the flailing removal removed most of the marking while doing little damage to the road surface. The second pass using the high-pressure water blasting removed the little remaining material but appeared to also remove more of the road surface material than when the water blasting was used by itself, even though the speed was about twice as fast. Similar to the PCC surface, it is likely that the uneven surface resulting from the flailing method, combined with the flailing method possibly doing some unintended damage to the road surface, allowed the high-pressure water blasting to damage the surface further. The removal of the other paint and thermoplastic materials on the asphalt deck had similar visual results to the high-build paint and preformed thermoplastic markings.

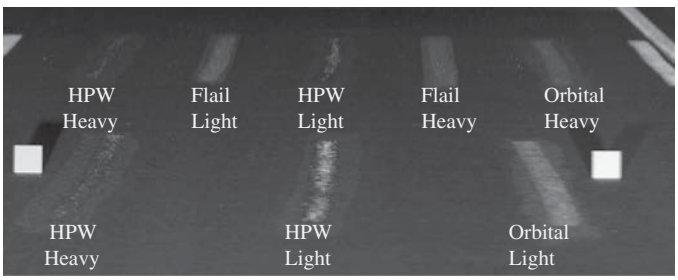
Figure 23 and Figure 24 provide a sample of the CCD images for the high-build paint and thermoplastic pavement markings on the asphalt test deck. The CCD images were taken during the day (looking both toward and away from the sun) and at night. The CCD images provide a driver's perspective of the visibility of the marking removal. From the daytime images, it is clear that the position of the sun in relationship to the viewing position of the removed area can affect the visibility of the removed area. For both materials, when looking toward the sun, the removed areas look darker than the surrounding pavement and do not stand out as much as when the sun is behind the viewer. When the sun is behind the viewer, the removed areas look lighter than the surrounding pavement, and for the flailing and orbital flailing methods, they stand out quite a bit. The material left on the pavement surface is also much more noticeable when the sun is behind the viewer. From the night images, the material left in the surface voids is apparent. The high-pressure water blasting heavy removal was conducted on a double-wide line, and the entire width was not removed prior to taking the CCD images or other measurements. That is the reason why there



a) Day Image Looking South

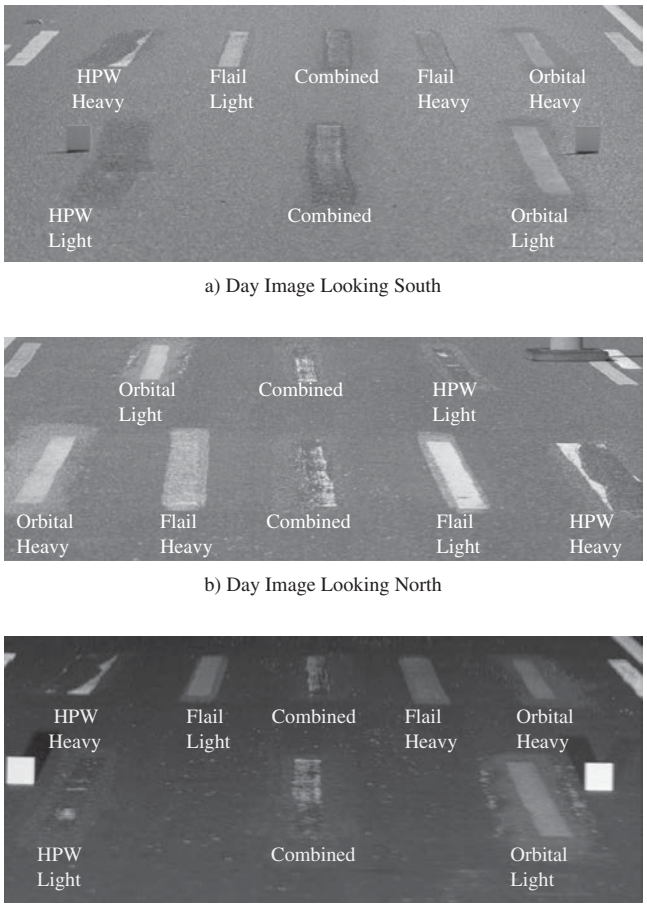


b) Day Image Looking North



c) Night Image

Figure 23. CCD images of high-build paint removal on asphalt.



a) Day Image Looking South

b) Day Image Looking North

c) Night Image

Figure 24. CCD images of thermoplastic removal on asphalt.

is excess material on the edges of the heavy high-pressure water removed area in Figure 24.

Table 53 summarizes the data collected at the removal of the high-build paint and preformed thermoplastic markings on the asphalt deck. The data include the removal with each method and whether it was light or heavy removal. The data also include the measures of the adjacent road surface for comparison purposes. Included with the measured quantitative data are the qualitative values of degree of removal and removal rating.

Comparing the removal speeds revealed that the full-size removal trucks were faster than the skid steer-mounted orbital flailer, but it is expected that if multiple orbital flailers were used in sequence, like the flailing truck, comparable speeds could be maintained. The removal speeds of the flailing truck and high-pressure water blasting truck were close for the material types tested on asphalt. The combined removal was able to yield high-pressure water blasting speeds that were typically twice as fast as when the water blasting was used alone.

On the asphalt surface, the high-pressure water blasting resulted in the smallest difference from the surrounding road surface with regard to the reflectance measures of retroreflectivity, luminance day away from sun and night, and measured brightness for all markings. For the luminance day toward sun, the results differed between removal method and marking type. In general, both the high-pressure water blasting and flailing resulted in large scar depths that were less than those of the orbital flailing method, but a higher percentage of the material was removed. The high-pressure water blasting had the greatest scar depth when removing the preformed

Table 53. Asphalt test deck evaluation summary.

Marking Type	Removal Method	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L (mcd/m^2/lux)	CCD Luminance (cd/m^2)			Measured Brightness (Y)	Scar Depth (in.)	Estimated Texture Depth (mm)
						Day (Toward Sun)	Day (Away from Sun)	Night			
High-Build Paint	Road Surface				9	3002	1554	0.2851	7.15		0.901
	Orbital Flailing Light	2400	6	2	66	3570	3026	1.423	20.3	0	0.6
	Orbital Flailing Heavy	780	8	3	47	3025	2744	0.906	26.51	0.04	0.789
	High-Pressure Water Light	3600	10	3	20	2330	1611	0.361	10.39	0.06	2.552
	High-Pressure Water Heavy	3300	10	3	18	2136	1703	0.42	9	0.07	4.236
	Flailing Light	5160	8	3	59	3404	3162	1.022	20.65	0.1	0.942
	Flailing Heavy	3300	9	3	41	3131	2937	0.795	29.45	0.11	0.862
Preformed Thermoplastic	Road Surface				9	2523	1744	0.343	9.97		1.062
	Orbital Flailing Light	480	4	2	64	3694	4911	1.692	30.45	0	2.405
	Orbital Flailing Heavy	420	5	2	69	3727	4851	2.241	36.55	0.02	1.746
	High-Pressure Water Light	1800	10	2	12	1737	1481	0.316	5.53	0.18	3.783
	High-Pressure Water Heavy	1620	10	2	21	1870	1550	0.477	5.03	0.2	5.091
	Flailing Light	3120	4	2	74	498	6411	2.337	53.93	0.1	0.862
	Flailing Heavy	1200	10	2	42	2761	3678	1.605	19.23	0.16	2.364
	Combined	3600(f), 3660(hpw)	9	1	41	2288	1839	0.853	6.6	0.18	4.195

thermoplastic marking. The estimated texture depths were more variable across the removal types. The high-pressure water blasting surface texture depth differed the most from the surrounding surface. Again, the orbital flailing appeared to smooth the surface out with some texture numbers that were lower than the surrounding pavement, but the material in the road surface voids was not adequately removed if full removal was required.

Closed-Course Test Deck

Two different pavement marking materials on two surfaces were removed using the five removal techniques on the closed-course test deck. The relatively smooth surface of the PCC did not allow marking materials to get down into any deep grooved or tined areas on this particular surface, resulting in an easier surface for removal than the previously described PCC pavement marking test deck. The closed-course PCC surface was very dirty, though, which greatly increased the color differences after removal. The asphalt surface was slightly open, allowing some material to get down below the surface and thus increasing the difficulty of the removal on this particular surface. In addition, the gradation of stone in the asphalt mix was uniform and of smaller-sized aggregate. All removal from the closed-course test deck is discussed in the body of this report. An additional data summary table can be found in Appendix D, Table D-3, with the rest of the controlled test deck data.

The results of the pavement marking removal on the closed-course deck were documented photographically. Figure 25 through Figure 28 provide images of the removal results of the paint and thermoplastic pavement markings on the concrete and asphalt surfaces. The pictures of the five removal methods show the marking closely from a low angle and from directly above. These figures provide a visual look at the quality of the removal from the perspectives of the percentage of material removed and how the pavement surface was impacted. The pictures provided are of the heavy removal, where the goal of the removal was to remove the marking to the point that little material remained while trying to minimize damage to the road surface.

The high-pressure water blasting removed all of the paint off the PCC surface. There was little damage to the road surface; the surface color change was the only noticeable difference. The orbital flailing of the paint on PCC removed most of the marking except that which was located in some of the lower portions of the surface. There was little damage done to the PCC surface from the orbital flailer. The flailing and hand flailing removal removed all of the paint marking material off the PCC, but this resulted in some surface scarring. All three flailing methods resulted in a greater change in surface color than the high-pressure water blasting. The flailing methods resulted in a removed area that was whiter than the surrounding pavement.

The high-pressure water blasting removed all of the paint off the asphalt surface. There was some damage to the road surface; some surface fines and asphalt were removed from the surface, resulting in a rougher texture with a darker color than the surrounding road surface. The orbital flailing of the paint on asphalt removed most of the marking except in areas where the machine was moving forward too fast. There was little damage done to the asphalt surface from the orbital flailer other than a slight discoloration of the surface that was whiter than the surrounding road surface. The heavy flailing and hand flailing removal removed all of the paint marking material off the asphalt, but this resulted in some surface scarring. The light flailing removed most of the marking material but not all. The light flailing had less surface damage than the heavy flailing. All three flailing methods resulted in a lighter surface color than the surrounding road surface, whereas the high-pressure water blasting resulted in a darker surface.

Old yellow thermoplastic pavement markings were also removed from the closed-course PCC surface. These markings were 0.4 mi in length, which allowed some adjustment during the removal. The high-pressure water blasting removed all of the thermoplastic marking while doing little damage to the road surface. The orbital flailing removed most of the marking with little damage to the road surface but was unable to remove most of the yellow stain on the PCC. The flailing removal removed most of the marking and did not scar the surface. The combined removal had a similar finish to that of just the high-pressure water blasting itself. The high-pressure water blasting, flailing, and combined removal all resulted in a noticeable change in surface color. The flailing color change was the most noticeable.

Figure 29 shows the remnants of the thermoplastic pavement marking on the closed-course PCC after the initial pass with the flailing removal technique. After the pass with the flailing truck, the high-pressure water blasting technique removed the remnants as the second part of the combined removal of this marking. The finished results can be seen in Figure 28.

Table 54 provides the summary of the data collected from the closed-course removal. Comparing the removal speed revealed that the skid steer-mounted orbital flailer was much faster than the hand-operated flailer, but both were much slower than the full-sized removal trucks. The removal speed of the high-pressure water blasting truck was faster for the paint removal on PCC and similar in speed to the flailing truck on the asphalt surface. The flailing was able to remove the thermoplastic on the PCC faster than the high-pressure water blasting. The combined removal of the thermoplastic on PCC was able to yield high-pressure water blasting speeds that were over three times as fast as when the water blasting was used alone.

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing

d) Hand Flailing

Figure 25. Paint removal on closed-course concrete.

a) High-Pressure Water Blasting

b) Orbital Flailing

c) Flailing Light (most removed)

d) Flailing Heavy (all removed)

Figure 26. Paint removal on closed-course asphalt.

a) High-Pressure Water Blasting

b) Orbital Flailing

Figure 27. Thermoplastic removal on closed-course concrete pt. 1.

a) Flailing

b) Combined Removal—Flailing and High-Pressure Water Blasting

Figure 28. Thermoplastic removal on closed-course concrete pt. 2.

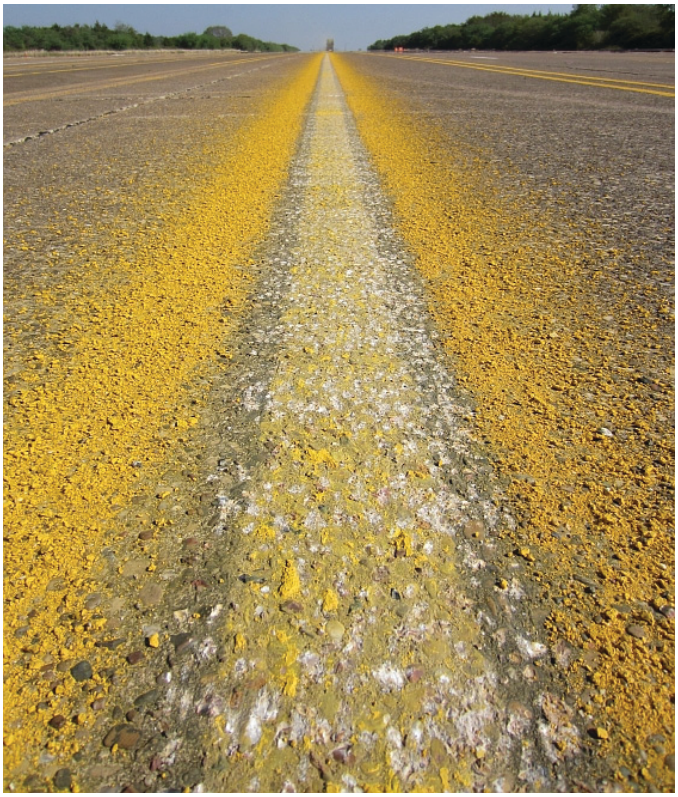


Figure 29. Combined removal remnants prior to high-pressure water blasting of thermoplastic on concrete.

For the thermoplastic removal on the PCC surface, the high-pressure water blasting and combined removal resulted in the smallest difference from the surrounding road surface with regard to the retroreflectivity and measured brightness. None of the removal methods left any measurable scar, but the surface texture of the PCC was changed slightly depending on the removal method used. For the paint removal on PCC, the high-pressure water blasting resulted in the smallest difference between the road surface and the removed area for retroreflectivity, day and night luminance, and measured brightness. The orbital flailing and high-pressure water blasting had the least amount of scar damage when removing the paint from the asphalt. The high-pressure water blasting had the greatest change in texture of the removal areas when the paint was removed from the PCC. For the paint removal on asphalt, the high-pressure water blasting resulted in the smallest difference between the road surface and the removed area for retroreflectivity, day and night luminance, and measured brightness. The orbital flailing had the least amount of scar damage when removing the paint from the asphalt, whereas the heavy flailing had the deepest scar damage. The high-pressure water blasting had the greatest change in texture of the removal areas when the paint was removed from the asphalt.

A graphical representation of the CCD luminance readings for the long-line thermoplastic removal can be found in

Table 54. Closed-course test deck evaluation summary.

Marking Type	Removal Method	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L(mcd/m^2/lux)	CCD Luminance (cd/m^2)		Measured Brightness (Y)	Scar Depth (in.)	Estimated Texture Depth (mm)
						Day	Night			
Thermoplastic on Concrete	Road Surface				17			13.57		0.883
	Orbital Flailing Heavy	2340	8	2	38			32.41	0	0.589
	High-Pressure Water Heavy	3960	10	4	26			23.91	0	1.059
	Flailing Heavy	7620	9	3	41			36.5	0	0.572
	Combined	27,120(f), 14,280(hpw)	10	4	25			27.12	0	0.801
Paint on Concrete	Road Surface				17	3143	0.451	13.57		0.854
	Orbital Flailing Heavy	720	9	3	86	8790	1.855	44.77	0.01	0.597
	High-Pressure Water Heavy	4320	10	4	26	5196	0.698	24.34	0.01	1.014
	Flailing Light	4320	9	3	76	9093	1.664	38.29	0.08	0.676
	Flailing Heavy	2700	10	2	43	7869	1.062	29.88	0.09	0.58
	Hand Flailing Heavy	240	10	2	49	8147	1.247	40.98	0.07	0.569
Paint on Asphalt	Road Surface				22	5043	0.765	15.51		0.588
	Orbital Flailing Heavy	1260	8	4	48	5407	1.381	25.3	0.06	0.815
	High-Pressure Water Heavy	3360	10	4	20	3194	0.571	12.56	0.1	1.331
	Flailing Light	6660	8	3	45	5515	0.935	31.95	0.13	0.951
	Flailing Heavy	3540	10	2	115	7381	2.1551	36.22	0.2	0.748
	Hand Flailing Heavy	300	7	2	74	6385	1.746	27.97	0.12	0.875

Appendix D, Figure D-1 and Figure D-2. The first figure represents the luminance along the marking at various distances when viewing the removed area looking toward the sun. The data indicate the flailing removal resulted in the marking that had the highest luminance readings, meaning it would be more noticeable than the others based on the reflectance of light off the removed area. There was no trend in the data as the lines were viewed at further distances. The second figure is of the same removal areas but at night under only low-beam illumination. Again, the flailing removal resulted in the highest luminance readings, meaning it would be the most noticeable of the removed areas. As expected, the nighttime luminance readings for all the removed areas decreased as distance increased.

Overall Assessment of Controlled Test Deck Removal Evaluation Data

There are several things to take away from the controlled test deck removal evaluations. For pavement marking removal, there is not one removal system that works for every marking on every road surface and does a perfect job. Where one removal technique may have an advantage on one road surface or material type, it may have disadvantages on other material types or road surfaces. In addition to the quality of the removal that was evaluated in this chapter, the costs of the removal and the environmental impact need to be considered.

The researchers collected many different types of data, attempting to yield a data set that could quantitatively rate the quality of the removal. The data set could then be used to compare the different removal techniques on the different road surfaces and markings. The quantitative data could also be compared to the qualitative data to see if a subjective rating of the removal could be an adequate technique to determine the quality of the removal. The previous sections in this chapter discuss some of the data collected and how they relate to the marking removal. In addition, the research team compared the collected data to see if any trends could be observed to aid in evaluating pavement marking removal. In Appendix D, Figure D-3 through Figure D-17 provide summary comparison charts of the data collected at the various test decks.

Figure D-3 through Figure D-5 show a comparison of the retroreflectivity of the removed areas versus the degree of removal and removal rating for all the evaluated markings at each of the three test decks. The data show that there was not a strong relationship between measured retroreflectivity and removal rating at any of the test decks. The same holds true for the degree of removal except on the asphalt test deck. On the asphalt test deck, there was good correlation between the measured retroreflectivity and degree of removal. In general, retroreflectivity alone is not a good measure to evaluate the degree of removal or to determine the quality of pavement marking removal.

Figure D-6 through Figure D-8 show a comparison of the CCD night luminance versus measured retroreflectivity and measured brightness versus measured retroreflectivity on the dual y-axis graph. A good relationship between the different measures is apparent. This would suggest that it is acceptable to use retroreflectivity as the only quantitative photometric measure, as it is the easiest to measure, and not consider measuring CCD luminance at night or measuring the brightness (Y). Figure D-9 through Figure D-11 show a comparison of the CCD night luminance versus removal rating and measured brightness versus removal rating on the dual y-axis graph. There is not an apparent relationship between the measures, indicating that CCD night luminance and measured brightness (Y) are not great predictors of an assessed removal rating. This would mean these measures alone do not correlate well with the researchers' subjective rating of the quality of the marking removal.

Figure D-12 through Figure D-14 show a comparison of the scar depth versus degree of removal and estimated texture depth versus degree of removal. In general, the scar depth did not correlate very well with the degree of removal, indicating that it is not necessary to create a deep scar to attain a high degree of removal. The same holds true for the estimated texture depth in that it is not necessary to change the texture in order to achieve a high degree of removal. Figure D-15 through Figure D-17 show a comparison of the scar depth versus degree of removal and estimated texture depth versus removal rating. There does appear to be some correlation between these measures and the removal rating on the concrete and asphalt test decks, but not on the closed-course evaluation. It makes sense that there would be some correlation because the qualitative removal rating is based in part on the visual observance of these measures. Since these are not the only measures considered in the removal rating, it should be expected that there may be some differences. The scar depth and estimated texture depth along with retroreflectivity are good measures to quantitatively evaluate the quality of pavement marking removal.

Field Observations of Removal Operations

In addition to the controlled test deck pavement marking removal, the research team also evaluated pavement marking removal at several other field sites. The field sites were selected to evaluate similar removal to what occurred on the test deck areas for comparison purposes and to view things that were not able to be captured on the test decks. In total,

six different sites were visited, and each presented a unique set of circumstances that provided beneficial findings to the research.

Removal 1: Flailing Thermoplastic on PCC and Asphalt

Members of the research team accompanied a contractor conducting night work on an interstate highway. The work being conducted consisted of removing and replacing pavement markings on both asphalt and transverse tined PCC surfaces. The removal technique was a state-of-the-art full-size flailing truck with vacuum system to control dust. The marking material being applied was epoxy, which is not compatible with the currently applied thermoplastic markings requiring the removal of the thermoplastic. Though this was a remove and replace job, the incompatibility of the marking materials still required a large portion of the existing markings to be removed to ensure a good bond of the new marking with the road surface.

Figure 30 provides a view from behind the removal truck just after it had removed a lane line marking. Figure 31 provides a look from directly above the removed area. Approximately 90 percent of the marking was being removed with minimal damage to the road surface. The material that remained was typically only in the grooves created from the transverse tined PCC surface or in the voids of the asphalt surface. The contractor indicated that this was his workers' typical remove and replace setup and that they try to do as little damage to the road surface as possible because the grooves will hold water and damage the road. Also, markings placed in areas with a deep groove are easily flooded by the water and are less visible. The contractor indicated that they do not change their operations much if the markings are to be permanently removed other than adjust the system slightly to remove as much of the material as possible while causing minimal damage to the road. The contractor indicated that they typically remove markings with this system between 0.5 and 3 mph. Their speed during this removal was timed at approximately 0.75 mph while removing the lane line markings. They increased speed in the gaps between the markings, but it was not always a consistent speed. The material that was not sucked up by the vacuum system was blown off the marking area using a compressed-air system on a separate vehicle. The new stripes were then applied.

Figure 30. Full-size flailing truck removing thermoplastic on PCC (behind).

Figure 31. Flailing truck removal of thermoplastic on PCC (above).

The observations at this field site were similar to the results that were found on the controlled test deck removal. Removal speed for this material type with this type of removal method was similar. The resulting surface changes were similar, with both the asphalt and PCC having slight grooves from the flailing teeth. The material that remained was below the pavement surface in the grooves or voids in the pavement surface. Any additional effort to remove the remaining material would result in creating a deeper groove in the road surface.

Removal 2: High-Pressure Water Blasting Thermoplastic on Asphalt

After speaking with a contractor, the research team was made aware of a recent removal area where a high-pressure

water blasting system was used. The high-pressure water blasting system was used to remove newly installed thermoplastic markings on a new asphalt overlay. The removal was necessary due to incorrectly aligned markings. After the removal, new markings were replaced in the area where the removal occurred but not in the same exact location. Members of the research team visited the removal site to see the results of the removal.

Figure 32 and Figure 33 provide views of the removal area looking toward and away from the sun. Figure 34 provides a closer view from above the removed area. The removal resulted in more than 95 percent of the material being removed. The material that remained was in the bottom of the voids of the asphalt surface. The vacuum recovery system recovered most of the removed marking material, but some still remained in the low spots of the asphalt surface. The high-pressure water blasting system not only removed the marking, it also removed the asphalt off the top surface of the aggregate and some from between the aggregate. The removal of the asphalt resulted in a very noticeable color contrast between the removed area and the surrounding pavement. As seen in the figures, the direction the removal is viewed from also plays a role in how visible the removed area is. Looking toward the sun, the color difference and the thermoplastic material that were not vacuumed up are not as noticeable as they are when looking away from the sun.

The observations at this field site were similar to the results that were found on the controlled test deck removal. The high-pressure water blasting removed the thermoplastic marking very well with minimal material remaining. The resulting surface changes were actually better on this asphalt site compared to the controlled removal areas. The large aggregate size at this site likely reduced the ability of the removal system to remove the fines like it did on the controlled test deck removal sites. The color change between the removed area and the surrounding pavement was very noticeable at this site. However, being that the alignment was only slightly changed, the impact on drivers would be minimal. In other cases of similar removal that may have a greater negative impact on drivers, corrective measures such as a fog seal over the removed area could be a good way to blend the removed area into the surrounding pavement as well as replace some of the asphalt that was removed.

Figure 33. Water blasted thermoplastic on new asphalt surface (away from sun).

Figure 32. Water blasted thermoplastic on new asphalt surface (toward sun).

Figure 34. Water blasted thermoplastic on new asphalt surface (close-up).

Removal 3: High-Pressure Water Blasting and Flailing Thermoplastic on Asphalt

The same contractor also made the research team aware of a second area where his crew had recently completed a pavement marking removal project. At the next location, both a hand-operated flailing machine and a high-pressure water blasting system were used to remove thermoplastic on an asphalt surface. Both the markings and the asphalt surface at this location were older than the previous location. The high-pressure water blasting system was used to remove a portion of the thermoplastic markings, and the hand-operated flailing machine was used to remove a separate area of thermoplastic markings. The removal of these markings was necessary to convert a two-way left-turn lane into turn bays for a new traffic signal that was being installed. Members of the research team visited the removal site to see the results of the removal.

Figure 35 and Figure 36 provide a wider view and a closer view of the area removed by the high-pressure water blasting system. The removal resulted in more than 90 percent of the material being removed. The material that remained was in the bottom of the voids of the asphalt surface. The vacuum recovery system recovered most of the removed marking material but some still remained in the low spots of the surrounding asphalt surface. In contrast to the removal on the new asphalt section where the removed area was lighter in color than the surrounding pavement, the removal here was darker in color than the surrounding pavement. Being that the asphalt was older, it had faded, and the area under the marking was protected from this fading. When the marking was removed, the dark surface under the marking was exposed. The high-pressure water blasting system did little damage to this asphalt surface, with minimal removal of asphalt or surface fines.

Figure 36. Water blasted thermoplastic on asphalt surface (close view).

Figure 37 provides an image of the removed area where the hand-operated flailing machine was used prior to the newly applied markings. In the left portion of the removed area, the removed yellow dash line is still partially visible because of the material left at the bottom of the voids in the asphalt surface. The removal did scar the asphalt surface and was still unable to get all of the marking material. Unlike the water blasting, the flailing polished the rock, creating a lighter-colored surface compared to the surrounding area.

The observations at this field site were similar to the results that were found on the controlled test deck removal. The high-pressure water blasting removed the thermoplastic marking very well with minimal material remaining. The

Figure 35. Water blasted thermoplastic on asphalt surface (wide view).

Figure 37. Hand flailed thermoplastic on asphalt surface.

resulting surface changes were again better on this asphalt site compared to the controlled removal areas. The larger aggregate size and reduced amount of fines in the mix at this site likely reduced the ability of the removal system to remove the fines, like it did on the controlled test deck removal sites. The flailing removal also provided similar results with some surface damage, with some marking still remaining below the surface. The color changes from both removal methods are unavoidable and can be corrected initially with a light fog seal, or just given time to age and blend in with the rest of the surrounding pavement.

Removal 4: High-Pressure Water Blasting Paint on a Surface Treatment

The research team evaluated the use of the high-pressure water blasting system while removing waterborne paint on an old surface treatment roadway. Figure 38 provides an example of the water blasting system in action. Since it was waterborne paint being removed, the system was able to remove all of the material at approximately 2 mph. Figure 39 provides a closer view immediately after removal. As seen in the image, the road surface is wet immediately after removal. The ambient conditions will determine how fast the pavement is able to dry and be ready for a new marking to be applied. The vacuum system did a good job vacuuming up most of the removed materials and water. The water blasting did erode the top of the surface treatment slightly, resulting in a more undulated surface than the surrounding pavement. One of the biggest things to note is the cracks in the roadway were in some areas greatly eroded by the water blasting. Protection of joints on jointed PCC pavements and areas on asphalt where there is cracking may be necessary to reduce damage.

Figure 38. Water blasting paint on surface treatment.

Figure 39. Removed area immediately after water blasting.

Removal 5: Removal on PCC

The research team visited a work zone area that was a prime example of an area where pavement marking removal resulted in an undesirable finished product. The removal occurred as part of construction phasing realigning the roadway. The material removed was thermoplastic, and a full-size flailing truck was used for the removal on the tined PCC surface. The removal was effective in that the material was adequately removed but ineffective in that the removed area was very apparent compared to the surrounding road surface. The change in alignment resulted in the removed marking leading motorists into a concrete barrier near a merge area. Though the new alignment was striped with new markings, the removed area could have potentially been mistaken as guidance, leading to a crash or, at a minimum, to a greater driver workload because of the added complexity of the driving scene.

The research team captured the results of this removal with video and pictures while driving through the work zone area. Figure 40 and Figure 41 provide two images of the removal area approaching the merge area as the lanes move to the left. In the images, the removal is apparent, as the removed areas cross the lanes and run in different directions than the new lane configuration. There is little to be done to reduce the change in surface color by any removal technique on a PCC surface such as this. High-pressure water blasting will clean the removed area, making it stand out from the surrounding area, as seen in the closed-course controlled test deck

Figure 40. Ghost markings due to surface color changes near merge area.

Figure 42. Photoshopped uniform surface color changes near merge area.

removal. Any of the grinding techniques will also clean and polish the surface, resulting in a removed area that will stand out from the surrounding pavement surface. One thing to reduce the impact of the surface color change is to remove a larger area so that the removed areas are less likely to be noticed as removed markings.

The research team spoke with a high-pressure water blasting contractor and found that his system is sometimes used to clean areas to create a more uniform surface appearance. The high-pressure water blasting system can be set to a less aggressive setting to not damage the road surface, and the removal heads can be operated parallel to each other to create a wider removal area. After the removal of the markings, the water blasting system could then be set up to just clean the surrounding pavement where the marking removal surface color changes may be problematic. Figure 42 and Figure 43 are copies of Figure 40 and Figure 41 but have been edited to show what a more uniform surface appearance may look like. The additional road surface cleaning will take additional time and money but may reduce driver confusion, which could reduce crashes especially if the phase of work is over a long period.

Removal 6: Removal on Asphalt

The research team visited another area of work zone activity that was a prime example of an area where pavement marking removal resulted in an undesirable finished product. The removal occurred as part of several construction areas where phasing resulted in lane shifts. The material removed was thermoplastic, and a full-size flailing truck was used for the removal on the asphalt surface. The research team

Figure 41. Ghost markings due to surface color changes at merge area.

Figure 43. Photoshopped uniform surface color changes at merge area.

Figure 44. Removed lane lines and wider markings.

Figure 45. Wider and continuous markings in lane shifts.

captured the results of this removal with video and pictures while driving through the work zone areas. Figure 44 provides an image of the removal area on a tangent section. From the image, the scarring to the asphalt surface is apparent, as is the marking material that remains on the surface. The contractor was trying to limit the damage to the road surface, but the amount of marking left on the road is undesirable. The DOT specified the use of wider pavement markings in this work zone to help reduce confusion between the removed markings and the new markings. The standard markings for this roadway are 6 inches wide, whereas the work zone markings are 8 inches wide.

In addition to wider markings, this DOT also uses continuous markings through lane-shift areas instead of broken line markings. Figure 45 provides an example of the wider-than-normal and continuous-lane line markings through the lane-shift area of the work zone. Again, the removal of the preexisting markings in this area does not appear to be very good, but the added guidance by the wider and continuous markings should be beneficial to drivers.

CHAPTER 6

Additional Areas of Study

Beyond the survey and field removal of pavement markings, the research team also evaluated three other areas of interest to the research project. These areas, described in this chapter, are environmental and worker safety issues, temporary tape pavement markings, and masking of markings or blending of removed areas. The authors do not discuss the environmental aspects of temporary tape pavement markings or the masking or blending of removed areas. The environmental discussion is related only to the removal of pavement markings that are not removed by hand from the road surface.

Environmental and Worker Safety Issues

The section summarizes the environmental and worker safety impacts of pavement marking removal that need to be considered. Based on the removal technique used and the composition of the pavement markings removed, different regulations may need to be addressed for each removal project. *Code of Federal Regulations* (CFR) Title 40, Protection of the Environment, is the governing document for federal regulations concerning the environment. CFR Title 29, Labor, is the governing document for federal regulations concerning workers.

Hazardous Waste Determination

Under EPA hazardous waste regulations, the term *generator* is defined by 40 CFR 260.10 as follows:

> Generator means any person, by site, whose act or process produces hazardous waste identified or listed in part 261 of this chapter or whose act first causes a hazardous waste to become subject to regulation.

In most cases, waste from activities associated with removing pavement marking materials will be associated with a work site. Thus, each work site could constitute a separate generator location. For such waste generation, if hazardous waste is produced in quantities of 220 lb or less in any month, the location would be considered a conditionally exempt small quantity generator (CESQG). A limited number of environmental rules apply to such generators.

Conditionally Exempt Small Quantity Generator Requirements. A CESQG may either treat or dispose of its hazardous waste in an on-site facility or ensure delivery to an offsite treatment, storage, or disposal facility. Regulation 40 CFR 261.5(b) states:

> . . . a conditionally exempt small quantity generator's hazardous wastes are not subject to regulation under parts 262 through 266, 268, and parts 270 and 124 of this chapter, and the notification requirements of section 3010 of RCRA, provided the generator complies with the [prescribed rules for managing the waste].

The hazardous wastes must be sent to a treatment, storage, and disposal facility (TSDF) located in the United States that is "permitted, licensed, or registered by a State to manage municipal or industrial solid waste" (40 CFR 261.5 (f)(3)). Most local industrial or municipal solid waste landfills can accept such waste. Such facilities typically have their own requirements for accepting certain wastes, including hazardous waste.

Waste from Removal of Pavement Marking Materials. Waste resulting from removing pavement marking materials would include the chemicals and compounds found in the pavement marking materials as well as any compounds mixed with the pavement marking material. The additional waste products might include:

- Pavement (e.g., asphalt or concrete);
- Contaminants on the pavement surface, such as oil, grease, or heavy metals such as lead or chromium; and
- Material associated with the removal process, such as sand from sand blasting or water from high-pressure water blasting.

Hazardous Waste. In order to determine whether a pavement marking removal waste stream is producing toxic hazardous waste, the responsible party should either test the waste using the Toxicity Characteristic Leaching Procedure (TCLP) described in 40 CFR 261.24, or apply knowledge of the waste stream to make this determination. As each waste stream is different, this study cannot present a universal determination of all pavement marking waste streams with respect to the applicability of hazardous waste rules. In order to determine whether these solid wastes are hazardous, four lists must be checked, along with the definitions of characteristic hazardous wastes.

F-List hazardous wastes are wastes from non-specific sources. They are listed under 40 CFR 261.31 (F-List). K-List wastes are hazardous wastes from specific sources, listed under 40 CFR 261.32. P-List and U-List hazardous wastes are from discarded chemical products. They are listed under 40 CFR 261.33. Characteristic hazardous wastes are defined under 40 CFR 261.21-261.24. These are solid wastes that are hazardous due to ignitability, corrosivity, reactivity, or toxicity. Table 55 is a list of some of the chemicals contained in pavement marking materials that are listed hazardous wastes. These include acetone, methanol, methyl methacrylate, and xylene.

Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) provides a mechanism for the EPA to identify, list, and categorize existing and new chemicals used in manufacturing and commerce. The primary purpose is to identify potentially dangerous products or uses that should be subject to federal control. The act also provides regulatory authority over polychlorinated biphenyls (PCBs), asbestos, radon, and lead.

Section 8 of the TSCA requires the EPA to develop and maintain an inventory of all chemicals, or categories of chemicals, manufactured or processed in the United States (the Chemical Substance Inventory). The initial list published in 1979 included approximately 55,000 chemicals in commerce. All chemicals not on the original inventory are considered new chemicals and are subject to the notification requirements of Section 5 of the TSCA. The list now totals more than 83,000 chemicals. It offers a valuable reference that complements material safety data sheet (MSDS) information.

Much of the information contained in the TSCA database duplicates or supplements the information found on MSDS documents. Some MSDSs may refer to particular TSCA items,

Table 55. Representative list of chemicals used in pavement marking materials.

Chemicals from Representative Pavement Marking Material Safety Data Sheet Information	Hazardous Waste?	Hazard Listing & Applicable Regulation
Acetone	Yes	F-003, 40 CFR 261.31 U-002, 40 CFR 261.33
Acrylated urethane	No	—
Acrylic polymer(S) (trade secret)	No	—
Alkyl glycidyl ether	No	—
Barium sulfate	No	—
Bisphenol-A-(epichlorhydrin) epoxy resin	No	—
Dibenzoyl peroxide	No	—
Dicyclohexyl phthalate	No	—
Diethylenetriamine	No	—
Diglycidyl ether of bisphenol	No	—
1,6-Diisocyanatohexane homopolymer	No	—
Butyl methacrylate	No	—
Hexamethylene diisocyanate	No	—
2-Ethyl hexyl acrylate	No	—
Limestone	No	—
2-Ethylhexyl acrylate	No	—
Methanol	Yes	F-003, 40 CFR 261.31 U-154, 40 CFR 261.33
Methyl methacrylate	Yes	U-162, 40 CFR 261.33
4-Nonylphenol	No	—
Modified polyamine	No	—
Polyurethane	No	—
Silica (quartz/crystalline)	No	—
Titanium dioxide	No	—
2,2,4-Trimethylpentane-1,3-diol monoisobutyrate	No	—
Trimethylolpropane triacrylate	No	—
Urethane acrylate	No	—
Xylene	Yes	F-003, 40 CFR 261.31 U-239, 40 CFR 261.33

and TSCA information can be useful when constructing a new MSDS document. Some MSDSs may contain code letters that are used in the TSCA Inventory to identify substances that are the subject of an EPA rule or order promulgated under TSCA, or to indicate a full or partial exemption from TSCA reporting requirements. These codes are not required for an MSDS.

The special flags used throughout the TSCA Inventory are intended to identify those substances on the inventory that are the subject of an EPA rule or order promulgated under TSCA, as well as to indicate the types of full or partial exemptions from TSCA reporting requirements. The following is a list of flags that are used (U.S. EPA 2011):

- E—indicates a substance that is the subject of a Section 5(e) consent order under TSCA.
- F—indicates a substance that is the subject of a Section 5(f) rule under TSCA.
- N—indicates a polymeric substance that contains no free-radical initiator in its inventory name but is considered to cover the designated polymer made with any free-radical initiator regardless of the amount used.
- P—indicates a commenced premanufacture notification (PMN) substance.
- R—indicates a substance that is the subject of a Section 6 risk management rule under TSCA.
- S—indicates a substance that is identified in a proposed or final significant new uses rule.
- T—indicates a substance that is the subject of a Section 4 test rule under TSCA.
- XU—indicates a substance exempt from reporting under the inventory update reporting rule, i.e., Partial Updating of the TSCA Inventory Data Base Production and Site Reports (40 CFR 710(C)).
- Y1—indicates an exempt polymer that has a number-average molecular weight of 1,000 or greater.
- Y2—indicates an exempt polymer that is a polyester and is made only from reactants included in a specified list of low-concern reactants that comprises one of the eligibility criteria for the exemption rule.

Section 5 of the TSCA requires that a premanufacture notice be filed if a manufacturer plans to manufacture a product using a chemical not listed in the Chemical Substance Inventory. This would apply to pavement marking manufacturers using a new chemical for their product. (See http://www.epa.gov/oppt/newchems/index.htm).

Clean Water Act

The Clean Water Act (CWA) regulates discharges of pollutants from a point source into navigable waters. Such discharges are regulated under the EPA's National Pollutant Discharge Elimination System (NPDES). Nonpoint sources of water pollution are also regulated under the CWA. The Nonpoint Source Management Program provides grant money for states, territories, and Native American tribes to support a variety of activities to control nonpoint sources of water pollution. These activities may include technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring.

As a result of efforts by states and Indian tribes throughout the United States, many state departments of transportation have developed guidance to control nonpoint source water pollution associated with their construction and maintenance activities. A representative sample of these requirements follows.

Alaska DOT & Public Facilities (AKDOT&PF 2005). The Alaska DOT&PF has published the Alaska Stormwater Pollution Prevention Plan Guide (effective January 14, 2005) to help contractors, consultants, and the public understand and comply with the requirements of the NPDES Stormwater Construction General Permit (CGP) for small and large construction sites. The guide covers site evaluation and assessment, best management practices for stormwater control, and requirements during construction and at the completion of the job.

California DOT (Caltrans 2003). The Caltrans Stormwater Management Plan (CTSW-RT-02-008), May 2003, provides guidance to reduce the discharge of pollutants associated with the stormwater drainage systems for highways and highway-related properties, facilities, and activities. These would include removal of pavement markings.

Colorado DOT (CDOT 2011). As part of the permit that allows discharges from the roadway storm drain system, CDOT has several different programs in place to make sure the amount of pollutants being discharged is reduced; several of these programs include the following:

- **Construction sites program:** CDOT assures the adequate design, implementation, and maintenance of temporary best management practices (BMPs) at its construction sites.
- **New development and redevelopment program:** CDOT ensures that permanent BMPs are installed at appropriate construction sites to reduce the discharge of pollutants into stormwater after construction is complete. This program also provides for maintenance of the BMPs.
- **Illicit discharges program:** CDOT detects and removes illegal discharges to its storm drain system. CDOT has a permit from the Colorado Department of Public Health and the Environment to discharge stormwater from its storm drain system. The permit states that only stormwater (and a few other allowable discharges like landscape

irrigation overflow) can be discharged from CDOT's storm drain system (CDOT 2008).
- **Industrial facilities program:** CDOT requires all facilities that discharge stormwater into CDOT's storm drain system to obtain a specific authorization. The program prioritizes education to promote minimization of pollutants in the stormwater that the facilities are contributing to the system. CDOT also provides an Environmental Clearances Information Summary for permittees.
- **Wet weather monitoring program:** CDOT assesses wet weather impacts from highways and the performance of BMPs used to control stormwater discharges.

Florida DOT, Florida Department of Environmental Protection (FDEP 2011). Florida regulates stormwater associated with construction activities through the Florida Department of Environmental Protection under a general permit. The permit regulates stormwater discharge associated with large construction activity, as defined in 40 CFR Part 122.26(b)(14)(x) and regulated pursuant to Section 402(p)(2) of the federal CWA. Stormwater discharge associated with small construction activity, as defined in 40 CFR 122.26(b)(15), is regulated pursuant to Section 402(p)(6) of the CWA. The permit provides authorization to discharge stormwater associated with large and small construction activities to surface waters of the state, including through a Municipal Separate Storm Sewer System (MS4).

Minnesota DOT (MnDOT 2011). The MS4 programs are required by the EPA and the Minnesota Pollution Control Agency (MPCA) to reduce pollution from stormwater to surface waters and groundwater. Municipalities with populations of 50,000 or greater and some smaller designated cities along with other public entities with significant stormwater drainage systems such as universities, counties, or state transportation departments have been selected to have MS4 programs. MnDOT Metro is one of these designated MS4 programs.

New York State DOT (NYSDOT 2003). The Memorandum of Understanding between the DOT and the Department of Environmental Conservation Regarding the SPDES [State Pollutant Discharge Elimination System] General Permit for Stormwater Discharges from Construction Activity, GP-02-01, 2003, provides requirements to control soil erosion, sediment, and pollutants on construction projects.

Ohio Department of Transportation Stormwater Program (Ohio DOT 2011). "ODOT created the Stormwater Management Program in response to being regulated as a Municipal Separate Storm Sewer System (MS4) under CWA requirements administered by Ohio EPA [Environmental Protection Agency]. The Stormwater Management Program was designed to comply with NPDES stormwater permits issued by Ohio EPA, including the MS4 permit and statewide and watershed-specific construction stormwater permits."

Tennessee DOT (TDOT 2007). On May 10, 2007, the TDOT formally submitted the final Statewide Storm Water Management Plan (SSWMP) documents to the Tennessee Department of Environment and Conservation (TDEC). The SSWMP outlines the steps TDOT will take to implement erosion prevention and sediment control materials and practices for TDOT construction projects. The plan contains several documents, including:

- Program Rationale, Evaluations, and Recommendations for Erosion Prevention and Sediment Control Materials and Practices for TDOT Construction Projects.
- TDOT Environmental Division Mitigation Practices.
- TDOT Environmental Division Environmental Procedures Manual—Updates.
- Manual for Management of Stormwater Discharges Associated with Construction Activities.
- Procedures for Providing Offsite Waste and Borrow on TDOT Construction Projects.
- Comprehensive Inspections Program.

Texas DOT (TxDOT 2002). TxDOT published the *Stormwater Management Guidelines for Construction Activities* in July 2002. The guidelines are intended to prevent degradation of receiving waters, facilitate project construction and minimizing overall costs, and help TxDOT comply with federal, state, and local regulations.

Virginia DOT (VDOT 2004) and Virginia Department of Environmental Quality (VDEQ 2004). Guidance Memo No. 04-2016, dated June 30, 2004, outlines the procedures that will be used to permit VDOT Virginia Pollutant Discharge Elimination System (VPDES) stormwater construction projects. The VDOT Manual of Practice for Stormwater Management, dated November 2004, provides information regarding the management of stormwater at VDOT projects and facilities.

Clean Air Act

Air emissions regulated under the federal Clean Air Act (CAA) that may be associated with removing pavement markings include particulate matter, lead, and volatile organic compounds (VOCs). Particulate matter is regulated under the National Ambient Air Quality Standards (NAAQSs). The NAAQSs regulate six criteria pollutants: carbon dioxide, lead, nitrogen oxide, PM_{10} (particulate matter smaller than, or equal to, 10 micrometers in diameter), $PM_{2.5}$ (particulate matter smaller than or equal to 2.5 micrometers in diameter), ozone, and sulfur dioxide.

The limits include primary and secondary standards. Primary standards set limits to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against visibility impairment and damage to animals, crops, vegetation, and buildings.

Under the CAA, as amended in 1990, each state must develop a plan describing how it will attain and maintain the NAAQSs. This plan is called the State Implementation Plan (SIP) and is required under Section 110 of the CAA (40 CFR Part 51, Subparts F & G). In general, the SIP is a collection of programs (monitoring, modeling, emission inventories, control strategies, etc.) and documents (policies and rules) that the state uses to attain and maintain the NAAQSs. A state must engage the public in approving its plan prior to sending it to the EPA for approval. The application and removal of traffic marking would be affected by SIPs under the NAAQSs. The applicability of these requirements are discussed in this section.

Air Quality—Particulate Matter. Particulate matter may be produced when pavement markings are removed. During marking removal, particulates are most likely to be generated when dry blasting or grinding with sand, shot, or other hard materials as part of the removal process. The Clean Air Act requires the EPA to issue designations after the agency sets a new NAAQS or revises an existing standard. If an area does not meet the standard, the EPA formally designates the area as non-attainment (not meeting the standard).

Once a non-attainment designation takes effect, the state and local governments have 3 years to develop implementation plans outlining how the area will attain and maintain the standards by reducing air pollutant emissions contributing to fine particle concentrations. This can affect pavement marking removal processes that generate particulates, such as dry blasting and grinding. The use of blasting or other removal procedures that produce particulate matter may be restricted in non-attainment areas.

Air Quality—Lead. The EPA strengthened the air quality standards for lead on October 15, 2008, revising the level of the primary (health-based) standard from 1.5 micrograms per cubic meter ($\mu g/m^3$) to 0.15 $\mu g/m^3$, measured as total suspended particles (TSP). The agency revised the secondary (welfare-based) standard to be identical to the primary standard.

This change will affect the manner in which states control ambient lead concentrations. State and local environmental regulatory agencies promulgate regulations directed toward meeting the EPA standard. Pavement markings may be affected if quantities near the regulatory levels are identified in air emissions from removing them.

Air Quality—Mobile Sources. Under the National Emission Standards for Hazardous Air Pollutants (NESHAPs), the EPA regulates activities such as paint stripping. However, pavement marking removal activities are not covered under the NESHAPs Paint Stripping and Miscellaneous Surface Coating Operations-Area Sources regulations. Regulation 40 CFR 63.11169 identifies the following three activities covered by these regulations:

- Paint stripping operations that involve the use of chemical strippers that contain methylene chloride (MeCl).
- Autobody refinishing operations that encompass motor vehicle and mobile equipment spray-applied surface coating operations.
- Spray application of coatings containing compounds of chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni), or cadmium (Cd).

Further, the EPA does not intend to promulgate a Maximum Achievable Control Technology (MACT) rule for major sources of paint stripping because applicable major source facilities have not been identified. Paint stripping operations currently performed are regulated under other NESHAP categories such as wood furniture and aerospace. The source category will not be delisted because the EPA is required to consider area sources of paint stripping under its NESHAP rulemaking. Mobile source regulations under the CAA do not apply to pavement marking product removal.

Air Quality—Volatile Organic Compounds. Certain organic compounds are readily emitted as gases from solids or liquids. These are known as VOCs. Some materials that emit VOCs include paints, lacquers, paint strippers, solvents, and pesticides. VOCs can be released during storage or use of these materials. VOCs are regulated under the NAAQSs. VOCs are important with respect to ground-level ozone (O_3), which is typically created by a ground-level chemical reaction between oxides of nitrogen (NOx) and VOCs in the presence of sunlight. Pavement marking removal is subject to any VOC requirements in SIPs.

The EPA Office of Air Quality Planning and Standards (OAQPS) has established several standard procedures for the preparation of SIP emission inventories. The Emission Inventory Improvement Program's (EIIP's) Area Sources Committee developed a guidance document on area sources. As part of this objective, the committee published a report that provided estimates of VOCs and hazardous air pollutants (HAPs) from traffic markings (Eastern Research Group 1997). The report provided information regarding estimated VOC emissions from various types of installed traffic markings. The VOC and HAP regulations would primarily affect the application and lifetime use of pavement markings. These regulations would apply to pavement marking removal operations only

to the extent that removal creates additional airborne sources of VOCs or HAPs. VOCs released from pavement marking material removal have not been identified as a significant source of VOCs. Subsequently, while it is possible that VOC requirements could be included in SIPs, it is unlikely that SIPs will include requirements on VOC emissions with regard to pavement marking removal.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) became law in 1970. Among its provisions is the requirement for environmental reviews of all major federal actions. It was directed toward assuring that the federal government considered potential impacts of its actions and decisions on the environment.

NEPA requirements come into play when federal agencies are involved in funding, permitting, licensing, or making decisions that can affect the environment. The primary tools under NEPA are environmental assessments (EAs) and environmental impact statements (EISs). These documents include processes that are designed to assess the likelihood of impacts from alternative courses of action.

FHWA regulations, specifically 23 CFR 771—Environmental Impact and Related Procedures, address FHWA actions under NEPA. Regulation 23 CFR 771.101—Purpose states:

> This regulation prescribes the policies and procedures of the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) for implementing the National Environmental Policy Act of 1969 as amended (NEPA), and supplements the NEPA regulation of the Council on Environmental Quality (CEQ), 40 CFR parts 1500 through 1508 (CEQ regulation). Together these regulations set forth all FHWA, FTA, and Department of Transportation (DOT) requirements under NEPA for the processing of highway and public transportation projects. This regulation also sets forth procedures to comply with 23 U.S.C. 109(h), 128, 138, 139, 325, 326, 327, and 49 U.S.C. 303, 5301(e), 5323(b), and 5324(b) and (c).

Pavement marking removal would not typically be the center of a NEPA process. Regulation 23 CFR 771.117 sets forth the FHWA categorical exclusions under NEPA. The regulation states in part:

> (a) Categorical exclusions (CEs) are actions which meet the definition contained in 40 CFR 1508.4, and, based on past experience with similar actions, do not involve significant environmental impacts. They are actions which: do not induce significant impacts to planned growth or land use for the area; do not require the relocation of significant numbers of people; do not have a significant impact on any natural, cultural, recreational, historic or other resource; do not involve significant air, noise, or water quality impacts; do not have significant impacts on travel patterns; or do not otherwise, either individually or cumulatively, have any significant environmental impacts.
>
> (c) The following actions meet the criteria for CEs in the CEQ regulation (section 1508.4) and § 771.117(a) of this regulation and normally do not require any further NEPA approvals by the Administration:
>
> 8. Installation of fencing, signs, pavement markings, small passenger shelters, traffic signals, and railroad warning devices where no substantial land acquisition or traffic disruption will occur.

While this addresses the installation of pavement marking, the removal of pavement making is not specifically identified as a CE. Therefore, the applicability of NEPA to a project must be considered for each project based on the project's characteristics. This would be a function of the processes utilized. The presence of the marking material would have been a CE when installed. Therefore, the applicability of NEPA would focus on what other materials, equipment, or processes are necessary for the pavement marking removal, and their associated impacts.

Health and Safety Requirements

Some of the worker health and safety requirements associated with pavement marking material removal are reviewed in this section. These include exposure to noise, lead, hexavalent chromium, silica, and asbestos. Health and safety aspects that are standard to construction and maintenance activities such as interaction with heavy machinery and traffic are not discussed.

Exposure to Lead

Worker exposure to lead is regulated under 29 CFR 1926.62 *et seq.* Regulation 29 CFR 1926.62(c)(1) establishes a permissible exposure limit (PEL) for lead at a maximum of 50 $\mu g/m^3$ of air averaged over an 8 hr period. The PEL is measured as a function of what a worker may breathe in. The standard applies to:

- Demolition or salvage of structures where lead or materials containing lead are present;
- Removal or encapsulation of materials containing lead;
- New construction, alteration, repair, or renovation of structures, substrates, or portions thereof, that contain lead, or materials containing lead;
- Installation of products containing lead;
- Lead contamination/emergency cleanup;
- Transportation, disposal, storage, or containment of lead or materials containing lead on the site or location at which construction activities are performed; and
- Maintenance operations associated with the construction activities described in this paragraph.

For activities covered by the lead standard, the employer is required to perform an assessment of the exposure to lead

by collecting personal samples representing a full shift of work. Exposure to lead during removal of pavement marking materials could occur, depending on the type of removal process used and the type of material being removed. The concentrations would vary, depending on the type of material being removed, the location, weather conditions, and type of removal process employed. The only pavement marking materials known to contain lead are yellow markings, where lead chromate has been used as a pigment.

Hexavalent Chromium

Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1910.1026 *et seq.* regulates worker exposure to chromium (VI) in all forms and compounds in general industry, except:

> 1910.1026(a)(4)
> Where the employer has objective data demonstrating that a material containing chromium or a specific process, operation, or activity involving chromium cannot release dusts, fumes, or mists of chromium (VI) in concentrations at or above 0.5 μg/m^3 as an 8-hour time-weighted average (TWA) under any expected conditions of use.

Exposure to chromium (VI) during removal of pavement marking materials could occur if present in the marking material, depending on the type of removal process used. The concentrations would vary, depending on the type of material being removed, the location, weather conditions, and type of removal process employed. The only pavement marking materials known to contain chromium are yellow markings where lead chromate has been used as a pigment.

Exposure to Silica and Asbestos

OSHA regulation 29 CFR 1926.55, Appendix A, establishes threshold limit values (TLVs) for airborne contaminants for construction activities. Values include TLVs for seven silica compounds and six silicates (with less than 1 percent crystalline silica).

OSHA regulation 29 CFR 1910.1001(c) establishes a worker exposure limit to airborne asbestos of 0.1 fiber per cubic centimeter of air as an 8-hr time-weighted average. The regulation identifies monitoring and other requirements associated with ensuring that this standard is met.

For working environments where workers may be exposed to a TLV for silica or an asbestos exposure limit, monitoring and worker protection measures may be required. With respect to pavement marking products, the area of focus would be removing marking materials (including glass beads) that may contain silica. Some removal processes (e.g., blasting or grinding) can generate dust from the marking materials and pavement. Forms of sand blasting may also use abrasive materials that may contain silica that would also need to be considered in the TLV along with the removed marking material and any removed road surface material that may become airborne.

Table 56. Permissible noise exposures.[1]

Duration per Day, Hours	Sound Level, dBA Slow Response
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
½	110
¼ or less	115

[1] When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions—$C_1/T_1+C_2/T_2C_n/T_n$—exceeds unity, then the mixed exposure should be considered to exceed the limit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Noise

Applying and removing traffic markings may require noise protection for exposed workers. The OSHA requirements for noise control and hearing conservation are set forth in 29 CFR 1910.95, *Occupational Noise Exposure.* This regulation establishes permissible noise exposures for short time periods (¼ hr or less) up to a full 8-hr day. Noise levels that exceed the permissible noise exposure levels require hearing protection, noise reduction, and in certain instances, hearing conservation programs. Table 56 indicates the permissible noise levels established in 29 CFR 1910.95(b).

Environmental, Health, and Safety Issues Related to Specific Pavement Marking Removal Procedures

The general environmental health and safety issues of pavement marking removal are discussed in the previous section. This section will look specifically at how these issues relate to specific forms of removal on specific road surfaces. Worker safety issues and the impact from the marking material removed will be similar for all road surfaces.

Grinding

Environmental and Worker Safety Considerations—Asphalt and Seal Coat Surfaces. Grinding can be used for removal of all pavement marking materials on asphalt. Solid waste generated from the removal process would include the

marking material, asphalt and oil, and other contaminants on the asphalt surface. Asphalt contains aliphatic hydrocarbons in addition to the mononuclear aromatics and polycyclic aromatic hydrocarbon (PAH) mixtures found in both asphalt and tars (Irwin et al. 1997).

Waste material resulting from grinding will be subject to hazardous waste determination if it is suspected the waste has hazardous constituents. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed.

It is possible for asphalt waste to create a hazard to aquatic life due to the PAHs and alkyl PAHs in asphalt that can move into the aquatic ecosystem from the breakdown of asphalt. However, the effects of the low concentrations of these contaminants associated with asphalt to aquatic life or waterfowl are unknown. Hazards to humans associated with asphalt include inhalation of compounds in heated or fresh asphalt as well as ingestion of PAHs entering the food chain as the result of breakdown of asphalt.

Asphalt can lower contaminant leaching rates by binding contaminants in the asphalt matrix. The amount the leaching is lowered depends on the physical and chemical characteristics of the particular environment. Chemical and physical actions on the asphalt can break it down. Greases can soften asphalt, while xylene and toluene can diffuse through it. Under certain conditions, solvents and road salts can accelerate the breakdown of asphalt.

As the asphalt road surface wears away, road dust and other erosion components are a potential source of PAHs in the sediments of urban waterways. Asphalt wear products may be responsible for some of the petroleum in urban runoff as well as for some of the PAHs found in the sediments of some urban lakes.

The chemical constituents in the pavement markings will be reflected in the grinding waste. A projection of the potential contaminants can be made by reviewing the constituents listed in the product MSDS. Grinding can expose workers to contaminants contained in the dust particles, including lead, chromium, silica, and asbestos. Noise exposure can also be a concern.

Environmental Considerations—PCC Surfaces. The concrete waste material produced from grinding pavement markings on PCC pavement has a low environmental impact. The most notable impact is a potential increase in pH in surrounding soil if waste material is mixed in it. The primary impacts will be from the chemicals in the marking materials and other contaminants on the roadway surface. Waste material resulting from grinding on PCC pavement will be subject to hazardous waste determination. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed of.

High-Pressure Water Blasting

Environmental Considerations—Asphalt and Seal Coat Surfaces. The waste water produced from high-pressure water blasting will wear away some of the asphalt surface, along with removing the marking material. The asphalt waste will present the same environmental concerns as grinding, but in varying quantities, and will be combined with water. High-pressure water blasting will result in minimal airborne contaminants. Noise exposure is a concern.

Environmental Considerations—PCC Surfaces. High-pressure water blasting is effective in removing the pavement marking material while removing very little of the PCC pavement. The primary impacts will be from the chemicals in the marking materials. A projection of the potential contaminants can be made by reviewing the constituents listed in the product MSDS.

Media Blasting (shot or glass)

Environmental Considerations—Asphalt or Seal Coat Surfaces. Environmental considerations for removing pavement markings with media blasting are similar to grinding. In addition to waste from the asphalt pavement and pavement marking, there will be waste material from the medium (shot or glass) being used, unless the medium is dry ice. Waste material resulting from media blasting on asphalt will be subject to hazardous waste determination. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed of. Media blasting can expose workers to contaminants contained in the dust particles, including lead, chromium, silica, and asbestos. Noise exposure can also be a concern.

Environmental Considerations—PCC Surfaces. The concrete waste produced from media blasting pavement markings on PCC pavement has a low environmental impact. The most notable impact is a potential increase in pH in surrounding soil if waste material is mixed in. The primary impacts will be from the chemicals in the marking materials and the medium itself. Waste material resulting from media blasting on PCC pavement will be subject to hazardous waste determination. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed of.

Chemical System

Chemical systems would only be used on paint. There are some paint systems designed specifically to be removed with a chemical system.

Environmental Considerations—Asphalt Surfaces. Chemical systems can be used on asphalt but are less effective on porous asphalt surfaces. An assessment of the environmental considerations should begin with a review of the MSDS for the chemical remover. Waste material will include chemicals from the remover, pavement marking material, and contaminants on the roadway surface. Waste material resulting from chemical removal on asphalt will be subject to hazardous waste determination. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed of. Worker safety issues will center on handling the chemicals and exposure to waste material after removing the pavement marking.

Environmental Considerations—PCC Surfaces. As with use on asphalt, an assessment of the environmental considerations should begin with a review of the MSDS for the chemical remover. Waste material will include chemicals from the remover, pavement marking material, and contaminants on the roadway surface. Waste material resulting from media blasting on PCC pavement will be subject to hazardous waste determination. The waste should either be tested using the TCLP, or knowledge of the waste stream should be applied to make this determination. The results of this determination will dictate how the waste should be disposed of.

Summary

A summary of the environmental issues associated with the pavement marking removal methods under consideration is shown in Table 57.

Recommended Best Practices for Management of Environmental and Worker Safety Issues

The potential adverse impacts on the environment and on workers can be minimized by the application of BMPs. Best management practices for removal of pavement markings include the following:

- Selecting the appropriate removal method for the job (i.e., road surface, pavement marking, etc.).
- Assessing potential VOC, lead, chromium, silica, asbestos, or other chemical hazards and addressing such hazards in accordance with regulatory requirements.
- Developing a plan that manages:
  - the removal of waste products that complies with applicable environmental regulatory requirements, and
  - airborne particles, material spills, and disposal.

A representative series of TCLP tests should be conducted on the waste products if there are questions that waste material from any of the pavement marking application or removal processes may contain toxic wastes (as defined by EPA or state regulations).

Worker exposure to lead, chromium, silica, or asbestos would be in the form of an inhalation hazard. This would

Table 57. Summary of environmental issues related to removal techniques.

Removal Techniques	Hazardous Waste & TSCA	CWA	CAA	NEPA
Grinding	Solid waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements
High-Pressure Water Blasting	Solid waste and wastewater generated subject to regulation	Water runoff from waste products subject to regulation	Limited air quality concerns	Site-specific determination of requirements
Media Blasting	Solid waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements
Chemical Removal*	Solid and chemical waste generated subject to regulation	Water runoff from waste products subject to regulation	Limited air quality concerns	Site-specific determination of requirements
Combination Grinding & Chemical Removal	Solid and chemical waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements

*Chemical removal currently is only used on paint markings.

normally only occur during removal of material containing lead, chromium, silica, or asbestos. The following factors should be considered when assessing the potential lead or chromium exposure hazard:

- The amount of contaminant in the materials being removed.
- Whether the removal activity is being conducted in a confined area (such as a tunnel) or an open area.
- The type of removal process being used and its potential for creating an inhalation hazard for the contaminant.

If there are concerns that the exposure limits for lead, chromium, silica, or asbestos might be approached, then OSHA procedures for sampling and monitoring the potential exposure should be followed.

Temporary Tape Pavement Markings

The masking of permanent markings using temporary tape markings or using temporary tape markings as a form of delineation have been identified as practices used in work zones. The durability of these markings and the remnants they leave behind when removed are key factors to consider when deciding to implement this type of marking. Temporary tape pavement markings have frequently been included in AASHTO's National Transportation Product Evaluation Program (NTPEP 2011). This program uses test decks around the country to evaluate pavement marking materials.

Because of the quantity of data in the NTPEP database that is available for anyone to review, the research team elected to review the NTPEP data and use the results to further this study. These results allow for recommendations into the use of temporary tape markings and ways that the NTPEP database can be used to help identify the best materials for usage.

NTPEP Database

NTPEP DataMine 1.0 was used as the source of temporary tape pavement marking data (NTPEP 2011). All years with available temporary tape data at the time of the analysis were included in the evaluation (2000–2009). In total, there were 11 test decks that had temporary pavement marking materials installed on them. For temporary (removable and non-removable) tapes, the markings were evaluated monthly for 6 months. Every month, one longitudinal and one transverse stripe of each removable tape were removed for evaluation. The data evaluated in this report only looked at the longitudinal markings. The types of data collected during the evaluations included quantitative measures of reflectivity and color, subjective ratings of durability, and subjective ratings of removability, discernability, and other performance factors of the temporary tapes. The durability, color, and retroreflectivity of the temporary tape markings are an important aspect to consider when selecting the marking but are not discussed in this evaluation. This evaluation focused on the removability and discernability of these temporary tape markings.

The subjective ratings during NTPEP evaluations are made by a team of trained raters. Pull-up tests are performed for testing removability, which is rated based on how many pieces have to be removed for complete removal (internal tape strength), how much effort is required to remove tape (adhesive bond), and presence of residual adhesive to road surface (tackiness). Subjective discernability ratings after removal are about the outline and image of remaining adhesive, dirt, etc., left on a road surface right after removal and 30 days after removal. The rating criteria as specified in the NTPEP best practices document are as follows (NTPEP 2005):

The rating for internal tape strength with the rating scale 1–10 is as follows:

- 1—Tape removed intact, in one piece.
- 3—Tape removed in three to four pieces.
- 5—Tape removed in five pieces.
- 7—Tape removed in seven pieces.
- 10—Tape only removed in very small fragments.

The rating for adhesive bond with the rating scale 1–10 is as follows:

- 1—Tape removed easily (potentially by one hand).
- 3—Tape removed with moderate, two-handed effort.
- 5—Tape removed with significant, two-handed effort, requiring multiple pulls.
- 9—Tape removed only by exhausting, two-handed effort.
- 10—Tape could not be removed from surface.

The rating for tackiness with the rating scale 0–10 is as follows:

- 0—Least adhesive remaining on the pavement surface.
- 10—Most adhesive remaining on the pavement surface.

The rating for discernability after removal with the rating scale 0–10 is as follows:

- 0—No discernible marking on road surface.
- 5—50 percent of marking (adhesive outline) left on road surface.
- 10—100 percent of marking left on road surface.

NTPEP Evaluation

The research team extracted all of the available data on the temporary pavement markings from the NTPEP DataMine

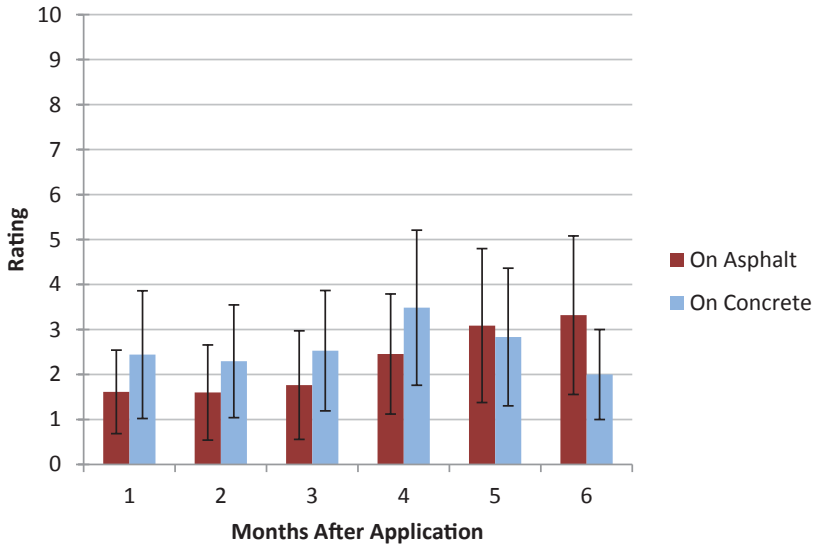


Figure 46. Internal strength, white pavement markings.

(NTPEP 2011). The data from each of the 11 test decks were combined to make one data set for each evaluation criteria. The data sets were further divided by road surface (asphalt or concrete) and by marking color (white, yellow, or black). The results of the evaluation showed that the white and yellow markings performed similarly, so only the white and black markings will be discussed.

Each of the figures in this section plots the average rating of all the markings across all the test decks for the given evaluation period after installation in months. In addition to the average value, error bars representing, in total, one standard deviation are also included. The figures are differentiated by the given evaluation criteria, the given road surface, and the given marking color.

Figure 46 provides the summary of the internal strength data for white markings on asphalt and concrete surfaces. The average strength ranged between 1.6 and 3.5 for the two surfaces. On the asphalt surface, the average value increased as the marking aged, which actually indicates the marking broke up into more pieces as it was removed. There was no evident trend on the concrete surface. These data are useful in that it would be preferable to have a marking that removes in as few pieces as possible.

Figure 47 provides the summary of the adhesive bond data for white markings on asphalt and concrete surfaces. The average adhesive bond ranged between 2.6 and 4.9 for the two surfaces. On the asphalt surface, the average value generally increased as the marking aged, which indicates the mark-

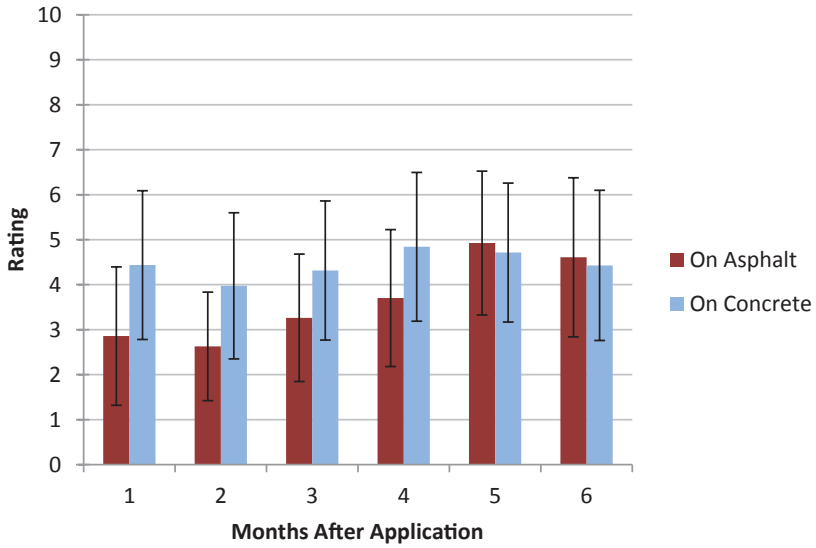


Figure 47. Adhesive bond, white pavement markings.

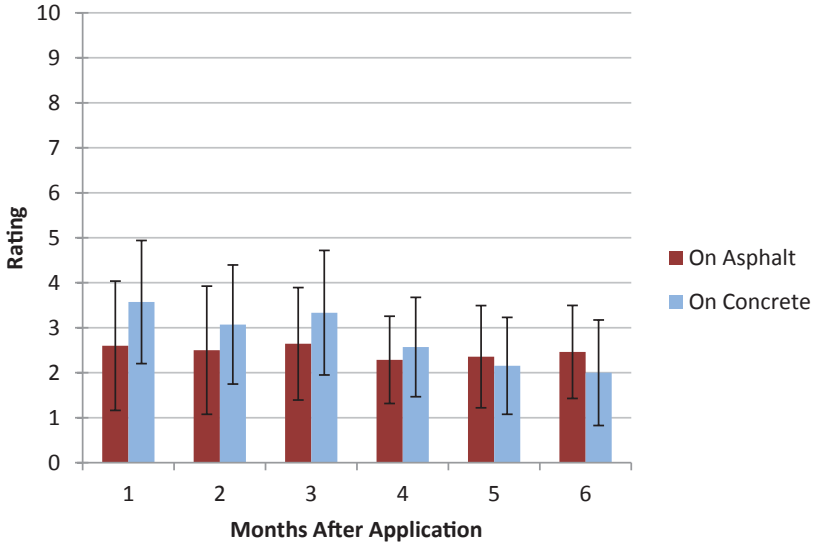


Figure 48. Tackiness, white pavement markings.

ing was more difficult to pull up. There was no evident trend on the concrete surface, but the average values overall were higher than on the asphalt surface. These data are useful in that it would be preferable to have a marking that is easier to remove, but the trade-off may be durability.

Figure 48 provides the summary of the tackiness data for white markings on asphalt and concrete surfaces. The average tackiness ranged between 2.0 and 3.6 for the two surfaces. On the asphalt surface, there was no trend as the marking aged. On the concrete surface, the trend was generally decreasing, indicating less adhesive remaining on the road surface as the marking aged. These data are useful in that it would be preferable to have a marking that leaves as little adhesive on the roadway as possible.

Figure 49 provides the summary of the discernability data for white markings on asphalt and concrete surfaces immediately after removal. The average discernability immediately after removal on asphalt ranged between 3.5 and 6.2 and between 5.1 and 6.8 on concrete. In general, the longer the material was installed, the more discernible it was after removal. Overall, the discernability on concrete was higher than on asphalt immediately after removal. These data are useful in that it would be preferable to have a marking that leaves the least discernible marking on the roadway after removal.

Figure 50 provides the summary of the discernability data for white markings on asphalt and concrete surfaces 30 days after removal. The average discernability 30 days after removal on

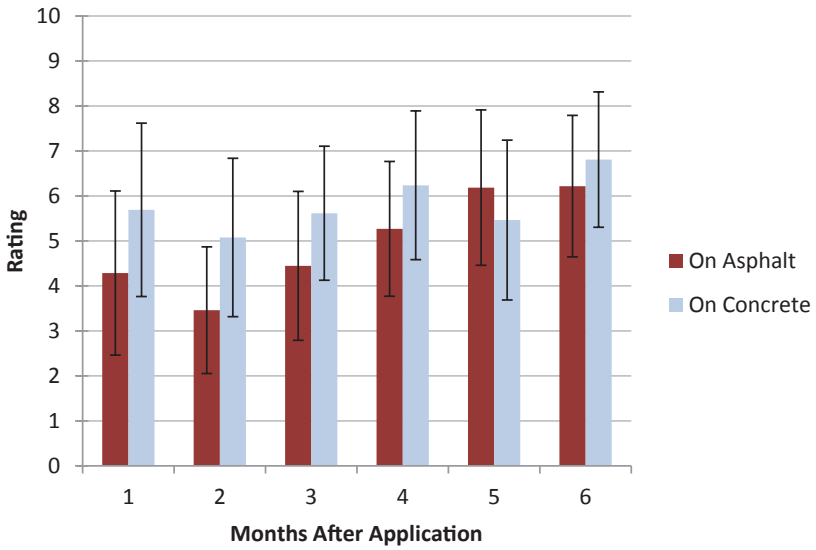


Figure 49. Discernability after removal, white pavement markings.

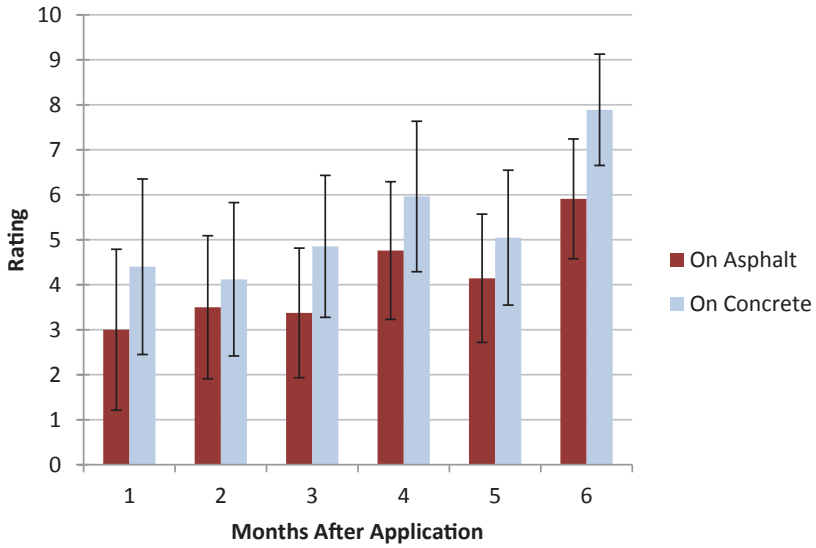


Figure 50. Discernability 30 days after removal, white pavement markings.

asphalt ranged between 3.0 and 5.9, and between 4.1 and 7.9 on concrete. Overall, the discernability on concrete remained higher than on asphalt 30 days after removal. In general, the longer the material was installed, the more discernible the material was 30 days after removal. The 30 days after removal values on asphalt were lower than the immediately after removal values, and the decrease ranged from 0 to 2.0 rating points. The 30 days after removal values on concrete were lower than the values immediately after removal, and the decrease ranged from 0.3 to 1.3 rating points. The only exception was the removal on the concrete 6 months after installation. In the 30 days after removal evaluation, only about half of the products had data recorded compared to the data immediately after removal. This reduced data set may be the reason that the evaluation 30 days after removal resulted in a higher value than immediately after removal. These data are useful in that it would be preferable to have a marking that leaves the least discernible marking on the roadway 30 days after removal.

Figure 51 provides the summary of the discernability data for black markings on asphalt and concrete surfaces immediately after removal. The average discernability on asphalt ranged between 5.1 and 7.4 immediately after removal, and on concrete, it ranged between 5.2 and 9.1 immediately after removal. In general, the removed markings were more discernible on concrete than asphalt.

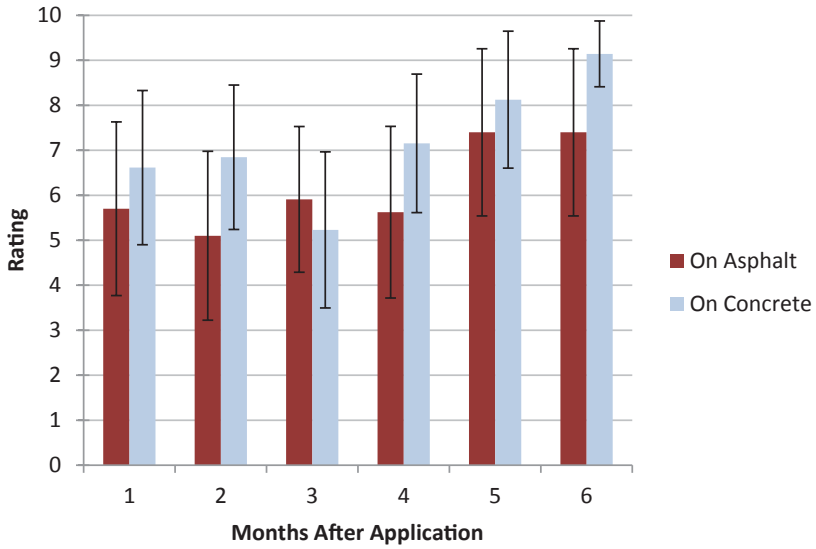


Figure 51. Discernability after removal, black pavement markings.

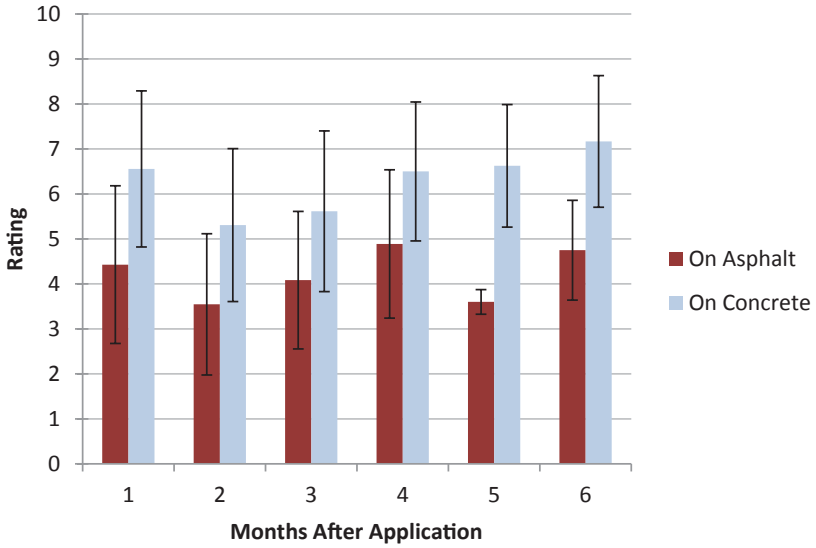


Figure 52. Discernability 30 Days after removal, black pavement markings.

Figure 52 provides the summary of the discernability data for black markings on asphalt and concrete surfaces 30 days after removal. The average discernability ranged between 3.6 and 4.9 on asphalt 30 days after removal and between 5.3 and 7.2 on concrete 30 days after removal. On asphalt, the values 30 days after removal were lower than the values immediately after removal, and the decrease ranged from 0.7 to 3.8 rating points. On concrete, the values 30 days after removal were lower than the values immediately after removal, and the decrease ranged from –0.4 to 2.0 rating points. The increase at the 30-day evaluation period was due to some markings not being evaluated at the 30-day period. This was common for the white markings as well, but there were fewer black markings, so some missing data had a larger impact on the results.

The information provided here is a summation of some of the information provided in the NTPEP database. Further exploration of the NTPEP database would allow for more specific information to be evaluated that may be beneficial to a particular set of conditions. Users should evaluate the temporary tapes they want to use to select the most durable, the least discernible, or a material that is the best combination of the two. In addition, other factors such as cost, color, and removability need to be taken into consideration.

Masking of Markings and Blending of Removal Areas

The masking of markings and blending of removal areas have been identified as practices used when conducting pavement marking removal. The durability and color-matching characteristics of the masking material that is applied over the marking are critical to being able to effectively remove (cover) the marking. In situations where a marking is removed, it may be advantageous to attempt to blend in the removal area with the surrounding pavement in order to reduce the confusion caused by scarring or changes in surface color or texture. Beyond masking markings or blending in removed areas, the entire road or lane width can be resurfaced to cover the markings that need to be removed. These areas of pavement marking removal are discussed in this section.

Masking Markings Using Surface Treatments

Surface treatments can be used as a method to cover markings or to blend areas where markings have been removed. A surface treatment may just cover the area where the marking is or cover the entire road surface. Surface treatments are typically used for rehabilitation and preservation of aging asphalt roadways. For PCC roadways, diamond grinding could be used across the entire traveled lane. Diamond grinding is typically used to correct surface irregularities or to improve surface friction. Diamond grinding on PCC typically costs $1.70–$10.00/sq yd (Correa and Wong 2001). Any use of a surface treatment or full road width grinding to mask markings or to blend removed markings needs to consider the following:

- Are there changes in friction (skid) characteristics to the road surface?
- Will the treatment be an interim or final surface?
- If not covering the entire road width, will the treatment area match the surrounding roadway color and texture?

- Will the underlying markings be removed or remain in place?
- Based on the expected service life of the surface treatment and markings left in place, could the markings begin to show through prior to installing a new road surface?

Several of the more common surface treatment methods are discussed herein. The discussion includes the general nature of the surface treatments and how they can be used in conjunction with the need to remove pavement markings or to blend removed areas. Estimated costs are also discussed so that the costs of covering the markings can be compared to removing the markings (Morian 2011, Wu et al. 2010, Yamada 1999). An advantage for all the surface treatments is that if they are used across the entire roadway or lane width, there will not be any color difference, and differences in surface characteristics will be minimal. The uniform color and surface texture of a new surface treatment will allow for improved delineation of the roadway and less confusion to drivers.

Fog Seals. A fog seal is a light application of a diluted slow-setting asphalt emulsion to the surface of an aged pavement surface with no additional aggregate added. Fog seals are low cost and are used to seal and rejuvenate deteriorating pavement surface. Fog seals are also used on new chip seal surfaces to reduce early stone loss. Fog seals were mentioned in several surveys as a means to blend in removed areas with the surrounding pavement so that scarring is less evident. Fog seals would not be used to cover markings, per the MUTCD, but rather as a means of blending removed areas with the surrounding pavement. Literature showed costs at $0.45/sq yd (Yamada 1999), $1,029–211,579/lane-mi ($0.14–30.05/sq yd) (Wu et al. 2010), and $1,000–3,500/lane-mi ($0.14–0.50/sq yd) (Morian 2011).

Slurry Seals. A slurry seal is a mixture of emulsified asphalt, water, well-graded fine aggregate, and mineral filler that has a creamy fluid-like appearance when applied. Slurry seals are used to fill existing pavement surface defects, to provide a uniform surface, and to prevent moisture and air intrusion. Slurry seals can also be used to improve or restore skid resistance. There are three basic aggregate gradations used in slurry seals: fine, general, and coarse. Literature showed costs at $1.20/sq yd (Yamada 1999), $26,505–32,542/lane-mi ($3.76–4.62/sq yd) (Wu et al. 2010), and $4,900–10,600/lane-mi ($0.70–1.51/sq yd) (Morian 2011).

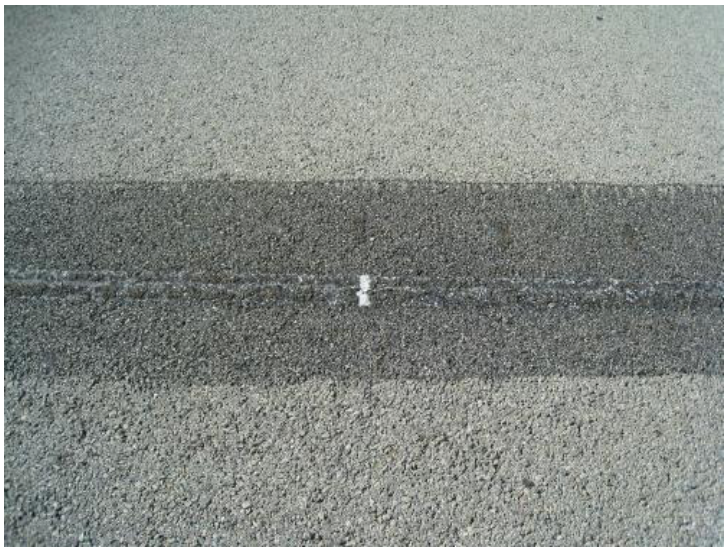
Microsurfacing. Microsurfacing is an advanced form of slurry seal that uses the same basic ingredients as slurry seals and combines them with advanced polymer additives. It is useful for sealing pavement surfaces and for providing improved friction characteristics. Literature showed costs at $1.50/sq yd (Yamada 1999), $19,463–32,698/lane-mi ($2.76–4.64/sq yd) (Wu et al. 2010), and $1,000–34,100/lane-mi ($0.14/sq yd–4.84/sq yd) with an average of $12,600/lane-mi ($1.79/sq yd) (Morian 2011).

Chip or Sand Seal. Chip seals are also known as seal coat and are a thin protective wearing surface that is applied to a pavement or base course. The size or type of aggregate distinguishes chip seal from sand seal. The aggregate for chip seal can be crushed stone, gravel, or slag; the aggregate for sand seal can be either natural sand or rock screenings. Chip seals are generally used to improve the skid resistance of pavement surfaces and to improve the surface seal by filling cracks and voids to prevent water intrusion. Many chip seals are often followed by a fog seal to help fill voids and to lock in any loose aggregate. Literature showed single chip seal costs at $1.20/sq yd (Yamada 1999), $6,732–145,976/lane-mile ($0.96–20.70/sq yd) (Wu et al. 2010), and $3,900–12,300/lane-mile ($0.55–1.75/sq yd) with an average of $7,460/lane-mile ($1.06/sq yd) (Morian 2011). Literature showed sand seal costs at $0.70/sq yd (Yamada 1999) and $4,900/lane-mile ($0.70/sq yd) (Morian 2011).

Studies in Florida (Ellis et al. 2010, Ellis 2003) investigated pavement marking eradication alternatives that masked or covered pavement markings with an inexpensive surface treatment. The estimated installation costs were $0.47–1.15/lf ($1.03/sq yd) for a modified sand seal coat. This was assuming covering one travel lane and one marking. If multiple markings were covered, the unit costs would be even lower. While the study period with regard to durability was short, at 30 days, the method proved effective. Friction characteristics of the modified sand seal coat were deemed acceptable.

Figure 53 shows an example of using a surface treatment to cover markings on an HMA road surface. The area of road was converted from two lanes in the same direction to a merge area before entering the realigned roadway. Images a and b were taken approximately 2 years after installation. The markings are mostly covered, but the surface treatment does not match the color of the surrounding road surface very well. The 2-ft width of the surface treatment may help reduce confusion due to the different colored surfaces. Images c and d were taken approximately 9 months after images a and b. The loss of the surface treatment material over time has exposed much of the marking below and reduced the color differential between the surrounding road and the surface treatment. This area will now need to have the markings removed or a new surface treatment added. To avoid issues like this, a surface treatment that would last until the road was to be resurfaced should have been used, or the markings could have been removed and the areas blended with the surface treatment. Over time, any scarring or discoloration from the

a) Surface treatment masking



b) Close-up of marking and surrounding area

c) 9 months later

d) Close-up 9 months later

Figure 53. Surface treatment masking example.

removal would become less evident as the surface treatment wore away.

Masking Markings Using Marking Materials

In some instances where markings only need to be removed for a short period of time, it may be beneficial to just cover the markings instead of removing them. By covering the markings using a temporary removable tape, there will be no damage to the underlying road surface, and after removal of the temporary pavement marking, the original marking may still be usable. Based on the survey responses, black tape on asphalt surfaces is the most common form of temporary tape used to mask markings. The use of "removable, non-reflective, preformed tape that is approximately the same color as the pavement surface may be used where markings need to be covered temporarily" is allowed by the MUTCD (FHWA 2009).

Being that temporary marking tapes used for masking are typically only available in black, a major problem arises when the pavement surface is not black. The black marking will only work for newer asphalt road surfaces, not aged and faded asphalt or concrete. If the black masking material is used on a lighter-colored surface, the black marking will be noticeable and could be confusing and mistaken for delineation. A

means of counteracting this would be to produce tapes of differing shades to better match road surfaces. The smaller production quantities of these types would greatly increase the costs, but the results could be much better. Studies in Florida (Ellis et al. 2010, Ellis 2003) found that 8-inch wide temporary black tape costs ranged between $1.83–1.97 installed per foot for small quantities.

There is at least one effort underway to design a pavement marking tape that will be able to match the surface color of a roadway better. A mottling technique using shades of gray to better match colors is being developed. The technique is currently being developed by SBS Systems, LLC under Patent Application #61/572,895. The concept if issued would be made available to all producers of pavement marking tapes. Figure 54 represents an image of some of the prototype markings being developed. It is clearly evident that the marking in the middle much more closely matches the surface's color than the standard black marking.

According to the MUTCD, "Painting over existing pavement markings with black paint or spraying with asphalt shall not be accepted as a substitute for removal or obliteration" (FHWA 2009). The tape is allowable for temporary situations where the underlying markings will be reused. It is not allowable, though, to paint or spray asphalt over a marking in a temporary (the underlying markings would no longer be usable) or permanent application. The concern is that the underlying marking will eventually wear through the covering marking, resulting in a traffic hazard. In addition, the underlying marking wearing through the covering material may not match the road surface color adequately to start with or over time. Since road surfaces and marking materials deteriorate at different rates, even a good initial color match may not last for long. Even though this technique is not acceptable according to the MUTCD, several instances of this occurring have been viewed around the country.

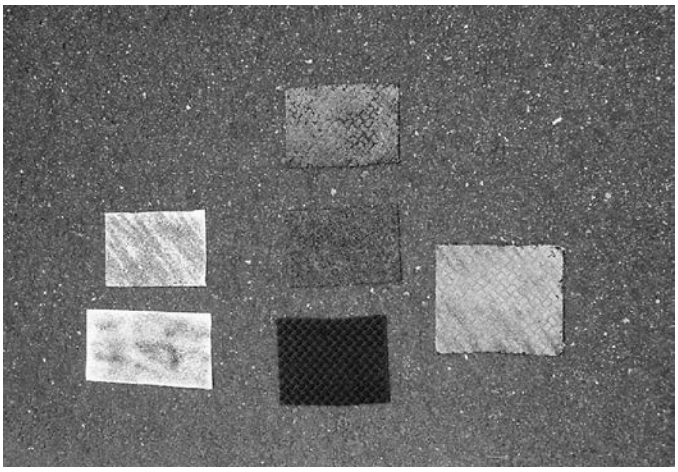


Figure 54. Various versions of preformed tape with a mottled color (SBS Systems 2011).

Figure 55. Black marking material covering old marking.

Figure 55 shows a black non-tape marking material being used to permanently mask the underlying white material where lane lines were not placed in the proper location after a new road surface was installed. The color difference between the black marking and the asphalt road surface is very noticeable. Some of the white marking is also beginning to be exposed along the edges, which is a reason why the MUTCD does not allow this practice for permanent situations. Figure 1c showed both lane lines and a center gore area marking being covered by a black non-tape marking material. This is likely not a permanent application due to the ongoing work that will likely include a new final surface layer. According to the MUTCD, this practice is not acceptable, but for a situation such as this, as long as the non-tape pavement markings are maintained, it should be allowable.

Blending Removed Markings

When markings are removed, the removed area may be discolored from the surrounding pavement and may also have different surface characteristics that reflect light differently than the rest of the surface. This discoloration and change in surface characteristics may result in confusing the removed area with an actual marking. To counteract this, the removed area could be blended into the surrounding pavement using surface treatments or other materials to match the color of the surface. Several surveys indicated the use of fog seals to blend marking removal with the surrounding surface on asphalt roadways. The fog seal could be used across the entire roadway so that as the fog seal ages, the entire road surface would remain the same color. The black color of the fog seal

would not be a viable option on concrete road surfaces. On concrete surfaces or asphalt surfaces where a fog seal is not viable, color-matching paint or mottling colors like the tape in the previous section would be viable options.

There are currently no paint pavement marking systems that are specifically designed for color-matching road surfaces. Black paint can be used by itself or blended with white paint until the color matches as best as possible. A solid color may also not match the road surface very well, as there are typically many colors in a road surface. Using a mottling technique with paints of different colors may yield the best color-matching results. Road surfaces and paints age at different rates, so a good match initially may not be good for long, which is a drawback of blending in a small area around the marking.

A small scale test was conducted as part of this research to see if mottling paint could produce a color-matching coating that reduced the discernability of the color difference between the removed area and the surrounding pavement. The concrete surface that some of the markings were removed from was relatively dark, and after removal, a large color difference was evident. Two colors of paint representing colors within the pavement surface were produced in spray paint cans for ease of application in the test. The material sprayed was not a pavement marking paint, so its durability was unknown, but this was not a concern since it was for demonstration purposes. Standard pavement marking paint could be dyed in a similar fashion. The paints were sprayed in a mottled fashion along approximately 3 ft of the removed area.

Figure 56 provides images of a removed marking area with and without blending. The removal method used was grinding, which caused the top surface of the concrete to appear much lighter in color than the surrounding surface (see Figure 56a). After using the two colors of paint to blend in the area, the color difference was much less noticeable (see Figure 56b). Though not perfectly blended in with the surrounding road surface, the blended area is much less noticeable than the area without blending.

a) Without Blending

b) With Blending

Figure 56. Grinding on concrete, looking away from sun.

Figure 57 provides another set of images of a removed marking area with and without blending. The removal method used was water blasting, which cleaned the top surface of the concrete, resulting in a lighter-colored surface than the surrounding surface (see Figure 57a). This color difference was not as great as it was for the grinding, but it was still very noticeable. After using the two colors of paint to blend in the area, the color difference was much less noticeable (see Figure 57b). Though not perfectly blended in with the surrounding road surface, the blended area is much less noticeable than the area without blending.

Blending of removed areas using fog seals or color-matching paint, especially when mottled, can be an effective means to hide scarring or discoloration caused by pavement marking removal, at least in the short term. The long-term impacts depend on the durability of the materials used for blending, the difference in aging of the blending materials compared to the road surface, and the natural blending over time of the removed area with the surrounding area.

a) Without Blending

b) With Blending

Figure 57. Water blasting on concrete, looking away from sun.

CHAPTER 7

Conclusions, Recommendations, and Suggested Research

The objective of this research was to determine best practices for the safe, cost-effective, and environmentally acceptable removal of work zone and permanent pavement markings with minimal damage to the underlying pavement or visible character of the surface course. The objective itself had many areas that needed to be evaluated in order to determine the best practices for pavement marking removal. The summation of the conclusions and recommendations from this research effort are described in this chapter. The conclusions address information gathered during the research and how that information addresses the research objectives. The recommendations provide guidance to practitioners by using the results of the research and the conclusions to establish best practices for pavement marking removal.

Conclusions

To address the objectives, the research team used a multifaceted approach. The literature review, survey, controlled test deck removal, field observations, and additional research areas all yielded information used in forming the conclusions and recommendations of the research. Appendix E contains a standalone table of pros and cons of the most common forms of pavement marking removal. This table highlights the advantages and disadvantages of each removal technique, which should aid in the selection of the most appropriate removal technique.

The survey responses indicated that grinding was the most common form of pavement marking removal and that it was preferred by many, even though most noted the drawbacks of pavement scars that are often left behind. Water blasting was also commonly used and is becoming more common as more equipment makes its way to the field. Water blasting was the most common method that the survey respondents would like to try. Both sand and shot blasting were commonly used, but they also both received several responses that indicated they were no longer being used. Outside of those four removal techniques, the temporary masking of markings was the only other method regularly used in the field. Other removal methods, such as chemical, heat, laser, and other forms of blasting, such as soda, dry ice, or glass, are not commonly being used.

Grinding removal is the most available removal technique and is also the least expensive type of marking removal. Water blasting systems are becoming more common, but availability is limited in some areas. Water blasting is more expensive than grinding; the survey responses and literature review indicated water blasting can be, on average, 10 to 40 percent more expensive than grinding. The cost of removal is highly dependent on the availability of equipment and size of the removal contract. Typically, only grinding and water blasting are used for long stretches of removal because they can remove marking at a greater rate than other techniques. Other removal techniques, such as shot and sand blasting, as well as grinding and water blasting, are used for shorter removal sections.

The environmental impact of pavement marking removal is something that should be considered when selecting a removal method. Removal can generate dust, limiting visibility for nearby drivers, or produce waste that may require special containment and disposal. Sweeping and vacuuming as well as wet removal are methods used to combat dust and collect the removal debris. Wet removal may be limited in colder weather due to the chance of freezing. State specifications indicate that 19 states require equipment to contain dust and debris especially when conducting removal within 10 ft of an occupied lane. An additional 14 states require the prompt removal of dust and debris as the work progresses. Grinding equipment may or may not have a vacuum system that can capture dust and smaller debris. Grinding removal will require an additional pass from a vacuum truck or sweeper to remove the remaining material from the road surface. The new water blasting equipment has a high-powered vacuum system that is able to capture most of the removal debris and water, which results in no dust or the need for additional cleaning of the removed material. Sand blasting results in large amounts of debris from the sand

and the removed markings and requires a vacuum truck or sweeper to remove the material from the road surface.

The survey responses and literature review indicated that there are chemical removal systems that are environmentally acceptable, but these systems are seeing limited use. The use is limited because of dissatisfaction with previous removal results and length of time and costs necessary to remove the marking. Another possible limitation is that only paint pavement markings can be removed with chemical systems. There were no chemical removal systems found that have been used to remove any pavement marking type other than paint.

There are methods of applying durable coatings over the markings to blend into the appearance of the pavement. The problem is that these coatings and the surrounding pavement may change colors at different rates over time, and the covered area will no longer blend as well as it did originally. The surface texture of the painted areas and the surrounding pavement will also be different and may be noticeable under certain driving conditions, such as the sun being low on the horizon or the pavement being wet. Simply covering the markings with a durable material also leaves the possibility that the marking may later be exposed and need to be either removed or recovered with another durable material. Subsequently, the MUTCD only allows the markings to be covered for temporary conditions. Color-matching paint systems may be better suited in a light application over removed areas in the short term to help blend in color differences after removal until the removed area has time to age and blend into the surrounding pavement. Any materials placed over a marking to mask it need to be maintained so that the marking does not become exposed over time.

The literature review yielded research that evaluated the use of a sand seal across the entire lane width to mask the markings. This technique was found to be effective at masking the markings while maintaining adequate surface friction. The cost of the sand seal was also much cheaper than removable black masking tape. This type of masking could be useful in certain situations but would need to be monitored to ensure that the covered markings do not begin to show through the masking material.

The survey responses indicated that after the removal of pavement markings, fog or slurry seals have been used to help blend the removed areas with the surrounding pavement surface. The use of a fog seal or slurry seal to help blend color changes, scarring, or surface texture changes to the surrounding pavement will only be useful on asphalt road surfaces. The researchers propose that on concrete surfaces where a discoloration occurred after marking removal, a larger area could be washed or cleaned with a high-pressure water blasting system to help blend in the removed area to the surrounding pavement. The field studies indicated that when the sun is behind the viewer, it makes the removal area more visible by lighting up the unremoved marking and reflecting off the textured surface. When looking toward the sun, there is glare off smooth surfaces, and textured surfaces look dull. Using a technique such as a fog seal or water blasting a larger area will reduce visibility issues associated with the sun because the area will be more uniform in appearance.

The survey responses did not indicate any usage of a combination of heat and mechanical processes to remove markings. Several state DOTs indicated they have used a combination of grinding and blasting techniques, but not heat. The combination method some respondents typically use is grinding to remove the marking above the road surface and then a blasting method to remove the marking below the road surface. The thought is that the grinding can quickly remove the bulk of the material without damaging the road surface, and then the blasting can remove the rest of the marking quicker than it normally could because there is less material to remove. This results in a technique that can remove all of the marking relatively quickly with minimal scarring. The field testing showed that this method can be effective, but there is still the opportunity for pavement damage if the blasting technique is too aggressive. This technique is also only effective for pavement marking materials that are thick enough for the grinding technique to be able to remove them without damaging the road surface.

The MUTCD calls for removing or obliterating markings until they are unidentifiable as markings. There are not standards for acceptable levels or criteria for how to determine a marking is no longer identifiable. The level of removal needed to make a marking no longer identifiable will differ for each situation. White markings on lighter-color road surfaces will not require the same level of removal as white markings on a dark surface. Removing a marking to the point of making the marking itself no longer identifiable may result in damage to the road surface that could be confusing to drivers. The MUTCD indicates that the removal of the marking should minimize pavement scarring. Again, there are not standards for acceptable levels or criteria for how to determine scarring. The wording in the MUTCD regarding how to minimize scarring acknowledges that when removing pavement markings, some scarring may occur. It is the agencies' job to ensure that appropriate pavement marking removal practices are used to minimize the scarring while removing enough of the marking material to no longer be considered as guidance or be confusing to drivers.

In general, the state DOT specifications call for the complete removal of the markings while limiting damage to the road surface. Several states did call for specific levels of required removal, ranging from 75 to 100 percent, with the majority indicating 90 or 95 percent removal. Several states also indicted maximum allowable depth of pavement scarring ranging from 1/16 to 1/4 inch, with the majority indicating 1/8 of an inch or less. The survey responses did acknowledge the need for a balance between the removal percentage and damage to the road surface. The thought is that to attain 100 percent

removal, excessive damage to the road will occur, whereas 90 or 95 percent removal may do minimal damage to the road surface. Leaving marking material on the road surface or damaging the road surface will both be visible to drivers, so an adequate balance needs to be sought for each individual situation. The required level of pavement marking removal should vary depending on the reason for the removal and the roadway conditions where the removal takes place. Based on current practice, typical removal should be specified at 90–95 percent, with ⅛ of an inch or less of pavement damage.

The majority of survey respondents indicated that only subjective visual assessments were used to determine if marking removal was acceptable or not. While these assessments may be deemed acceptable, supplementing the assessment with quantitative measures may be beneficial to help promote consistency between inspectors. Retroreflectivity measurements, scar depth measurements, and estimated texture depth measurements were found to be quantitative measures that could help supplement subjective assessment when trying to determine the quality of pavement marking removal. Retroreflectivity measurements will give an indication of nighttime retroreflective contrast that drivers will see between the removed area and the surrounding pavement. Minimizing the retroreflective difference between the removed area and the surrounding pavement will reduce confusion of the removed area at night. Scar depth and estimated texture depth measurements will provide a measure of damage to the road surface. Minimizing the scar depth reduces road surface damage and the likelihood the removed area will be confused as a marking, especially in wet conditions. Estimated texture depth measurements should be as close to the measurements on the surrounding road surface as possible, or in any lighting situation, the removed area and surrounding road surface will appear different.

The controlled field test deck removal and field observations found many good and some bad pavement marking removal results. High-pressure water blasting provided good removal on the PCC surfaces with little damage to the road surface and good removal of the marking materials. On asphalt surfaces, the results were mixed. The system typically removed all of the marking, but in some test areas, the high-pressure water blasting system removed some of the surface asphalt and fines. The flailing truck had mixed results on both the PCC and asphalt surfaces. To achieve a high level of removal, the flailing truck typically left a scar on the road surface. Minimal scarring may be okay in some areas, but in critical areas such as lane-shift areas, scarring needs to be minimized as much as possible. The speed of removal depended on the marking type and the quality of the removal. The water blasting was as fast as or faster than the flailing for many of the tests.

The orbital flailing system was not as aggressive as the full-size truck drum flailing system, and so it left minimal scarring on the road surface. The orbital flailing system did not dig into the road surface like the standard flailing systems did, resulting in minimal changes to the surface texture and minimal scar depth. The drawback to this was the system seemed to have difficulty removing paint and preformed thermoplastic markings that found their way into voids below the pavement surface. The orbital flailing system was not a full-size system, which resulted in much slower removal than the other full-size removal methods tested.

The combination removal had mixed results. On PCC, the removal was good, with removal results similar to those of the high-pressure water blasting alone, but at a higher rate of removal. On the asphalt surface, there was quite a bit of scarring of the road surface that was slightly worse than the removal using the high-pressure water blasting by itself. Care needs to be taken when doing the initial grinding of the marking above the road surface to not damage the road surface and to remove the marking as evenly as possible so that the water blasting can remove an even layer of the remaining material.

Temporary tape is often used on final surfaces so that the material can be pulled up, unlike other materials that have to be removed by other removal techniques that are more likely to damage the road surface. Temporary tape is still not a perfect solution, as its removal may leave behind residue that may appear to look like a marking especially on PCC or light-colored surfaces. Further exploration of the NTPEP temporary tape database would allow for more specific information to be evaluated that may be beneficial to a particular set of conditions. Users should evaluate the temporary tapes they want to use to select the most durable, the least discernible when removed, or a material that is the best combination of the two. In addition, other factors such as cost, color, and removability need to be taken into consideration.

Recommendations

The recommendations include factors to consider that relate to pavement marking removal and a set of best practices to assist in improving pavement marking removal quality. The standalone table of pros and cons of the most common forms of pavement marking removal in Appendix E should be used to help determine which type of pavement marking removal may be best suited for a given situation.

The selection of a removal system needs to take into account many factors, each of which may be more or less influential on some projects. The proper consideration of each of these factors is the best way to achieve acceptable pavement marking removal results. These factors include the following:

- What marking material is being removed?
- What road surface is the material on?
- How much of the material needs to be removed (what is the purpose of the removal)?
- Is speed of removal important?

- What removal techniques are available and at what cost?
- Are there special environmental conditions that need to be considered?
- How long will the removed area be viewed by drivers (will a new surface be installed or markings restriped in the future)?
- Will the removed area be in a location where confusion could lead to an accident?
- Are there other measures that can be taken to minimize confusion to the driver?

Best Practices

Pavement marking removal should be specified as a percentage of material removed based on the purpose of the removal. The percentage of material removed equates to the percentage of the road surface made visible where the marking was removed. The purpose of the removal should also play a role in the removal method selected and other measures selected to provide a roadway with delineation that is not confusing to drivers. Table 58 provides suggested percentage levels of pavement marking removal based on the purpose of the marking removal. These suggested percentages are based on the results of the survey, literature review, and field evaluations. Based on current practice, damage to the road surface should be ⅛ of an inch or less while changing the road surface texture as little as possible.

Changing pavement marking patterns is the most critical pavement marking removal because the old markings are no longer conveying the travel path to the drivers. Any errors in removal can lead to drivers being confused by the old markings or the removed areas. A high percentage of the material needs to be removed, but damage to the road surface also needs to be considered. Open-graded or tined surfaces may require the material below the pavement surface to be removed with a blasting technique to minimize scarring. Depending on the road surface type and the road conditions, additional measures may need to be taken to reduce driver confusion with the removed markings. These additional measures can include fog or slurry seals over the removed area or the entire lane width on asphalt surfaces. The friction of the road surface needs to be considered, but these techniques will help blend the removed areas with the surrounding pavement. On PCC surfaces, additional light removal around the removed area or across the entire lane width can be conducted with a blasting technique such as water blasting to help blend in the removed area.

Remove and replace is the process of removing the current pavement marking material and restriping in the same location where removal occurred. This type of removal is conducted to remove a poorly bonded material so the new material can form a good bond, to reduce the overall thickness of restriped markings, or to remove an aged marking that is incompatible with the new marking that is being applied. For remove and replace with compatible markings, the whole marking does not always need to be removed, so removal can be limited to at or above the road surface. This can help limit scarring to the road surface. Removal by grinding may be the best option, but if full removal or removal of material below the surface is needed, then water blasting or another blasting technique may be a better option to minimize scarring.

When installing a new surface treatment or new surface overlay, it is advisable and sometimes required to remove the existing pavement markings. Pavement markings under a surface treatment or thin overlay may eventually become exposed as the new surface wears. Therefore, the majority of the material should be removed to ensure that the new surface does not eventually become exposed, and so that the new surface can bond well with the surface below it. The buildup of pavement markings under surface treatments may also be detrimental to the drainage of the road.

Practitioners need to consider the work phasing and the final road surface. If markings are to be removed for a short duration prior to a new surface, then damage to the road surface is not as critical compared to a removed area that will be visible for a longer duration. Any removal on the final road surface needs to be accomplished with minimal damage to the road surface. It may be best to use temporary pavement markings on the final road surface until the final marking configuration so that removal will do as little damage to the road surface as possible.

Table 58. Suggested percentage of pavement marking removal based on purpose of removal.

Purpose of Pavement Marking Removal	Suggested Percentage of Material Removed
Change marking patterns	90–95 (100 percent may be necessary in some instances)
Remove and replace compatible materials	70–90 Follow new marking material manufacturer guidelines
	80–100
Remove and replace incompatible materials	Follow new marking material manufacturer guidelines
Apply surface treatment or new surface overlay	Follow state guidelines

The selection of the most appropriate pavement marking removal system needs to consider the amount of removal that is required and the length of time available to complete the removal. If the removal quantity is large, full-size removal trucks should be used. If the removal quantity is small, hand units and the slower removal methods can be considered.

The removal of symbols and text should be removed in a square or rectangular pattern so that the previous shape is not left as a scar or discoloration. This requires removal of the marking and the necessary removal/cleaning around the marking to help blend in the area with the surrounding pavement by creating a larger removal area that is no longer recognized as a symbol or text.

Older road surfaces that are experiencing cracking or surfaces with joints may need special consideration when removal occurs. The use of high-pressure water blasting on these surfaces can lead to road damage if the water is allowed to penetrate into the cracks or joints. Grinding may also pose a threat to cracks and joints. Removal around these areas should be conducted carefully, such that the joints are not disturbed and the cracks are not made worse by the removal.

Initially, any pavement marking removal project should begin with testing the removal equipment in a non-critical area to evaluate the removal. This initial testing will show how well the operators can use the equipment to remove the marking material and how much damage is done to the road surface. The test area can be used to adjust the equipment to find the ideal setup for the work required. If the operator and equipment cannot provide satisfactory results, another removal system should be considered.

The quality of removal needs to be evaluated during the day, at night, and during wet conditions. Surface color changes and scarring will have a greater impact during the day than at night, whereas retroreflectivity from remaining marking material or retroreflectivity differences because of surface texture changes will be more noticeable at night. The direction of travel and the position of the sun also need to be considered. Wet conditions may fill pavement scarring, resulting in an area that looks like a wet marking and thus creating confusing delineation. Any areas with color, texture, or retroreflectivity issues should be corrected to reduce or eliminate driver confusion.

Pavement marking specifications for areas where removal has occurred should consider post-removal conditions. Wider markings and continuous markings in transition areas will provide better guidance to drivers and may reduce confusion of the removed marking areas by enhancing the new markings. Markings with high retroreflectivity levels should also be maintained in areas where previous removal could lead to confusion by drivers at night. The high retroreflectivity of the new markings will be more noticeable to drivers than removed areas of markings with lower retroreflectivity levels.

Implementation

This research report will serve as the primary means of transferring the research results to practitioners. The report will be distributed directly to the survey respondents, as they have already shown interest in the research by participating in the survey and thus are the most likely candidates to be interested in implementing the results of the research. The report will also be distributed through the *TRB E-Newsletter*. In addition to this research report, the researchers intend to develop a paper to be submitted for presentation at the TRB's Annual Meeting and for publication in the *Transportation Research Record*. A webinar on this research project, or pavement marking removal in general, may also be a good means of transferring these research results to those who can best implement them.

Suggested Research

The research described in this report used several quantitative and qualitative measures to evaluate the quality of pavement marking removal. What was not conducted was a human factor study to evaluate drivers' responses to visibility issues associated with pavement marking removal. A human factor study could evaluate the areas of pavement marking removal that are viewed as the most confusing by drivers and/or provide additional information on developing required removal levels or how much change to the road surface is acceptable from a driver's perspective.

The survey of the current state of the practice indicated that chemical removal systems are not being used very often. Several possible reasons for this are dissatisfaction with removal results, length of time and costs necessary to remove the marking, health and environmental concerns, and the limited marking types that can be removed with current chemical removers. Near the conclusion of this research project, the research team was made aware of a new chemical removal system that claimed to be able to remove paint, epoxy, and urethane markings while doing no damage to asphalt or PCC road surfaces and being environmentally safe. There was no time to evaluate this removal system, but if the claims are true, the chemical system may prove viable for the removal of applicable marking systems in certain circumstances, such as lane-shift areas. The researchers suggest further research into recently developed chemical removal systems to evaluate their claims and to determine if their use in the field by transportation agencies is feasible.

References

AKDOT&PF, Alaska Department of Transportation and Public Facilities, *Alaska Storm Water Pollution Prevention Plan Guide,* January 14, 2005, http://www.dot.state.ak.us/stwddes/desenviron/assets/pdf/swppp/english/eng_guide_all.pdf, Accessed May 2, 2011.

Berg, K., and S. Johnson. *Field Comparison of Five Pavement Marking Removal Technologies.* Report No. UT-08.12. Utah Department of Transportation. Salt Lake City, UT. 2009.

Bryden, J. E., and W. D. Kenyon. *Methods for Removal of Pavement Markings.* Report No. 130. Engineering Research and Development Bureau, New York State Department of Transportation. Albany, NY. May 1986.

Caltrans, California Department of Transportation, *Statewide Storm Water Management Plan* (CTSW-RT-02-008), May 2003, http://www.dot.ca.gov/hq/env/stormwater/pdf/swmp_may2003final.pdf, Accessed May 2, 2011.

Cho, Y., K. Kabassi, and J. Pyeon. *Effectiveness Study on Temporary Pavement Marking Removal Methods.* Report No. SPR-P1 (11) M305. Nebraska Department of Roads, Lincoln, NE. June 2011.

Coherent Inc. Laser Diode Paint Stripping. http://www.coherent.com/index.cfm, Accessed October 28, 2010.

CDOT, Colorado Department of Transportation, Stormwater Program, Updated Feb 2011, http://www.coloradodot.info/programs/environmental/water-quality/stormwater-programs.html, Accessed May 2, 2011.

CDOT, Colorado Department of Transportation, *Water Quality Program: Illicit Discharges Program,* factsheet, 2008, http://www.coloradodot.info/programs/environmental/water-quality/documents/illicit-discharge-program/cdot-idde-factsheet_1-21-08.pdf/at_download/file, Accessed May 2, 2011.

Correa, A. L., and B. Wong. *Concrete Pavement Rehabilitation—Guide for Diamond Grinding.* FHWA-SRC-1/10-01(5M). Federal Highway Administration, Washington, DC. 2001.

Eastern Research Group. *Traffic Markings.* Volume III, Chapter 14, U.S. Environmental Protection Agency. 1997.

Ellis, R. *Development of Improved Procedures for the Removal of Pavement Markings During FDOT Construction Projects.* University of Florida, Gainesville, FL. July 2003.

Ellis, R., B. Ruth, and P. Carola. *Development of Improved Procedures for the Removal of Pavement Markings During FDOT Construction Projects.* Report No. WPI 0510792. University of Florida, Gainesville, FL. June 1999.

Ellis, R. D., J. Pyeon, S. Lee, and B. Kim. "Evaluation of Seal Coating Treatments to Manage Temporary Pavement Paint Markings During Highway Construction." *KSCE Journal of Civil Engineering.* Vol. 14, No. 4, July 2010, pg. 461–471.

FHWA. *Manual on Uniform Traffic Control Devices.* 2009 Edition. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, December 2009.

FDEP, Florida Department of Environmental Protection, NPDES General Permits (Chapter 62-621), Effective 2011, http://www.dep.state.fl.us/legal/Rules/shared/62-621/62-621.pdf, Accessed May 2, 2011.

Heydon, A. "Surface condition, equipment dictate marking removal success." In *Pavement Maintenance and Reconstruction Journal.* Johnson Hill Press: Fort Atkinson, WI. February 1997. pg. 19–20.

Irwin, R. J., M. VanMouwerik, L. Stevens, M. D. Seese, and W. Basham. *Environmental Contaminants Encyclopedia.* National Park Service, Water Resources Division, Fort Collins, Colorado. 1997.

Jackson, N. M., R. Salem, and S. Thiesse. Evaluation of Temporary Pavement Marking Materials and Methods. University of Tennessee. Prepared for the Second International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control. Auburn, Alabama. 2001.

Kilgore, D. *Equipment Improvements for Removal of Traffic Markings by High Temperature Burning with Excess Oxygen.* Federal Highway Administration. Washington, D.C. 1980.

Mathis, D., and K. Ward. *FHWA/WSDOT Pavement Marking Removal Issues and Solutions Joint Review.* Olympia, WA. September 2006.

Migletz, J., J. Fish, and J. Graham. *Roadway Delineation Practices Handbook.* Report FHWA-SA-93-001. Federal Highway Administration, Washington, DC, August, 1994.

MnDOT, Minnesota Department of Transportation, MnDOT Metro District's MS4 Stormwater Program, http://www.dot.state.mn.us/metro/waterresources/, Accessed May 2, 2011.

Morian, D. A. *Cost Benefit of Including Microsurfacing in Pavement Treatment Strategies & Cycle Maintenance.* Report FHWA-PA-2011-001-080503. Pennsylvania Department of Transportation, Harrisburg, PA. January 2011.

NTPEP, National Transportation Product Evaluation Program. NTPEP DataMine for Pavement Marking Materials. http://data.ntpep.org/TechnicalCommitteeInformation.aspx?tc=PMM, Accessed April 22, 2011.

NTPEP, National Transportation Product Evaluation Program, "NTPEP Best Practices Manual." 2005.

NYSDOT, New York State Department of Transportation, *Memorandum of Understanding Between the Department of Transportation and the*

Department of Environmental Conservation Regarding the SPDES General Permit for Stormwater Discharges from Construction Activity, GP-02-01, 2003, https://www.nysdot.gov/divisions/engineering/environmental-analysis/repository/spdes_mou_2003.pdf, Accessed May 2, 2011.

Niessner, C. W. *Traffic Stripe Removal.* Report No. FHWA-TS-79-227. Federal Highway Administration, Washington, DC, 1979.

Ohio DOT, Ohio Department of Transportation, Storm Water Management Program, http://www.dot.state.oh.us/stormwater/Pages/default.aspx, Accessed May 2, 2011.

Oregon DOT, Oregon Department of Transportation, Research Notes: Methods for Traffic Stripe Removal. November, 2001. http://www.oregon.gov/ODOT/TD/TP_RES/research_notes/rsn02-05.pdf?ga=t. Accessed October 28, 2010.

Pew, H., and J. Thorne. *Laser Removal of Paint on Pavement.* Innovations Deserving Exploratory Analysis (IDEA) Project 16. Transportation Research Board, National Research Council. Washington, DC. February 2000.

SBS Systems, LLC. Image of Pavement Marking Development under Patent Application #61/572,895. September 2011.

TDOT, Tennessee Department of Transportation, *Statewide Storm Water Management Plan,* 2007, http://www.tdot.state.tn.us/sswmp, Accessed May 2, 2011.

TxDOT, Texas Department of Transportation, *Storm Water Management Guidelines for Construction Activities,* 2002, http://www.txdot.gov/txdot_library/consultants_contractors/publications/environmental_resources.htm#storm, Accessed May 2, 2011.

U.S. Environmental Protection Agency (EPA), Help Using the TSCA Chemical Substance Inventory Files. http://www.epa.gov/oppt/newchems/pubs/tscainventorydatahelp.htm Accessed May 2, 2011.

VDEQ, Virginia Department of Environmental Quality, Guidance Memo No. 04-2016, *VDOT VPDES Storm Water Construction Permitting.* June 30, 2004. http://www.deq.virginia.gov/waterguidance/pdf/042016.pdf, Accessed May 2, 2011.

VDOT, Virginia Department of Transportation, *Manual of Practice for Stormwater Management,* November 2004, http://www.virginiadot.org/vtrc/main/online_reports/pdf/05-cr5.pdf, Accessed May 2, 2011.

Wu, Z., J. L. Groeger, A. L. Simpson, and R. G. Hicks. *Performance Evaluation of Various Rehabilitation and Preservation Treatments.* Report FHWA-HIF-10-020. Federal Highway Administration, Washington, DC, January 2010.

Yamada, A. Asphalt Seal-Coat Treatments. Report No. 9977 1201-SDTDC. U.S. Department of Agriculture, Forest Service, Technology and Development Program. April 1999.

APPENDIX A

Original State DOT and Local Agency Survey

1. What are the most common reasons for pavement marking removal?

1.
2.
3.

2. Does your agency contract out for pavement marking removal or use in-house crews and equipment? Please explain the conditions of each.

☐	Contract out:
☐	Use in-house crews and equipment:
☐	Both contract out and in-house:

3. Does your organization have any standard practices or specifications for pavement marking removal?

☐ Yes ☐ No

If yes, please provide a copy or a website address:

4. What types of pavement marking removal methods are used or have been used by your organization? Please list the status of the removal type (currently used, no longer used, experimental, never used) types of pavements or road surfaces where each type is used (HMA, PCC, surface treatment, etc.) and the types of marking removed (paint, thermoplastic, tape, epoxy, polyurea, MMA, etc.).

Type of Removal	Status of Removal Type	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed
Water Blasting			
Grinding			
Sand Blasting			
Shot Blasting			
A Combination of Blasting and Grinding			
Masking (black markings, slurry or black tape to cover existing markings)			
Other (describe):			

5. If your organization uses any masking technologies (black pavement markings, slurry or black tape) to cover existing markings, are they covered for temporary applications, permanent application, or a combination of both?

☐	Temporary:
☐	Permanent:
☐	Combination of Both:

6. If your organization no longer uses or have not used a type of removal, please explain why they are not used.

7. Are you aware of any emerging technologies in the field of pavement marking removal such as chemical systems or a combination of mechanical processes?

☐ Yes ☐ No

If yes, please describe and/or provide a website link or more information.

8. Are there any removal technologies that you would like to try that you are not currently using?

☐ Yes ☐ No

If yes, please describe which types you would like to use.

9. What are typical removal costs, listed by removal technique/road surface type/marking material?

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Estimated Removal Cost ($/Line-mile)

10. What are typical production quantities for marking removal (time to remove a specific amount of marking)? List by removal technique/road surface type/marking material.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Estimated Production Rate (Line-miles/day)

11. Does your organization specify a production rate for pavement marking removal? If yes, please explain.

☐ Yes ☐ No

12. Are temporary work zone markings removed in a similar manner as permanent markings? Please explain.

☐ Yes ☐ No

13. When selecting markings for a work zone is the quality and cost-effectiveness of removal (and subsequent remnants/scarring) taken into consideration? Please explain.

☐ Yes ☐ No

14. In areas where construction or maintenance has occurred and the markings will not go back to their previous pattern are any steps taken (e.g., blending) to ensure the areas of removed marking are not still perceived to be acting as delineation (i.e., ghost markings)? Please explain.

☐ Yes ☐ No

15. Describe any environmental concerns or issues associated with pavement marking removal processes used by your organization. Indicate whether these issues are related to solid and hazardous waste, water quality, air quality, or other factors.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Environmental Concerns or Issues by Marking Removal Process

With respect to these environmental concerns or issues describe techniques or processes used to reduce potential environmental impacts associated with the removal processes, including the disposal of removed materials.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process

16. Describe any worker/general public safety concerns or issues associated with pavement marking removal processes used by your organization. Indicate whether these issues are related to hazardous substances, noise, heavy equipment, traffic hazards, or another safety concern.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process

With respect to these worker safety concerns or issues describe techniques or processes used to reduce potential impacts associated with the removal processes, including the disposal of removed materials.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process

17. On a scale of 1-10 (1=poor, 10=excellent and N/A denotes Not Applicable), rate the quality of the following pavement marking removal methods used by your organization for each of the listed criteria. If the rating is different for different road surfaces or marking types please indicate separately.

Type of Removal	Road Surface	Marking Material	Rating 1-10 or N/A				
			Extent of Removal	Level of Scarring	Environmental Impact	Cost-Effectiveness	Production Rate
Water blasting							
Grinding							
Sand blasting							
Shot blasting							
A combination of blasting and grinding							
Masking (black markings, slurry or black tape to cover existing markings)							
Other (describe):							

18. Describe your organization's preferred removal technique and indicate whether this varies by marking or road surface type?

19. Is there a method you would prefer to use but do not due to environmental impact, cost, unavailability or some other factor? Please explain.

20. Discuss how much pavement damage (surface scarring) is acceptable to completely remove a marking. Are there acceptable threshold levels?

Are traces of marking on the road surface acceptable if the majority of the marking is gone? Are there acceptable threshold levels?

21. Does your organization have any measurers of effectiveness to determine the quality of marking removal? (such as amount of scarring of the pavement, amount of marking material remaining, damage to joints or sealer)

☐ Yes ☐ No

If yes, please describe.

22. Have you received any public comments about the removal of markings?

☐ Yes ☐ No

If yes, please describe the types of comments (indicate whether the comments were positive, negative, or mixed).

23. Please describe past pavement marking removal experiences (either good or bad) that may be of benefit to this research.

24. Do you know of any other research projects that have evaluated pavement marking removal issues?

☐ Yes ☐ No

If yes, please describe and/or provide a website link.

APPENDIX B

Revised Survey

1. Does your organization have any standard practices or specifications for pavement marking removal? ☐Yes ☐No
   If yes, please provide a copy or a website address:

2. What types of pavement marking removal methods are used or have been used by your organization? Please list the status of the removal type (currently used, no longer used, experimental, never used) types of pavements or road surfaces where each type is used (HMA, PCC, surface treatment, etc.) and the types of marking removed (paint, thermoplastic, tape, epoxy, polyurea, MMA, etc.). Also, please list comments on your satisfaction with the removal types such as the pros and cons.

Type of Removal	**Status of Removal Type**	**Types of Pavements or Road Surfaces**	**Types of Marking Material(s) Removed**	**Comments on Satisfaction with Results (Pros and Cons of the Removal Method)**
Water Blasting				
Grinding				
Sand Blasting				
Shot Blasting				
Combination of Blasting and Grinding				
Masking (black markings, slurry or black tape to cover existing markings)				
Other (describe):				

3. Describe your organization's preferred removal technique and indicate whether this varies by marking or road surface type?

4. Is there a method you would prefer to use or like to try but do not due to environmental impact, cost, unavailability or some other factor? Please explain.

5. Are you aware of any emerging technologies in the field of pavement marking removal such as chemical systems or a combination of mechanical processes?
   ☐ Yes ☐ No
   If yes, please describe and/or provide a website link or more information.

6. Discuss how much pavement damage (surface scarring) is acceptable to completely remove a marking. Are there acceptable threshold levels?

7. Are traces of marking on the road surface acceptable if the majority of the marking is gone? Are there acceptable threshold levels?

8. Does your organization have any measurers of effectiveness to determine the quality of marking removal? (such as amount of scarring of the pavement, amount of marking material remaining, damage to joints or sealer)
   ☐ Yes ☐ No
   If yes, please describe.

9. What are typical removal costs, listed by removal technique/road surface type/marking material?

Type of Removal	Types of Pavement or Road Surface	Types of Marking Material(s) Removed	Estimated Removal Cost ($/Line-mile)

10. What are typical production quantities for marking removal (time to remove a specific amount of marking)? List by removal technique/road surface type/marking material.

Type of Removal	Types of Pavement or Road Surface	Types of Marking Material(s) Removed	Estimated Production Rate (Line-miles/day)

11. Describe any environmental concerns or issues associated with pavement marking removal processes used by your organization. Indicate whether these issues are related to solid and hazardous waste, water quality, air quality, or other factors.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Environmental Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Environmental Impacts for Each Process

12. Describe any worker/general public safety concerns or issues associated with pavement marking removal processes used by your organization. Indicate whether these issues are related to hazardous substances, noise, heavy equipment, traffic hazards, or another safety concern.

Type of Removal	Types of Pavements or Road Surfaces	Types of Marking Material(s) Removed	Describe Worker Safety Concerns or Issues by Marking Removal Process	Describe Techniques or Processes Used to Reduce Potential Worker Safety Concerns or Issues for Each Process

13. Have you received any public comments about the removal of markings?

☐ Yes ☐ No

If yes, please describe the types of comments (indicate whether the comments were positive, negative, or mixed).

14. Please describe past pavement marking removal experiences (either good or bad) that may be of benefit to this research.

15. Do you know of any other research projects that have evaluated pavement marking removal issues?

☐ Yes ☐ No

If yes, please describe and/or provide a website link.

APPENDIX C

State Pavement Marking Removal Specifications

STATE	REMOVAL SPECIFICATION
Alabama	http://www.dot.state.al.us/conweb/doc/Specifications/2008%20Standard%20Specifications%20for%20Highway%20Construction.pdf
	6. REMOVAL OF TEMPORARY STRIPE. A temporary solid line stripe of marking tape used on an underlying pavement layer, or any type temporary stripe of marking tape used on a wearing surface shall be removed. A temporary solid or broken line stripe of paint used on a wearing surface shall be removed if it is not to be completely covered with a Class 1H or 2 permanent stripe. Other types of temporary stripe may remain in place if the temporary stripe will be covered by the placement of paving layers or permanent stripe. (i) REMOVING STRIPE AND MARKERS. Existing traffic stripe (permanent or temporary), markers and adhesive shall be removed by a method that will not damage or disfigure the appearance of surfaces that will be visible at the completion of construction. Burning or painting over the old stripe will not be permitted. Removal of traffic stripe, existing or temporary, will be paid for as a separate item of work.
Alaska	http://www.dot.state.ak.us/stwddes/dcsspecs/assets/pdf/hwyspecs/english/2004sshc.pdf
	670-3.04 PAVEMENT MARKING REMOVAL. Remove all existing traffic markings that are in conflict with the striping details shown on the Plans, an approved TCP, or any temporary striping as directed. Do not paint over existing markings. Do not use open flame on the final paving lift. Remove pavement markings to the fullest extent possible without materially damaging the pavement surface, color, or texture. As the work progresses, remove sand or other material deposited on the pavement as a result of removing markings. Remove accumulations of sand or other material that might interfere with drainage or constitute a hazard to traffic. Before making any change in the traffic pattern, remove or obliterate pavement markings that may create confusion to motorists. Where using blast cleaning to remove pavement markings or objectionable material within 10 feet of a lane occupied by public traffic, immediately remove the residue (including dust) after contact between the sand and the surface being treated. For such removal, use a vacuum attachment operating concurrently with the blast cleaning operation or by other approved methods. Repair any damaged pavement or surfacing caused by the pavement marking removal operation.

Arizona	http://www.azdot.gov/Highways/ConstGrp/Contractors/PDF/2000_Standard_Spec/Sec701_737.pdf 701-3.06 Obliteration of Existing Pavement Markings: Pavement marking obliteration shall be accomplished by the contractor as indicated on the plans or as directed by the Engineer. Pavement markings shall be removed to the fullest extent possible from the pavement by any method that does not materially damage the surface, color, or texture of the usable pavement. Abrasive blasting, using air or water, is an acceptable method for removing pavement markings, however, other methods may be approved by the Engineer. Overpainting of markings with paint or asphalt will not be permitted. Sand or other material deposited on the pavement as a result of removing pavement markings shall be removed as the work progresses. Accumulations of sand or other material, which might interfere with drainage or might constitute conditions adverse to traffic safety, shall be removed by the contractor. Where blast cleaning is used for the removal of pavement markings or for removal of objectionable material, the residue, including dust, shall be removed immediately after contact between the sand and the surface being treated. Such removal shall be by a vacuum attachment operating concurrently with the blast cleaning operation, or by other methods approved by the Engineer. Blast cleaning shall not be used within 12 feet of a lane occupied by public traffic unless a suitable barrier separates traffic from the area being cleaned. Obliteration or removal of raised pavement markers shall include removal of the marker and adhesive pad, or adhesive pad alone if the marker is missing. Any damage to the pavement caused by pavement marking removal shall be repaired by methods acceptable to the Engineer. When asphalt slurry is used to repair damage to the pavement caused by pavement marking removal or the obliteration of the marks remaining after the markings have been removed, the asphalt slurry shall be placed parallel to the new direction of travel and shall be at least two feet in width. If obliteration of lead-based striping is necessary, it shall be accomplished by a method that is in compliance with 29 CFR, Lead Exposure in Construction, Interim Final Rule. If lead exposure prevention measures are required, the contractor shall ensure that all contractor personnel, subcontractors, and ADOT personnel present on the job site are notified of the activity and advised of precautions necessary to avoid contamination by lead compounds. The contractor shall submit a lead exposure plan to the Engineer for review at least 48 hours prior to the start of any striping obliteration activities. Payment for additional work to remove lead-based striping shall be in accordance with Subsections 104.02 or 109.04.
Arkansas	http://www.arkansashighways.com/standard_spec/2003/03-600.pdf http://www.arkansashighways.com/standard_spec/2003/final700.pdf Conflicting pavement markings shall be removed to prevent confusion to drivers. Removal of pavement markings shall leave a minimum of pavement gouging. Unless otherwise specified, painting over conflicting markings as a means of line removal will not be allowed. Line removal as specified on the plans shall be performed in such a manner that no conflicting pavement marking will be left in place. Removal of the pavement marking by a means that will gouge the surface will not be permitted. Conflicting pavement markings that exist shall be removed by blasting with water and/or sand or by grinding. This blasting or grinding is considered pavement marking removal. Line removal as specified on the plans shall be performed in such a manner that no conflicting pavement marking will be left in place. Removal of the pavement marking by a means that will gouge the surface will not be permitted.
California	http://www.dot.ca.gov/hq/esc/oe/specifications/std_specs/2006_StdSpecs/2006_StdSpecs.pdf 15-2.02B Traffic Stripes and Pavement Markings Traffic stripes and pavement markings shall be removed by any method that does not materially damage the existing pavement. Pavement marking images shall be removed in such a manner that the old message cannot be identified. Where grinding is used, the pavement marking image shall be removed by grinding a rectangular area. The minimum dimensions of the rectangle shall be the height and width of the pavement marking. Residue resulting from removal operations shall be removed from pavement surfaces by sweeping or vacuuming before the residue is blown by the action of traffic or wind, migrates across lanes or shoulders, or enters into drainage facilities. Traffic stripes shall be removed before any change is made in the traffic pattern.

Colorado	http://www.coloradodot.info/business/designsupport/construction-specifications/2005-construction-specs/2005book/sec201-307.pdf/view 202.05 Pavement Markings. Pavement markings shall be removed from the pavement to the maximum extent possible, by methods that do not materially alter or damage the surface or texture of the pavement, to the satisfaction of the Engineer. The proposed method of pavement marking removal shall be designated by the Contractor at the preconstruction conference, and approved by the Engineer. Operations that do not produce the desired result, damage the pavement, or may constitute a hazard to the traveling public will not be permitted. Materials deposited on the pavement as a result of removal of pavement markings shall be promptly removed so as not to interfere with traffic or roadway drainage. Pavement markings, designated to be removed, shall be removed before any change is made in traffic patterns. Temporary marking tape sections longer than one foot shall be removed before placement of the final pavement course. All tape shall be removed on sections where tape conflicts with revised traffic lanes prior to opening of new lanes to traffic.
Connecticut	http://www.ct.gov/dot/lib/dot/documents/dpublications/816/012004/2004_816_original.pdf SECTION 12.11 REMOVAL OF PAVEMENT MARKINGS 12.11.03—Construction Methods: Pavement markings shall be removed from the pavement by any method that does not materially damage the surface or texture of the pavement. Any damage to the pavement surface caused by pavement marking removal shall be repaired by the Contractor at its expense by methods acceptable to the Engineer. Sand or other material deposited on the pavement as a result of removing pavement markings shall be removed as the work progresses. Accumulations of sand or other material which might interfere with drainage or might constitute a hazard to traffic will not be permitted. Protection of the work area shall be as indicated in the Specification for "Maintenance and Protection of Traffic." SECTION 12.12 TEMPORARY PLASTIC PAVEMENT MARKING TAPE 12.12.01—Description: This item shall consist of furnishing, installing and removing temporary plastic pavement marking tape of the color and width specified at the locations shown on the plans or as directed by the Engineer. 12.12.02—Materials: Materials for this work shall be commercially available pavement marking tape designed and suitable for the purpose intended and readily removable, when required. The tape shall be reflective with the use of glass beads throughout the pigments. 12.12.03—Construction Methods: Removal shall be accomplished without the use of heat, solvents, grinding or sandblasting and in such a manner that no damage to the pavement results. SECTION 12.14 PREFORMED BLACK LINE MASK PAVEMENT MARKING TAPE 12.14.01—Description: This item shall consist of furnishing, installing, and removing preformed, patterned, black line mask pavement marking tape of the width specified to temporarily cover existing pavement markings in accordance with this section and in conformance with the plans and as directed by the Engineer. The preformed, patterned, black line mask pavement marking tape shall be a highly durable, skid resistant, nonreflective, pliant polymer tape designed for the temporary covering of existing pavement markings. The black line mask pavement marking tape shall be removed when no longer needed, unless directed otherwise by the Engineer. The black line mask pavement marking tape, when applied according to the recommendations of the manufacturer, shall provide a neat, durable masking that will not flow or distort. The black line mask pavement marking tape shall be weather resistant and, through normal traffic wear, shall show no lifting or shrinkage which will significantly impair the intended usage of the tape throughout its useful life and show no significant tearing or other signs of poor adhesion. 12.14.03—Construction Methods: The patterned, black line mask pavement marking tape shall be applied in accordance with the manufacturer's recommendations, and shall mask the existing markings being covered.

Delaware	http://www.deldot.gov/information/pubs_forms/manuals/standard_specifications/pdf/division_700.pdf http://deldot.gov/information/pubs_forms/manuals/standard_specifications/pdf/supplemental/supplemental_specifications_2006-05-15.pdf Subsection 748.09 Application. (f) Removal of Pavement Markings when they are not properly applied. When it is necessary to remove pavement markings the following shall apply: (1.) For paint and epoxy resin, shot/abrasive grit blasting or water blasting equipment shall be used. (2.) For alkyd thermoplastic, in addition to the removal techniques discussed for paint and epoxy, burning or grinding equipment may be used. The removal operation shall be performed in a manner that will not damage the pavement surface to a depth more than 1/8 inch. The contractor must satisfactorily demonstrate his/her proposed equipment and method of removal. Alternative equipment and methods will be considered if satisfactory results can be demonstrated. The contractor shall collect and dispose of all shot/abrasive grit and pavement marking materials removed from the pavement surface. Washing or sweeping such materials to the roadside will not be permitted. (3.) After removal of striping on bituminous concrete pavement, approved flat black paint or asphalt sealer shall be used to cover any exposed aggregate or embedded paint. Price and payment will also include payment for black paint or asphalt sealer.
Florida	ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/SpecBook/2010Book/102.pdf http://www.dot.state.fl.us/statemaintenanceoffice/SMSP%2001-01-10/ME7107000.doc http://www.dot.state.fl.us/statemaintenanceoffice/SMSP%2001-01-10/ME7117000.doc 102-5.8 Conflicting Pavement Markings: Where the lane use or where normal vehicle paths are altered during construction, remove all pavement markings (paint, tape, thermoplastic, raised pavement markers, etc.) that will conflict with the adjusted vehicle paths. Use of paint to cover conflicting pavement markings is prohibited. Remove conflicting pavement markings using a method that will not damage the surface texture of the pavement and which will eliminate the previous marking pattern regardless of weather and light conditions. Remove all pavement markings that will be in conflict with “next phase of operation” vehicle paths as described above, before opening to traffic. ME710-70.2 Paint Removal Requirements. Remove existing pavement markings by water blasting, sandblasting, or other method approved by the Engineer. Do not use chemicals for the removal of painted traffic stripes and/or markings. Provide positive means to control dust and accumulation of debris from the removal operations. Remove all pavement marking materials from the pavement surface. Remove accumulated piles of any debris as a result of the removal operation from the right of way and dispose of in accordance with applicable Federal, State, and Local regulations, at no additional cost to the Department. ME710-70.3 Protection of Existing Pavement Surfaces. Conduct removal operations in a manner that will not damage existing pavement surfaces (concrete or asphalt) or damage pavement joint materials. Repair, to the satisfaction of the Engineer, any damage as a result of the removal operations. Do not paint over existing pavement markings to blackout, hide, or disguise markings. ME711-70.2 Thermoplastic Removal Requirements. Remove existing pavement marking by water blasting, grinding, sandblasting, or other method approved by the Engineer. Do not use chemicals for the removal of thermoplastic traffic stripes and/or markings. Provide positive means to control dust and accumulation of debris from the removal operations. Remove all pavement marking materials from the pavement surface. Remove accumulated piles of any debris as a result of the removal operation from the right of way and dispose of in accordance with applicable Federal, State, and Local regulations, at no additional cost to the Department. ME711-70.3 Protection of Existing Pavement Surfaces. Conduct removal operations in a manner that will not damage existing pavement surfaces (concrete or asphalt) or damage pavement joint materials. Repair, to the satisfaction of the Engineer, any damage as a result of the removal operations. Do not paint over existing pavement markings to blackout, hide, or disguise markings.

Georgia	http://www.dot.state.ga.us/doingbusiness/TheSource/specs/ss656.pdf 656.3.05 Construction: Remove pavement markings before changing the traffic pattern. This Specification does not relieve the Contractor of the responsibilities in Section 150 or Subsection 107.07. Utilize blasting, such as sand blasting or water blasting, grinding, or other approved methods to completely remove pavement markings without materially damaging the pavement surface or texture. Repair (at the Contractor's expense) damage to the pavement or other surface from removing the markings. Use repair methods acceptable to the Engineer. A. Blast Cleaning Do not allow sand and other debris to accumulate and interfere with drainage or create a traffic hazard. 1. When blast cleaning within 10 ft (3 m) of a lane occupied by public traffic, immediately remove residue and dust when the sand hits the pavement surface. 2. Use a vacuum attachment operating simultaneously with blast cleaning, or use other methods approved by the Engineer. 3. Ensure that sand for blast cleaning conforms to Section 804.
Hawaii	http://hawaii.gov/dot/highways/specifications2005/specifications/specspdf/specspdf-626-640/629_Print.pdf Removal of Existing Pavement Markings: Remove and dispose of existing pavement markings before performing the following activities: applying temporary or permanent traffic paint, thermoplastic extrusion pavement marking, or preformed pavement marking tape; and making changes in traffic pattern. Dispose of material in accordance with Subsection 201.03(F) - Removal and Disposal of Material. Use one of the following removal methods: (1) Grinding. Feather edges of grinding to make smooth transition to existing roadway surface. Limit feathering to 3 inches beyond edge of existing striping to be removed. Vary feathered edges to differentiate them from traffic stripes. Coat ground asphalt pavement with rapid-setting slurry. (2) Burning. Burn off existing painted pavement markings using excess oxygen method. (3) Sandblasting. As work progresses, immediately remove sand and other material deposited on pavement. (4) Other. Remove preformed pavement marking tape by methods recommended by manufacturers. Eradication of existing markings by painting over them will not be allowed.
Idaho	http://itd.idaho.gov/manuals/Online_Manuals/Traffic/Traffic.htm 203.04 Pavement Marking Removal. Removal of painted pavement markings, plastic pavement marking tape, thermoplastic pavement markings, and raised pavement markings shall be with a method that completely removes old marking material and leaves minimal pavement scars or surface texture differences that could be confused with pavement markings regardless of road conditions or time of day. Painting over existing pavement markings with any obliteration product is an unacceptable method of pavement marking removal. The prerequisite for determining the best method of pavement marking removal is that treatment which has the least negative effect on the roadway surface.
Illinois	http://www.dot.il.gov/desenv/spec2007/div700.pdf 783.03 Removal of Conflicting Markings. Existing pavement markings that conflict with revised traffic patterns shall be removed as directed by the Engineer and shall be scheduled immediately to facilitate a change in lane assignments which requires removal of conflicting markings. If darkness or inclement weather prohibits the removal operations, such operations shall be resumed the next morning or when weather permits. In the event of removal equipment failure, such equipment shall be repaired, replaced, or leased so removal operations can be resumed within 24 hours. (a) Pavement Markings. The existing pavement markings shall be removed from the pavement by a method that does not materially damage the surface or texture of the pavement or surfacing. Very small particles of tightly adhering existing markings may remain in place, if in the opinion of the Engineer, complete removal of the small particles will result in pavement surface damage. Any damage to the pavement or surfacing caused by pavement marking removal shall be repaired by methods acceptable to the Engineer. The shape of the obliterated strip shall be disguised so the pattern of the removed marking is not retained. Where mechanical means of marking removal have been employed, flat paint of a color matching the pavement surface or an asphaltic seal coat may be used if necessary as a means of covering contrasting pavement texture. The use of flat paint to cover conflicting pavement markings will not be allowed. (b) Pavement Markers. The removal of existing markers shall consist of the reflective element and the base casting complete. On those improvements where no pavement rehabilitation is required, the pavement shall be repaired with material according to Article 406.05 to the satisfaction of the Engineer. When permanent raised reflective pavement markers are present and conflict with the revised traffic patterns, only the reflectors shall be removed.

Indiana	http://www.in.gov/indot/files/HAChapter_11.pdf Pavement markings which conflict with revised traffic patterns and confuse motorists should be removed before or immediately after the change in traffic patterns is made. Pavement markings may be removed by sandblasting, waterblasting, grinding, or other approved mechanical methods. The removal methods should, to the fullest extent possible, cause no significant damage to the pavement surface. Grooving is not permitted and grinding is permitted only for removing thermoplastic or epoxy pavement markings. Painting over existing markings to obliterate the markings does not work and is not permitted. When a blast method is used to remove pavement markings, the residue, including sand, dust, and marking material, is required to be vacuumed concurrently with the blasting operation or removed by other approved methods. Any damage to the pavement caused by pavement marking removal is repaired by approved methods with no additional payment.
Iowa	http://www.iowadot.gov/erl/current/GS/content/2527.pdf C. Removal of Pavement Markings. 1. Promptly remove, on the same day new lines are placed, all existing pavement markings in the newly marked traffic lanes that are confusing, conflicting, or misleading to traffic. The Engineer may designate other pavement markings for removal to maximize the effectiveness of the traffic control plan. 2. Upon completion of the project, remove all new pavement markings which are applied according to this specification and would change the color or placement of existing standard pavement markings. Removal may also be required during progress of the work if lines that are no longer needed cause confusion in traffic delineation. 3. Remove existing painted pavement markings so that 90% or more of the pavement is visible. Tightly adhering markings may remain in the bottom of the tining and other depressions on the pavement surface but shall not be visible to the motorist during daytime or night time. Remove tape markings according to the manufacturer's recommendations. Ensure removal processes do not cause functional damage to the transverse or longitudinal joint sealant materials. 4. Conduct pavement marking removal operations in a manner so that the finished pavement surface is not damaged or left in a pattern that may mislead or misdirect the motorist. When the operations are completed, power broom the pavement surface. Remove all marking removal debris from the pavement surface before the pavement is open to public traffic. 5. Perform pavement marking removal to a width no less than the width of the existing or new pavement markings plus 1 inch (25 mm). When symbols or legends are removed, remove the entire area of the existing symbol or legend; in a rectangular shape so no directionality may be observed from the removed symbol or legend. 6. Removal will not be required prior to being covered by a construction process unless specified in the contract documents. Removal of pavement markings may be by vacuum blasting, vacuum dry grinding, wet grinding, shot blasting, or high pressure water blasting. Open abrasive blasting or dry grinding without containment will not be allowed. 7. In lieu of physical removal, existing pavement markings may be covered by removable, nonreflective, preformed tape that is prequalified according to Materials I.M. 483.06 and meets the requirements of Articles 2527.02, D, 7, and 4183.06, D. 8. Ensure pavement marking removal equipment: a. Operates without the release of dust, b. Recovers all removed material, and c. Includes a waste collection and transfer system and for dry wastes, ensure the system incorporates HEPA methods and equipment. 9. Removal operations may be halted if the process and final result is not acceptable to the Engineer. 10. Remove collected material and dispose of according to applicable Federal and State regulations. 11. Remove temporary delineators, posts, and raised pavement markers when their need no longer exists or when directed by the Engineer.

Kansas	http://www.ksdot.org/burConsMain/specprov/2007/DIVISION-800.pdf 808.3 CONSTRUCTION REQUIREMENTS a. Removal of Existing Stripes and Symbols. Remove the existing pavement markings and symbols without damaging the pavement surface. As the work progresses, remove all material deposited on the pavement as a result of the removal operations. When blast cleaning within 10 feet of the traveling public, continuously remove all residue and dust. When replacement of the removed existing markings is a part of the Contract Documents, follow the manufacturer's requirements for the new pavement markings as to the method of removal of the existing markings, or surface preparation requirements. c. Repair. Use methods approved by the Engineer to repair all pavement damaged during the pavement marking removal operations.
Kentucky	http://transportation.ky.gov/construction/spec/2004/2004_SpecBook.pdf 714.03.02 Surface Preparation. 1) Remove existing pavement markings and clean grease, oil, mud, dust, dirt, grass, loose gravel, or other deleterious material from the surface where pavement markings are to be applied, as directed by, and by methods acceptable to, the Engineer. 2) Remove the existing pavement markings until a minimum of 90 percent of the pavement surface is uniformly exposed throughout. Ensure that the pavement surface is in proper condition for successful bonding of the pavement markings and provides a neat appearance. Do not leave any loose or flaking existing pavement markings. 3) When removing the existing pavement markings, ensure that the finished pavement surface is not damaged or left in a condition that may mislead or misdirect the motorist. Repair any damage to the pavement, pavement joint materials, or the pavement surface caused by the removal of the existing pavement markings in a manner acceptable to the Engineer. After completing these operations, use compressed air to blow clean the pavement surface of residue and debris resulting from the removal of existing pavement markings. 4) When removal of existing pavement markings and objectionable materials obscures existing pavement markings of a lane occupied by public traffic, immediately remove the residue, including dust, from the surface being treated. Obtain the Engineer's approval of the removal methods. 714.03.07 Marking Removal. Remove all markings made in error or not conforming to the traffic operation in use. Remove markings by either an abrasion or burning process to the satisfaction of the Engineer. Do not paint with asphalt binder or other material to obliterate the markings.
Louisiana	http://www.dotd.la.gov/highways/specifications/documents/2006%20Standard%20Specifications%20for%20Roads%20and%20Bridges%20Manual/11%20-%202006%20-%20Part%20VII%20-%20Incidental%20Construction.pdf Removal of Existing Markings: Existing thermoplastic markings that are not flaking or peeling will not require removal prior to placement of 40 mil (1.0 mm) thick thermoplastic. Existing thermoplastic markings, regardless of condition, shall be removed prior to placement of 90 mil (2.3mm) thick or greater thermoplastic except on asphalt pavements. When thermoplastic markings replace existing painted markings, the existing painted markings will not require removal prior to applying new thermoplastic markings, provided the existing painted markings are not flaking or peeling. When preformed plastic markings (tape) replace any existing markings, the existing markings shall be removed prior to applying the preformed plastic markings. Removal of markings shall be accomplished by methods that will not damage the pavement or bridge deck. Removal shall be to such extent that 75 percent of the pavement surface or bridge deck under the markings is exposed. After the markings are removed, compressed air or a power blower shall be used to blow clean the pavement surface of residue and debris resulting from the removal. At the end of each day's operations the engineer may direct that temporary pavement markings complying with Section 713 be used in areas where existing markings have been removed and new markings not placed. Temporary pavement markings shall be satisfactorily removed prior to resuming thermoplastic marking operations. All markings made in error or not conforming to the traffic operation in use shall be removed by either an abrasion or burning process to the satisfaction of the engineer. Markings shall not be obliterated by painting with asphalt binder or other material. The removal of temporary pavement markings, if required, shall be in accordance with the requirements for the type of permanent marking being used. There shall be no objectionable staining of pavement surface as a result of the removal procedure.

Maine	http://www.state.me.us/mdot/contractor-consultant-information/ss_division_600.pdf 627.08 Removing Lines and Markings. When it is necessary to remove pavement lines and markings, it shall be done by grinding, high temperature flame, sand blasting, solvent or other acceptable means. The method chosen must be capable of completely eradicating the existing line or marking without damage to the pavement. Burning and grinding to remove temporary markings from final pavement or from existing pavement not to be resurfaced will not be permitted.
Maryland	http://apps.roads.maryland.gov/businesswithsha/contBidProp/ohd/constructContracts/ifb/HA2705171.pdf 565.01 DESCRIPTION. Remove existing pavement markings (lines, letters, numbers, arrows, and symbols) during temporary or permanent traffic shifts, and repair any roadway areas damaged during the removal process. This Specification does not apply to raised or recessed pavement markers. Temporary blackout tape shall be applied when existing pavement markings will require salvaging for reuse after completion of temporary traffic shifts necessary to perform work specified in the Contract. 565.03.01 Quality Control/Quality Assurance. At least two weeks prior to the start of pavement markings removal, the Contractor shall submit a Quality Control Plan (QCP) to the Engineer for review. The QCP shall contain (as a minimum) the following information: (a) How the Contractor proposes to perform the work while ensuring conformance with the Specifications. (b) Proposed method of removal based on road conditions, type and number of equipment to be used, manpower expectations, and time frame to complete the work based on maintenance of traffic (MOT) restrictions. (c) Location and quantity of markings to be removed. (d) Protective shielding plan and containment system, particularly in the case of markings that may contain toxic materials. The QCP shall also detail when, how, and what corrective actions will be taken for unsatisfactory construction practices and deviations from the Contract Documents. Any deviation from the QCP shall be cause for immediate suspension of work. 565.03.02 Quality Control Test Strip. Prior to the beginning of work, the Contractor shall demonstrate the removal method to the Engineer for approval. A minimum of 100 ft of existing pavement markings shall be removed as a test strip at a location determined by the Engineer. If the method does not work or shows signs of damaging the road surface, then another method shall be tried. Additional control strips will be required. The preferred method is that which least damages the roadway and completely removes the markings. 565.03.03 Methods of Removal. The following removal methods are based on the pavement condition and type of marking material: (a) Manual. A scraper or putty knife shall be used to lift tape from the pavement surface. Open flame for tape removal is prohibited. (b) High Pressure Water Blasting. A high pressure water blast shall be used to break the bond between the marking material and the pavement surface. The water blast may contain fine grit. (c) Alternate Methods. Abrasive blasting or grinding methods shall be submitted for approval to the Office of Materials Technology prior to use. 565.03.04 Cleaning Pavement Surfaces. Immediately behind the removal operation, a vacuum equipped street sweeper capable of removing all loose material shall be used to remove all dust and debris generated by the removal process prior to returning the area to traffic. The Contractor shall prevent debris from draining into inlets and waterways, and all debris shall be collected and disposed of on an approved spoil area or landfill. 565.03.05 Alignment. Removal shall be performed in a straight and uniform manner, and shall follow the longitudinal alignment of the markings with a lateral deviation of no more than 1 in. in any 10 ft section. Affected area shall not exceed 1/2 in. on either side of the existing marking. The depth shall be uniform throughout, 1/8 in. or less, with no gouge areas in the pavement surface. If a second pass is necessary to completely remove the markings, the edges of the groove shall be feathered to a width of 1.25 in. on each side for every additional 1/8 in. of depth. 565.03.06 Corrective Action. Any pavement surface damaged beyond the requirements specified herein by the Contractor's operations shall be repaired or repaved as determined by the Engineer at no additional cost to the Administration.

Massachusetts	http://www.mhd.state.ma.us/downloads/manuals/1995Mspecs.pdf 850.48 Pavement Marking Removal. Pavement marking removal methods shall not cause damage to the pavement or cause drastic change in texture, which could be construed as delineation at night, and shall be approved by the Engineer. It is not permissible to paint over existing markings in lieu of removal. 850.69 Pavement Marking Removal. Pavement markings shall be removed to the fullest extent possible by an approved method. Any damage to the pavement or surfacing caused by pavement marking removal shall be repaired by the contractor at his/her expense by methods acceptable to the Engineer. Approved methods include but are not limited to: 1. Sand blasting using air or water. 2. High pressure water. 3. Steam or superheated water. 4. Mechanical devices such as grinder, sander, scrapers, scarifiers and wire brushes. Painting over a pavement marking line by use of asphaltic liquids or paints will not be permitted. Inappropriate pavement markings shall be removed before any change is made in the traffic pattern. Material deposited on the pavement as a result of removing markings shall be removed as the work progresses. Accumulations of sand or other material which might interfere with drainage or could constitute a hazard to traffic will not be permitted. Where blast cleaning is used for the removal of pavement markings and such removal operation is being performed within 3 meters of a lane occupied by traffic, the residue including dust shall be removed immediately after contact between the sand and the surface being treated. Such removal shall be by a vacuum attachment operating concurrently with the blast cleaning operation, or by other methods approved by the Engineer.
Michigan	http://mdotwas1.mdot.state.mi.us/public/dessssp/spss_source/03SP811K.pdf Pavement Marking Removal. Remove pavement markings that conflict with proposed temporary traffic markings before making any changes in the traffic pattern. Place temporary pavement markings when pavement markings are removed or obscured for more than 24 hours before a change in the traffic pattern. Type R markings must be placed according to subsection 812.03.F.9 before the close of the workday. Where blast cleaning is used for marking removal, and the removal location is within 10 feet of an open lane, immediately remove residue and dust. Use a vacuum attachment operating concurrently with the blast cleaning operation for removal of residue and dust. Properly dispose of collected residue and dust. 1. Removal of Less than 5000 Feet per Stage. Remove pavement markings causing as little damage as possible to the surface texture of the pavement and by methods approved by the Engineer. Methods that can provide acceptable results are: sandblasting using air or water; shot blasting; high-pressure water; steam or superheated water; mechanical devices such as grinders, sanders, scrapers, scarifiers, and wire brushes. The contractor is responsible to immediately clean up any debris that is generated. Continuous vacuuming equipment is not required. 2. Removal of Greater than 5000 Feet per Stage. Remove pavement markings using self-propelled truck mounted removal equipment. The equipment must be capable of continuously vacuuming up the removal debris as the operation progresses. If the amount of debris generated during the removal process is greater than the vacuuming capability of the removal truck, a self-propelled sweeper operating immediately behind the removal equipment is required. The removal truck must be capable of eliminating the airborne dust while operating. Remove pavement markings causing as little damage as possible to the surface texture of the pavement and by methods approved by the Engineer: a. Asphalt Surfaces. Contractor may use any type of self-propelled truck mounted removal equipment except water blasting, provided that the equipment is capable of continually vacuuming the removal debris. b. Concrete Surfaces to be Removed During Construction. Contractor may use any type of self-propelled truck mounted removal equipment provided that the equipment is capable of continually vacuuming the removal debris. c. Concrete Surfaces to Remain in Place. A self-propelled truck mounted water blaster must be used to minimize the scarring of the concrete surface. Use equipment capable of continually vacuuming the removal debris. Do not use paint or bituminous bond coat to cover existing and inappropriate pavement markings. Use tape only when authorized by the Engineer.

Minnesota	http://www.dot.state.mn.us/pre-letting/spec/2005/2021-2360.pdf 2102.1 DESCRIPTION This work shall consist of the removal of pavement markings that conflict with revised traffic patterns. The markings will usually be in the form of 100 mm (4 inches) wide widths, in solid line or skip line lengths, but may include other patterns or widths and the type will be as (one) of the following: A) Pavement Marking Removal: this work shall consist of the removal of non-durable pavement markings such as paint type markings. B) Pavement Marking Removal - Temporary: this work shall consist of the removal of Temporary Reflectorized Pavement Marking Tape or Removable Preformed Plastic Pavement Markings. C) Pavement Marking Removal - Permanent: this work shall consist of the removal of durable pavement markings. 2102.3 REMOVAL REQUIREMENTS Before effecting a change in traffic pattern, the Contractor shall remove all conflicting pavement markings approved by the Engineer, using methods and equipment that will not significantly damage the pavement structure or surface texture. Should the removal operations result in significant damage, as determined by the Engineer, the Contractor shall repair the damaged areas as the Engineer directs at no expense to the Department. Whatever methods of removal are employed, the Contractor shall control or restrict operations to avoid exposing traffic to hazardous or detrimental conditions. Any expended materials or agents used in the removal process shall not be allowed to accumulate on the pavement surface but shall be promptly removed by suction or other approved methods as the work progresses. Linear paint markings shall be removed so as not to leave a distinguishing pattern of removal. Where unsatisfactory results are achieved, the Contractor shall obliterate any deceptive lines remaining by applying a color-matched paint or asphalt sealer that will blend with the surface texture satisfactorily.
Mississippi	http://www.gomdot.com/Divisions/Highways/Resources/Construction/pdf/2004StandardSpecs/specbook.pdf 619.03.2—Temporary Stripe. Temporary paint stripe requiring removal shall be removed by carefully controlled blast cleaning, approved grinding or other approved methods in such a manner that the surface to which the stripe was applied will not be unnecessarily marred or damaged. Preformed tape is to be removed in accordance with the manufacturer's recommendations. Temporary paint stripe which has been placed on the final pavement course may be left in place and covered with permanent stripe of the same color provided the temporary stripe has been satisfactorily placed in the proper location. Under this condition, any remaining temporary paint stripe not covered by the permanent stripe shall be removed at no additional cost to the State. Painted traffic stripe which has been removed from the final asphalt pavement surface shall be sealed with an approved sealant. The Engineer may wave the sealant requirement when the area to be sealed is insignificant. This sealing operation shall be performed at no additional costs to the State. Existing pavement markings conflicting with temporary markings shall be removed. Removal of such materials (paint, tape, marker, etc.) will be measured and payment made under Section 202. When measuring removal of pavement markings for payment, the skips will not be included in the measurement.

Missouri	http://epg.modot.org/index.php?title=620.1_General_%28MUTCD_Chapter_3A%29 620.1.13 Obliteration of Pavement Markings This work consists of removing all existing or temporary pavement marking which is conflicting or might mislead traffic. The exception is short term marking tape which should be in place two weeks or less. During the process of detouring traffic around construction and maintenance areas and incorporating changes in traffic movements, it may be necessary to remove or obliterate inappropriate pavement markings on the roadway. If this is not done properly the original markings can misdirect traffic, resulting in possible conflicts for both motorists and workers. Standard. The use of asphalt or black paint to cover conflicting markings shall not be allowed. All removal methods must comply with EPA and MDNR regulations concerning air quality and material disposal. Guidance. Provisions should be made on the TCP for the removal of all conflicting or misleading markings. Pay items should be provided for removal of pavement marking when required. Removal or obliteration of inappropriate pavement markings should be performed by one of the following procedures: 1. Mechanical devices, such as grinders, sanders, scrapers, wire brushes or shot blasters. 2. High temperature burning with excess oxygen. 3. Sandblasting. Where pavement markings have been obliterated, nighttime inspections should be made to verify that the marking is no longer visible and does not interfere with the new pavement markings. Options. Where mechanical means of marking removal have been employed to completely remove the pavement marking, paint of a color matching the pavement surface or liquid asphalt materials may be used as a temporary means of covering contrasting pavement texture
Montana	http://www.mdt.mt.gov/other/contract/external/standard_specbook/2006/2006_stand_specs.pdf 620.03.10 Pavement Marking Removal Remove existing temporary and final pavement markings using any of the following: • Sand blasting with air or water; • High-pressure water; • Steam or super-heated water; or • Mechanically grinding, sanding, scraping, brushing. Submit the method or methods to be used. The Contractor may submit written proposals for other removal methods. An approved method may be subsequently disapproved if it damages the marking surface or inadequately removes existing markings. Remove sand or other material on the surface left by the removal as the work progresses. Satisfactorily repair surfaces damaged by marking removal at Contractor expense.
Nebraska	http://www.dor.state.ne.us/ref-man/specbook-2007.pdf 15. Pavement Marking Removal: The Contractor shall remove conflicting permanent (not “temporary”) pavement markings as shown in the plans or as required by the Engineer. 2. When markings are no longer needed, the Contractor shall remove them at no additional cost. If removing markings from the final wearing surface, the removal process shall not mar or damage the surface. Removed marking shall no longer be visible on the final wearing surface. 2. a. Temporary pavement marking tape, Type II, shall be a mixture of high quality polymeric materials and pigments with glass beads throughout the pigmented portion of the film and reflectized with glass beads bonded to the top surface. c. A nonmetallic medium shall be incorporated to facilitate removal either manually or with a recommended roll-up device. The tape shall be capable of being easily removed from asphalt and portland cement concrete surfaces intact (or in large pieces), at temperatures above 41°F (5°C). d. Removal shall be accomplished without the use of heat, solvents, grinding, or sandblasting.

Nevada	http://www.nevadadot.com/business/contractor/standards/documents/2001StandardSpecifications.pdf Remove painted traffic lines on surfaces to remain after the project's completion by hydroblasting. Perform removals on all other surfaces by approved methods. Exercise care to prevent damage to pavement surfaces, joint material and bridge joints. Remove temporary pavement striping immediately after traffic has been re-routed and the temporary pavement striping is no longer required.
New Hampshire	http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2010_Spec_Book.pdf 3.3.4 Pavement markings that are no longer applicable shall be obliterated immediately preceding or following the change in lane usage. Such change in lane usage shall not be implemented until sufficient time, equipment, materials, and personnel are available to completely obliterate the markings. 3.3.5 Removable pavement marking tape shall be removed prior to placing subsequent pavement courses but not until immediately prior to beginning paving operations. 3.1.6 The use of pavement markings other than in their final location on wearing course will only be permitted if the marking material is designed to be removed without the use of heat, solvent, grinding or blast treatment, and leaves no visible scar on the surface. 3.5 Obliteration of Pavement Markings. 3.5.1 Pavement marking obliteration shall result in a minimum of pavement scar and shall obliterate all evidence of the existing pavement marking material. Removal may be performed by grinding, sand or water blasting, blackout tape, or other method(s) approved by the Engineer that do not materially damage the pavement surface. 3.5.2 "Painting" over pavement markings with paint, asphalt mixtures or any other material is prohibited. 3.5.3 Removal and disposal of pavement markings including, but not limited to retroreflectorized paint, retroreflective thermoplastic, preformed retroreflective tape and raised pavement markers shall be the responsibility of the Contractor in accordance with all applicable federal, state, and local regulations.
New Jersey	http://www.state.nj.us/transportation/eng/specs/english/EnglishStandardSpecifications.htm#SIX 617.13 Removable Black Line Masking Tape. The black line masking tape shall temporarily obscure the existing permanent traffic stripe on HMA surfaces. The existing traffic stripe shall be completely covered or masked by the application of the black line tape. The black line masking tape shall be applied over dry existing traffic stripes according to the manufacturer's recommendations and when the weather is favorable as determined by the Engineer. Any portion of the black line masking tape that is loosened after placement over the existing traffic stripe, shall be replaced by the Contractor within two hours or as directed by the Engineer at no cost to the State. Proper care shall be taken in completely unmasking the existing underlying traffic stripe without the use of heat, solvents, grinding, sanding, or water, when the black line masking tape is no longer required. Existing permanent traffic stripes that become damaged during removal of the black line masking, including discoloration caused by the black masking tape, shall be replaced by the Contractor at no cost to the State. 618.12 Removal of Traffic Stripes or Traffic Markings. The Contractor shall remove all types of traffic stripes or traffic markings by methods that do not damage the integrity of the underlying pavement or adjacent pavement areas, and that do not cause gouging, or create ridges or grooves in the pavement that may result in compromising vehicular control. Obliterating stripes or markings by painting over them will not be permitted. Before starting removal operations, the Contractor shall demonstrate the proposed method to accomplish the removal of approximately 95 percent of the stripe or marking without the removal of more than 1/16 inch of pavement thickness. Area of removal includes the area of the stripe or marking plus 1 inch on all sides. Removal operations will not be permitted until the method of removal has been approved. The Contractor shall replace all existing pavement reflectors that have been damaged by removal operations, at no cost to the State. Debris from the removal of traffic stripes and markings shall be disposed of according to Subsection 201.10.

New Mexico	http://www.nmshtd.state.nm.us/upload/images/Contracts_Unit/2007_Specs_for_Highway_and_Bridge_Construction.pdf
	721.1 DESCRIPTION This Work consists of removing existing pavement stripes and markings. 721.3 CONSTRUCTION REQUIREMENTS Use Equipment that is capable of completely removing pavement stripes 1/4 in ± 1/8 in deep and at least twice the width of the stripe. Remove temporary pavement stripes and markings when the Project Manager determines that they are no longer required for traffic control. Do not use nonreflective black removable marking tape or overpainting to obliterate temporary pavement markings. Provide traffic control in accordance with Section 104.5, "Maintenance of Traffic," and Section 618, "Traffic Control Management." Remove and dispose of debris as directed by the Project Manager.
New York	https://www.nysdot.gov/main/business-center/engineering/specifications/english-spec-repository/espec-english-cd.pdf
	619-2.05 Covering or Removal of Pavement Markings. Paint used to cover existing pavement markings shall be an exterior, non-reflective paint, substantially similar in color to the pavement surface, in accordance with §727-09 Traffic Paint. Tape used to cover existing pavement markings shall be pavement marking masking tape in accordance with §727-06 Removable Pavement Tape. 619-3.05 Covering or Removal of Pavement Markings. The Contractor shall remove or cover existing permanent pavement markings and interim pavement markings, when indicated in the contract documents or directed by the Engineer, to accommodate traffic pattern changes by covering the markings with preformed removable pavement marking masking tape, or removing the markings, and/or painting over the markings. Masking and/or paint shall be placed in blocks to prevent the underlying shape of pavement marking symbols or letters from being confused with existing markings. A. Removal of Pavement Markings. The removal method will be at the Contractor's option, subject to its ability to achieve satisfactory results. Removal shall be completed prior to the installation of temporary pavement markings or interim pavement markings. Grinding to remove pavement markings will typically remove 1/8 to 1/4 inch of pavement surface. Paint or similar coatings shall be used only to obliterate existing markings, including edge lines or other markings that are not crossed by traffic, on pavement surfaces that will subsequently be removed or overlaid. Prior to installation, the existing marking and adjacent pavement shall be cleaned of debris by compressed air or sweeping. The Contractor shall apply the paint in accordance with the manufacturer's recommendations, and completely cover the existing marking. The paint shall be a substantial match to the pavement surface in color, such that appearance of a pavement marking is not visible to drivers under normal viewing conditions, day or night, wet or dry. Any painted-over markings on which the coating fails to adhere, or is worn away, or appears to be an in-service pavement marking, shall be removed or covered. B. Masking Pavement Markings. Removable pavement tape shall be installed in accordance with the manufacturer's written instructions. Prior to installation, the existing pavement marking and adjacent pavement shall be cleaned by compressed air, sweeping, or other means adequate to remove debris, but that does not result in damage to the existing pavement marking. The width of the removable pavement marking masking tape shall be sufficient to completely cover the existing pavement marking. The masking tape shall firmly adhere to the entire length and width of the existing pavement marking to be covered. The Contractor shall maintain the tape for the duration of its use. Any tape that is loosened, removed, or that fails to retain its original matte finish, or that for any other reason fails to obliterate the existing pavement marking shall be replaced immediately, at no additional expense to the State. When the covered pavement markings are to be restored to service, masking tape shall be removed. Temporary adhesive residues will be allowed to remain, providing that the existing pavement marking visibility is not impaired. Any damage to the existing pavement markings or to the pavement surface that results from the removal of the masking tape shall be repaired at no additional cost to the State. If the existing marking cannot be repaired satisfactorily, the Contractor shall remove damaged pavement markings completely and/or replace the pavement section at no additional cost to the State.

New York Cont.	https://www.nysdot.gov/main/business-center/engineering/specifications/english-spec-repository/espec-english-cd.pdf
	635-3.04 Cleaning Existing Pavement Markings. Existing pavement markings shall be cleaned for the purpose of: A. Preparing the pavement surface for the application of new pavement markings in the same location as the existing markings. B. To remove existing markings that are in good condition which, if allowed to remain, will interfere with or otherwise conflict with newly applied marking patterns. It shall be understood that in this context cleaning means the removal of an existing marking. It is not intended that all deteriorated existing pavement markings be removed. Example: If a new marking is applied to an unmarked "gap" in a broken line and the existing broken line pattern is worn or deteriorated, as determined by the Engineer, to the extent that it is not misleading or confusing to the motorist, the existing markings do not require removal. Pavement markings shall be cleaned to the extent that 95% to 100% of the existing marking is removed. Removal operations shall be conducted in such a manner that no more than moderate color and/or surface texture change results on the surrounding pavement surface. When waterblasting is performed, pavement markings shall be applied no sooner than 24 hours after the blasting has been completed. Waterblasting shall not be allowed for cleaning markings requiring replacement within the same day as removal as specified under §635-3.05. The determination of acceptable removal will be made by judgment of the Engineer and will be guided by the Department's pictorial standards of acceptable marking removal. Pictorial standards are available from the Materials Bureau.
North Carolina	http://www.ncdot.org/doh/preconstruct/ps/specifications/english/web12a.pdf
	(I) Removal of Pavement Markings Remove pavement marking lines, characters, and symbols by acceptable methods to the Engineer that will not materially or structurally damage the surface or the texture of the pavement. Leave the pavement surface in a condition that will not mislead or misdirect the motorist. Where existing pavement markings are to be removed and replaced by other pavement markings, do not begin removal until adequate provisions have been made to complete the installation of the replacement markings. Remove pavement markings such that the surface is in proper condition for adequate bonding of the new markings. Promptly remove any material deposited on the pavement as a result of removing pavement markings as the work progresses by acceptable methods. Provide the equipment necessary to control dust and the accumulation of debris resulting from the removal process. The removal equipment shall provide dust control and the capture of the removed material shall be done utilizing a separate vacuum equipped vehicle or other approved system. Perform the recovery process within the same operation as the removal. Do not let traffic use the lane where the removal is taking place until the recovery system is finished. Should the recovery system fail, cease removal operations until the recovery system is properly operating. The Contractor is responsible for all cleanup and proper disposal of all removed debris from the project site. When using a grinding method for pavement removal, the equipment shall have multiple heads working in tandem to provide adequate preparation of the surface to accept the new marking material. Do not apply polyurea/thermoplastic pavement markings over existing pavement marking materials having less adherence than the polyurea/thermoplastic. Application over existing pavement marking materials other than polyurea/thermoplastic will require the existing pavement marking material to be removed, so that a minimum of 85 percent of the existing pavement marking is removed. However, if pavement is less than 6 months old and one 15 mil application of paint was placed on the pavement initially, do not remove the existing paint pavement markings. Use black color #37038 in paint or tape, as determined by Contractor, to cover any remaining conflicting pavement marking after removal from asphalt pavement surfaces. Do not use black paint or tape on concrete pavement surfaces. The black paint will not have a defined shape or edges with a width not exceeding double of the existing lines. No direct payment will be made for black paint or tape.

<table>
<tr><td>North Dakota</td><td>http://www.dot.nd.gov/divisions/environmental/docs/Vol%201_102002.pdf
S. Pavement Marking Removal. Removal of existing marking and installation of short-term marking shall be as shown on the traffic control plan sheets. Inappropriate existing markings shall be removed and the new delineation placed before opening the affected lane or lanes to traffic. Removal of pavement markings shall not permanently damage the surface or texture of the pavement. Painting over existing stripes is not permitted. Where blast cleaning is used for removal of markings or other objectionable material, the sand or other blast material left on the pavement shall be removed immediately.
b. Correction of Defects/Penalties.
(1) All pavement markings not conforming to the requirements of the Contract shall be removed and replaced or otherwise repaired to the satisfaction of the Engineer. Removal of unacceptable work shall be accomplished with suitable blasting or grinding equipment unless other means are authorized by the Engineer.
(3) If the Engineer requires removal and replacement, the contractor shall remove (by an approved process) at least 90% of the deficient line, with no excessive scarring of the existing pavement. The removal width shall be one inch wider all around the nominal width of the pavement marking to be removed.</td></tr>
<tr><td>Ohio</td><td>http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2010%20CMS%20Final%2012222009.pdf
G. Conflicting Markings. Before placing work zone markings, remove or cover all conflicting existing markings visible to the traveling public. 1. Removal and Covering of Markings.
a. Removal Methods. Remove the markings so that less than 5% of the line remains visible. Repair damage to the pavement that results in the removal of more than 1/8 inch of pavement thickness. Remove the markings by using methods specified in the below table:
b. Covering Conflicting Markings. With the Engineer’s approval, use removable, non-reflective, preformed blackout tape according to Supplement 1187 to cover conflicting markings. Remove or replace the blackout tape within 15 days of installation. Furnish products according to the Departments Qualified Products List (QPL).
<table>
<tr><th colspan="2" rowspan="2">Type of Pavement</th><th colspan="2">Removal Method</th></tr>
<tr><th>grinder[1]</th><th>sand, shot or water blast</th></tr>
<tr><td rowspan="2">Existing Asphalt</td><td>Temporary</td><td>Y</td><td>Y</td></tr>
<tr><td>Permanent</td><td>N</td><td>Y</td></tr>
<tr><td rowspan="3">New Asphalt</td><td>Temporary</td><td>Y</td><td>Y</td></tr>
<tr><td>Intermediate</td><td>Y</td><td>Y</td></tr>
<tr><td>Permanent</td><td>N</td><td>Y</td></tr>
<tr><td rowspan="2">Existing Concrete</td><td>Temporary</td><td>Y</td><td>Y</td></tr>
<tr><td>Permanent</td><td>N</td><td>Y</td></tr>
<tr><td rowspan="2">New Concrete</td><td>Temporary</td><td>Y</td><td>Y</td></tr>
<tr><td>Permanent</td><td>N</td><td>Y</td></tr>
<tr><td colspan="4">Y - method is permitted to be used</td></tr>
<tr><td colspan="4">N - method is not permitted to be used</td></tr>
<tr><td colspan="4">[1] – when a drum is mounted to a skid steer loader, the drum must be able to accommodate a minimum of 150 teeth</td></tr>
</table></td></tr>
</table>

Oklahoma	http://www.okladot.state.ok.us/c_manuals/specbook/2009specbook.pdf D. Removal If detour or permanent pavement markings conflict with the permanent pavement markings of the next traffic control phase, remove as approved by the Resident Engineer before switching traffic. Place temporary pavement markings before removing existing markings from roadways open to traffic. Remove temporary pavement markings before installing final stripe. Remove the removable pavement marking and adhesive, as directed by the Resident Engineer. Install additional pavement markings according to the traffic conditions, as approved by the Resident Engineer. Immediately dispose of removed pavement marking tape and pavement markers. Remove pavement markings without damaging the pavement surface or pavement material texture. The department will not allow painting over or blotting out the existing pavement markings. When the removal operation deposits sand or other material on the pavement, remove as the work progresses. If blast cleaning within 10 ft of a lane carrying traffic, remove the residue immediately using a vacuum attachment operated concurrently with the blast cleaning operation, or other methods approved by the Resident Engineer. Repair pavement damage as directed by the Resident Engineer at no additional cost to the Department. A. Surface Preparation Use abrasive blasting or grinding to remove existing, temporary, or permanent traffic markings until at least 95 percent of the underlying pavement is visible, unless otherwise specified by the manufacturer.
Oregon	http://www.oregon.gov/ODOT/HWY/SPECS/docs/08book/08_00800.pdf 00851.40 General—Remove non-durable pavement markings by hydroblasting, steel shot blasting, or grinding so that the pavement surface is not damaged below a depth of 1/8 inch. Remove durable marking by steel shot blasting or grinding the pavement surface to a depth no greater than 1/8 inch, creating a smooth, flat slot of uniform depth. Remove pavement markings the same day permanent markings are applied. Use vacuum shrouded equipment or other equally effective containment procedures. Dispose of all waste materials according to 00290.20.
Pennsylvania	ftp://ftp.dot.state.pa.us/public/Bureaus/design/Pub408/Pub%20408%20Chg%207/Sections/963.pdf 963.3 CONSTRUCTION—Remove existing pavement markings, as indicated, immediately before any change in traffic patterns or before the application of final markings. Remove markings that conflict with revised traffic patterns and may confuse motorists. Do not paint over existing lines with black paint. Remove markings for restriping to the extent that 90% of the material is removed without materially damaging or grooving the pavement surface more than 0.8 mm (1/32 inch). For all other marking removal, eliminate the markings to the extent that the marking is not visible to motorists when viewed from a distance of 15 m (50 feet). Remove waterborne pavement markings by sandblasting, grit blasting, steel shot blasting, or waterblasting. Grinding is acceptable only for the removal of thermoplastic, cold plastic, or epoxy marking materials. Obtain approval from the Representative for the proposed removal method before beginning work. Vacuum or collect residue, including sand, dust, and marking material, concurrently with the removal operation unless alternate procedure is submitted and accepted. Clean the area of dust with compressed air. Perform this work only in the area where the markings are to be applied. Do not allow sand, dust, or other residual material, which may interfere with drainage or constitute a traffic hazard, to accumulate. Dispose of all residue in an acceptable manner. Repair any pavement or surface damage caused during the removal process. Prevent damage to transverse and longitudinal joint sealers, and repair any damage as specified in Section 513.

Rhode Island	http://www.dot.state.ri.us/documents/engineering/BlueBook/CD-Bluebook.pdf 1. Grinding. Markings shall be removed to a minimum of 95 percent of their surface area. The method shall not damage the surface in any way and have no more than a moderate color and/or texture change. The grinding truck must be capable of removing 80,000 linear feet of 6-inch line per day; and must be equipped with a vacuum and dust collector that is 99.99 percent efficient in removing particles no bigger than 0.5 microns. Any pavement markings removed must be replaced within 1 day. Removal is at no extra cost. A sweeper with the capacity to pick up grindings simultaneously with the removal operation is required. If the Contract eliminates grinding of material, power washing remains a requirement. 2. Power Wash. All special patterns, handwork, and oil or other deleterious substances shall be removed by a power wash machine with a pressure of 2400-2800 psi with the water heated to 180-195°F. No chemicals shall be added to the water in the process. The machine will be equipped with a turbo blast tip with oscillating head and shall be capable of supplying 5 gallon/minute/gun.
South Carolina	http://www.scdot.org/doing/StandardSpecifications/pdfs/2007_full_specbook.pdf 609.4.1.2 Removal of Pavement Markings Do not allow conflicting pavement marking schemes on any roadway open to traffic. Remove conflicting pavement markings as necessary and pavement markings designated by the Plans and the RCE prior to revising the traffic patterns. Remove obsolete pavement markings and any residue resembling a previous pavement marking scheme. If the pavement marking removal process damages the roadway, repair the damage or resurface the roadway as directed by the RCE with no additional compensation. Use the following acceptable methods for removal of pavement markings from a concrete pavement course: • Sand blasting using air or water, • High pressure water, • Steam of superheated water, or • Shot blasting. Use the following acceptable methods for removal of pavement markings from an asphalt pavement course: • Sand blasting using air or water, • High pressure water, • Steam of superheated water, • Shot blasting, and • Grinding. Use grinding for pavement marking removal on asphalt pavement courses only. Do not use grinding for removal of pavement markings from a concrete pavement course. Do not apply a black paint or any other color of paint or type of paint over pavement markings designated for removal as a singular method of removal of pavement markings. Remove the residue from a blast cleaning method, including the components of the blast method including sand, water, or shot. When operating within 10 feet of a travel lane open to traffic or in an area that the residue may encroach onto the adjacent travel lane, remove the residue immediately after contact between the blast component and the treated surface. Use a vacuum attachment operating concurrently with the blast operation or by an alternate method approved by the RCE. Provide all safety and protective measures required by the Department and federal, state, and local laws.

South Dakota	http://www.sddot.com/operations/docs/specbook04/634.pdf
	D. Removal of Pavement Markings: Pavement markings to be removed shall be designated by the Engineer. Pavement markings shall be removed from the pavement by methods that do not damage the surface or texture of the pavement. Pavement markings shall be removed before the traffic pattern is changed. Covering the markings is not acceptable removal. Sand or other material used for removal shall be disposed of as the work progresses. Accumulations of sand or other material, which interferes with drainage or constitutes a hazard to traffic, will not be permitted. When sand blasting is used for removal of pavement markings or objectionable material, and the removal operation is performed within 10 feet (three meters) of a lane occupied by the traveling public, the residue including dust shall be removed immediately by a vacuum attachment operating concurrently with the sand blasting operation. Damage to the pavement surface caused by pavement marking removal shall be repaired at the expense of the Contractor.
Tennessee	http://www.tdot.state.tn.us/construction/Supplemental%20Specs%202006/SS700.pdf
	Pavement Marking Removal. Conflicting pavement markings must be removed to prevent confusion to vehicle operators. Pavement marking removal shall be accomplished by the Contractor in a manner acceptable to the Engineer. Final surface pavement markings shall be removed by sand blasting, water blasting, or acceptable grinding methods that will cause the least possible damage to the pavement. Intermediate surface pavement markings shall be removed by sand blasting or water blasting, or other approved methods that will cause the least possible damage to the pavement. The following methods listed below are considered as acceptable for intermediate surface pavement markings: Sand blasting using air or water, High pressure water, steam or superheated water, or Mechanical devices such as grinders, sanders, scrapers, scarifiers, and wire brushes. The Contractor at his expense shall repair any damage to the pavement or surface caused by pavement marking removal by methods and materials acceptable to the engineer. The end result of the removal shall not cause a condition that appears to be a line that conflicts with the current markings. Traffic shifts that are done on the final surface shall be accomplished using interim traffic marking tape unless otherwise specified in the plans. Removal of an existing pavement marking by painting over with black paint or asphalt will not be an acceptable method. When the method of removal causes sand or other material to be accumulated on the pavement, the residue shall be removed as the work progresses.
Texas	ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s677.pdf
	677.4. Construction. Eliminate existing pavement markings and markers on both concrete and asphaltic surfaces in such a manner that color and texture contrast of the pavement surface will be held to a minimum. Repair damage to asphaltic surfaces, such as spalling, shelling, etc., greater than 1/4 in. in depth resulting from the removal of pavement markings and markers. Dispose of markers in accordance with federal, state, and local regulations. Use any of the following methods unless otherwise shown on the plans. A. Surface Treatment Method. Apply surface treatment material at rates shown on the plans or as directed. Place a surface treatment a minimum of 2 ft. wide to cover the existing marking. Place a surface treatment, thin overlay, or microsurfacing a minimum of 1 lane in width in areas where directional changes of traffic are involved or in other areas as directed by the Engineer. B. Burn Method. Use an approved burning method. For thermoplastic pavement markings or prefabricated pavement markings, heat may be applied to remove the bulk of the marking material prior to blast cleaning. When using heat, avoid spalling pavement surfaces. Sweeping or light blast cleaning may be used to remove minor residue. C. Blasting Method. Use a blasting method such as water blasting, abrasive blasting, water abrasive blasting, shot blasting, slurry blasting, water-injected abrasive blasting, or brush blasting as approved. Remove pavement markings on concrete surfaces by a blasting method only. D. Mechanical Method. Use any mechanical method except grinding. Flail milling is acceptable in the removal of markings on asphalt and concrete surfaces.

Utah	www.udot.utah.gov/main/uconowner.gf?n=504103321257835506 3.4 REMOVE PAVEMENT MARKINGS A. Use one of these removal methods: 1. High pressure water spray, 2. Sand blasting, 3. Shot blasting, 4. Grinding. Grinding is not allowed on the final surfacing unless the Engineer grants prior written approval. B. Do not eliminate or obscure existing striping, in lieu of removal, by covering with black paint or any other covering. 1. The Engineer may grant prior written approval for use of black paint or other obscuring material for work durations shorter than "long term stationary" as defined in the Temporary Traffic Control section of the MUTCD. C. Use equipment specifically designed for removal of pavement marking material.
Vermont	http://www.aot.state.vt.us/conadmin/Documents/2001%20Spec%20Book%20for%20Construction/2001DIV600.pdf 646.12 REMOVAL OF EXISTING PAVEMENT MARKINGS. Existing markings shall be obliterated in such a manner and by such means that a minimum of pavement scars are left and all of the existing marking is removed; i.e., grinding a square or rectangle on the pavement to remove a letter or arrow or grinding a large rectangle to remove a word so that the outline of the letter, symbol or word is not ground into the pavement and therefore still legible even though the marking has been removed. Painting over existing markings is not an acceptable method of removal. The work shall be completed to the satisfaction of the Engineer.
Virginia	http://www.virginiadot.org/business/resources/const/2007SpecBook.pdf (j) Eradicating Pavement Markings: Markings that may conflict with desired traffic movement, as determined by the Engineer, shall be eradicated as soon as is practicable: either immediately prior to the shifting of traffic or immediately thereafter and prior to the conclusion of the workday during which the shift is made. Eradication shall be performed by grinding, blasting, or a combination thereof. Grinding shall be limited to removal of material above the pavement surface except when removing thermoplastic and preformed tape markings, which may be removed by grinding alone. Blasting shall be used on both asphalt concrete and hydraulic cement concrete pavements to remove all other types of markings. Other methods may be submitted for approval by the Engineer. The Contractor shall ensure that the roadway surface is damaged as little as possible when performing the eradication. When eradicating pavement markings, the Contractor shall ensure workers are protected in conformance to the requirements of Occupational Safety and Health Administration's (OSHA) standards as detailed in 29 CFR 1910 or 1926, whichever is the most stringent at the time. The Contractor shall collect the eradication residue during or immediately after the eradication operation, except dust shall be collected during the entire operation. Eradication residue from the removal of any pavement markings is considered to be a non-hazardous waste material and shall be disposed of in a properly permitted waste disposal facility in accordance with state and federal laws and regulations. Testing of the eradication residue for the eight Resource Conservation Recovery Act metals will not be required. When markings are removed for lane shifts or transitions, 100 percent of the marking shall be removed. Non-reflective removable black construction pavement marking may be used to cover existing markings in lieu of eradication on asphalt concrete surfaces when its use will not be required for more than 120 days and when specified as a pay item. The Contractor shall use this material to cover markings as indicated in the plans or as directed by the Engineer. Non-reflective removable black construction pavement marking shall be applied in accordance with the manufacturer's recommendations. b) Eradication: Eradication of pavement markings for restriping when required shall be in accordance with the requirements of Section 512 except only 90 percent removal of the existing markings is required.

Washington	http://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/Division8.pdf
	8-22.3(6) Removal of Pavement Markings Pavement markings to be removed shall be obliterated until blemishes caused by the pavement marking removal conform to the coloration of the adjacent pavement. If, in the opinion of the Engineer, the pavement is materially damaged by pavement marking removal, such damage shall be repaired by the Contractor in accordance with Section 1-07.13(1). Sand or other material deposited on the pavement as a result of removing lines and markings shall be removed as the Work progresses to avoid hazardous conditions. Accumulation of sand or other material which might interfere with drainage will not be permitted.
West Virginia	http://www.transportation.wv.gov/highways/engineering/Specifications/2003/Y2KSpecB.pdf
	636.7—ERADICATION OF PAVEMENT MARKINGS: All markings which may conflict with desired traffic movement, as determined by the Engineer, shall be fully eradicated as soon as practicable. Eradication shall be performed prior to shifting of traffic. Eradication shall be performed by hydro-blasting, sand blasting, chemicals, burning with excess oxygen or other suitable method. Full eradication shall be defined as the removal of at least 90 percent of the existing marking. A 90 percent removal will be determined by the Engineer by comparison with the Eradication Visual Standard. This Standard can be obtained from the Engineer. In addition to the visual comparison, the 90 percent removal level is defined such that there will not be any remaining surface of the original paint film in the eradicated area. The remaining 10 percent of the existing marking will appear to be as part of the texture of the pavement. The method used shall not materially damage the surface or texture of the pavement. Any damage caused by the Contractor's operations shall be corrected at the Contractor's expense and in a manner approved by the Engineer. The Contractor shall take precaution to protect the public from any damage due to their operations. Accumulation of sand, water, dust or other residue resulting from the eradication operation shall be removed as the work progresses.
Wisconsin	https://trust.dot.state.wi.us/static/standards/stndspec/sect646.pdf
	646.3.4 Removing Pavement Markings Remove pavement markings from locations the plans show or as the engineer directs. Do not damage, discolor, leave a detrimental residue on the surface, or paint over existing markings. Provide a dust control system and remove accumulated sand or other materials. If blast cleaning within 10 feet of a lane open to public traffic, remove all dust and other residue continuously while blast cleaning. Collect, haul, and dispose of dust or residue from removals. Repair damage caused by the contractor's removal operations.
Wyoming	http://www.dot.state.wy.us/webdav/site/wydot/shared/Traffic/WYDOT%20Pavement%20Marking%20Manual.pdf
	Removal of Markings Occasionally pavement markings must be revised or removed due to changed geometrics, addition of lanes, etc. Existing markings that the DTE determines may cause confusion for the motorist shall be removed or obliterated as soon as practical. Markings may be temporarily masked with tape until they can be removed or obliterated.

APPENDIX D

Summary Data from Field Removal Evaluations

Table D-1. Data summary from removal on PCC test deck.

Marking Type	Removal Method	Removal Strategy	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L	CCD Luminance (cd/m^2)		Measured Brightness (Y)	Scar Depth (in)	Estimated Texture Depth (mm)
							Day	Night			
Modified Urethane	Road Surface	None				26	1434	0.696	28.34		0.457
	Orbital Flailing	Light	1980	7	3	78	1829	1.733	39.17	0.03	0.478
	Orbital Flailing	Heavy	1020	9	4	66	1520	1.617	47.72	0.04	0.597
	High Pressure Water	Light	6000	9	5	47	1289	1.076	31.41	0.02	0.761
	High Pressure Water	Heavy	4020	10	5	31	1417	0.806	28.23	0.04	0.657
	Flailing	Light	4500	8	3	66	1657	1.545	40.78	0.05	0.706
	Flailing	Heavy	4200	8	2	64	1795	1.555	40.09	0.09	0.66
Thermoplastic	Road Surface	None				30	548	0.74	30.37		0.655
	Orbital Flailing	Light	3600	7	4	51	683	1.339	49.56	0.01	0.594
	Orbital Flailing	Heavy	3000	9	5	46	687	1.179	41.72	0.02	0.506
	High Pressure Water	Light	5160	9	4	36	586	0.927	30.23	0.01	0.753
	High Pressure Water	Heavy	4020	10	5	37	542	0.982	30.83	0.02	0.853
	Flailing	Heavy	5160	10	3	50	658	1.349	39.39	0.04	0.731
	Combined		4800(f), 7980(hpw)	10	4	41	618	1.058	34.64	0.01	0.908
Methyl Methacrylate	Road Surface	None				29	808	0.71			
	Orbital Flailing	Light	3000	5	2	58	920	1.564			
	Orbital Flailing	Heavy	1500	9	5	54	870	1.313			
	High Pressure Water	Light	2040	8	4	68	652	1.381			
	High Pressure Water	Heavy	2040	9	4	56	809	1.313			
	Flailing	Light	2760	10	2	52	849	1.352			
	Flailing	Heavy	2580	10	2	51	873	1.321			
	Combined		4800(f), 5520(hpw)	10	4	34	639	0.964			
Polyurea	Road Surface	None				25	1092	0.736			
	Orbital Flailing	Heavy	1020	7	3	78	945	1.748			
	High Pressure Water	Light	4800	9	4	39	705	0.931			
	High Pressure Water	Heavy	3780	10	5	33	1094	0.813			
	Flailing	Light	4740	8	2	79	928	1.775			
	Flailing	Heavy	4260	10	1	71	979	1.832			

(continued on next page)

Table D-1. (Continued).

Marking Type	Removal Method	Removal Strategy	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L	CCD Luminance (cd/m^2)		Measured Brightness (Y)	Scar Depth (in)	Estimated Texture Depth (mm)
							Day	Night			
Preformed Thermoplastic	Road Surface	None				26	2486	0.733			0.488
	Orbital Flailing	Light	1980	8	4	49	3082	1.275		0.02	
	Orbital Flailing	Heavy	1020	9	4	54	2963	1.381		0.02	
	High Pressure Water	Light	4500	9	4	39	2301	1.065		0.03	0.779
	High Pressure Water	Heavy	3600	10	4	31	2466	0.729		0.03	0.605
	Flailing	Light	2040	9	1	72	3039	1.625		0.03	0.869
	Flailing	Heavy	1440	10	1	62	3203	1.705		0.09	
	Combined		4800(f), 4500(hpw)	10	4	57	2400	1.196		0.1	0.82
Permanent Tape	Road Surface	None				26	1820	0.74	30.8		
	Orbital Flailing	Light	1920	8	3	36	1892	1.037	34.43		
	Orbital Flailing	Heavy	1740	10	4	44	2137	1.183	41.82		
	High Pressure Water	Light	2400	7	4	34	1367	0.945	23.72		
	High Pressure Water	Heavy	1800	9	4	23	1629	0.667	27.23		
	Flailing	Light	2580	6	2	52	1513	1.256	37.97		
	Flailing	Heavy	1800	10	3	53	2316	1.453	47.12		
	Combined		4800(f), 4200(hpw)	9	4	40	1466	0.977	30.1		

Table D-2. Data summary from removal on asphalt test deck.

Marking Type	Removal Method	Removal Strategy	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L	CCD Luminance (cd/m^2)			Measured Brightness (Y)	Scar Depth (in)	Estimated Texture Depth (mm)
							Day (Toward Sun)	Day (Away from Sun)	Night			
High-Build Paint	Road Surface	None				9	3002	1554	0.2851	7.15		0.901
	Orbital Flailing	Light	2400	6	2	66	3570	3026	1.423	20.3	0	0.6
	Orbital Flailing	Heavy	780	8	3	47	3025	2744	0.906	26.51	0.04	0.789
	High Pressure Water	Light	3600	10	3	20	2330	1611	0.361	10.39	0.06	2.552
	High Pressure Water	Heavy	3300	10	3	18	2136	1703	0.42	9	0.07	4.236
	Flailing	Light	5160	8	3	59	3404	3162	1.022	20.65	0.1	0.942
	Flailing	Heavy	3300	9	3	41	3131	2937	0.795	29.45	0.11	0.862
Preformed Thermoplastic	Road Surface	None				9	2523	1744	0.343	9.97		1.062
	Orbital Flailing	Light	480	4	2	64	3694	4911	1.692	30.45	0	2.405
	Orbital Flailing	Heavy	420	5	2	69	3727	4851	2.241	36.55	0.02	1.746
	High Pressure Water	Light	1800	10	2	12	1737	1481	0.316	5.53	0.18	3.783
	High Pressure Water	Heavy	1620	10	2	21	1870	1550	0.477	5.03	0.2	5.091
	Flailing	Light	3120	4	3	74	498	6411	2.337	53.93	0.1	0.862
	Flailing	Heavy	1200	10	2	42	2761	3678	1.605	19.23	0.16	2.364
	Combined	Heavy	3600(f), 3660(hpw)	9	1	41	2288	1839	0.853	6.6	0.18	4.195

Table D-2. (Continued).

Marking Type	Removal Method	Removal Strategy	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L	CCD Luminance (cd/m^2)			Measured Brightness (Y)	Scar Depth (in)	Estimated Texture Depth (mm)
							Day (Toward Sun)	Day (Away from Sun)	Night			
Thermoplastic	Road Surface	None				9	2385	1684	0.281	7.21		1.08
	Orbital Flailing	Light	480	6	2	51	2897	3833	1.276	26.81		0.751
	Orbital Flailing	Heavy	420	8	3	37	2213	2458	1.002	19.15		1.117
	High Pressure Water	Light	1920	10	3	11	1465	1446	0.301	5.1		3.3
	High Pressure Water	Heavy	1800	10	2	12	1626	1500	0.34	5.81		3.707
	Flailing	Light	2580	6	2	50	2134	3776	1.101	20.26		1.656
	Flailing	Heavy	2400	9	2	47	2207	3674	1.214	22.04		1.957
	Combined	Heavy	2880(f), 3300(hpw)	10	1	15	1540	1778	0.44	7.67		3.534
Waterborne Paint	Road Surface	None				9	1437		0.29	9.6		0.9415
	Orbital Flailing	Light	1200	6	2	48	2047		1.099	19.21	0.01	0.804
	Orbital Flailing	Heavy	840	8	3	42	1951		1.063	25.4	0.04	0.759
	High Pressure Water	Light	3600	10	3	24	1358		0.553	6.7	0.06	2.702
	High Pressure Water	Heavy	2760	10	4	20	1197		0.491	6.14	0.06	2.228
	Flailing	Light	6000	8	3	59	2163		1.24	17.33	na	0.993
	Flailing	Heavy	2580	10	3	38	1969		0.922	24.57	0.1	1.066

Table D-3. Data summary from closed-course removal.

Marking Type	Removal Method	Removal Strategy	Removal Rate (ft/hr)	Degree of Removal	Removal Rating	Measured R_L	CCD Luminance (cd/m^2)		Measured Brightness (Y)	Scar Depth (in)	Estimated Texture Depth (mm)
							Day	Night			
Thermoplastic on Concrete	Road Surface					17			13.57		0.883
	Orbital Flailing	Heavy	2340	8	2	38	see Figure D-1	see Figure D-2	32.41	0	0.589
	High Pressure Water	Heavy	3960	10	4	26	see Figure D-1	see Figure D-2	23.91	0	1.059
	Flailing	Heavy	7620	9	3	41	see Figure D-1	see Figure D-2	36.5	0	0.572
	Dual Removal	Heavy	27120(f), 14280(hpw)	10	4	25	see Figure D-1	see Figure D-2	27.12	0	0.801
Paint on Concrete	Road Surface					17	3143	0.451	13.57		0.854
	Orbital Flailing	Heavy	720	9	3	86	8790	1.855	44.77	0.01	0.597
	High Pressure Water	Heavy	4320	10	4	26	5196	0.698	24.34	0.01	1.014
	Flailing	Light	4320	9	3	76	9093	1.664	38.29	0.08	0.676
	Flailing	Heavy	2700	10	2	43	7869	1.062	29.88	0.09	0.58
	Hand Flailing	Heavy	240	10	2	49	8147	1.247	40.98	0.07	0.569
Paint on Asphalt	Road Surface					22	5043	0.765	15.51		0.588
	Orbital Flailing	Heavy	1260	8	4	48	5407	1.381	25.3	0.06	0.815
	High Pressure Water	Heavy	3360	10	4	20	3194	0.571	12.56	0.1	1.331
	Flailing	Light	6660	8	3	45	5515	0.935	31.95	0.13	0.951
	Flailing	Heavy	3540	10	2	115	7381	2.1551	36.22	0.2	0.748
	Hand Flailing	Heavy	300	7	2	74	6385	1.746	27.97	0.12	0.875

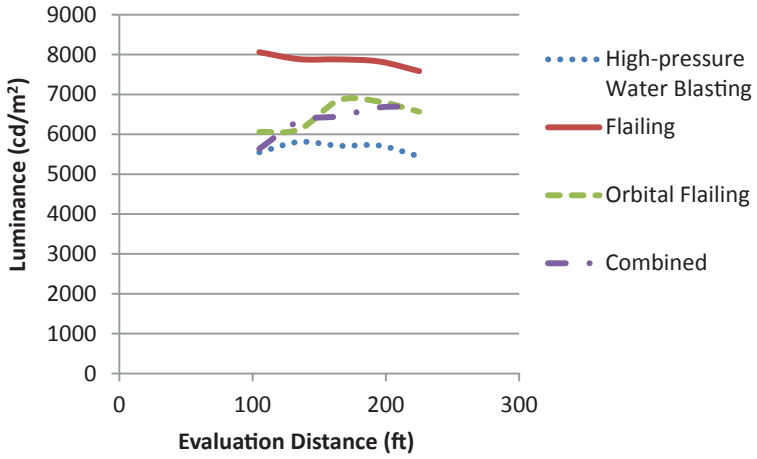


Figure D-1. CCD luminance during daytime toward sun from long-line thermoplastic removal on closed-course PCC.

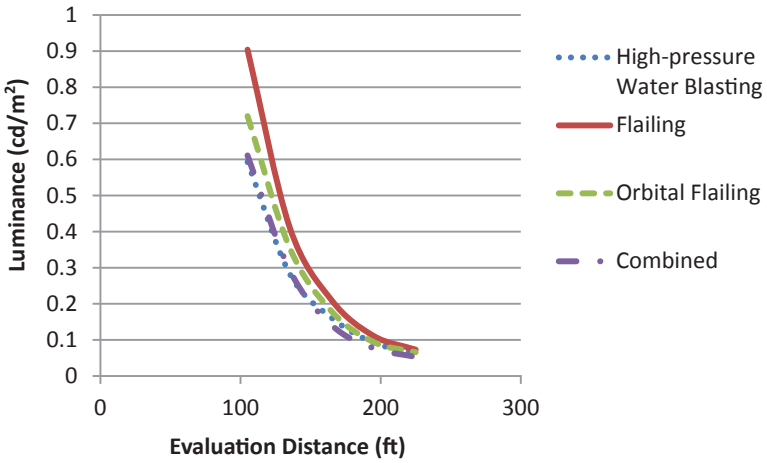


Figure D-2. CCD luminance during nighttime (low beam) from long-line thermoplastic removal on closed-course PCC.

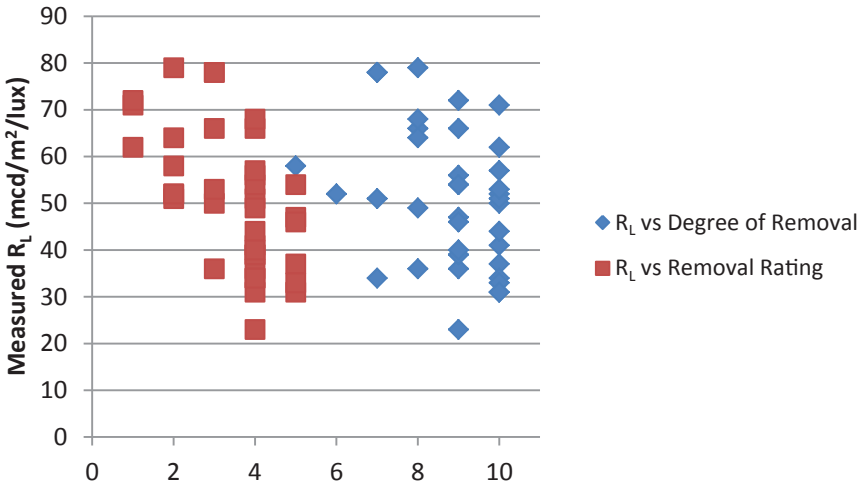


Figure D-3. PCC test deck retroreflectivity vs qualitative assessments.

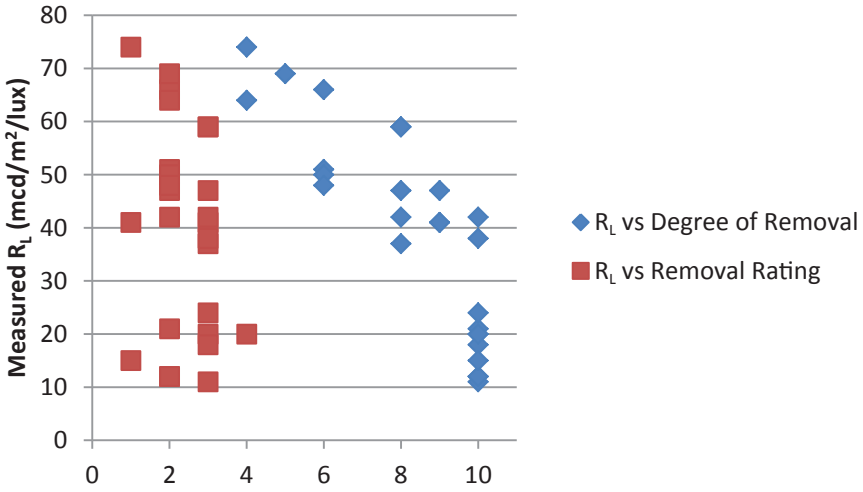


Figure D-4. Asphalt test deck retroreflectivity vs qualitative assessments.

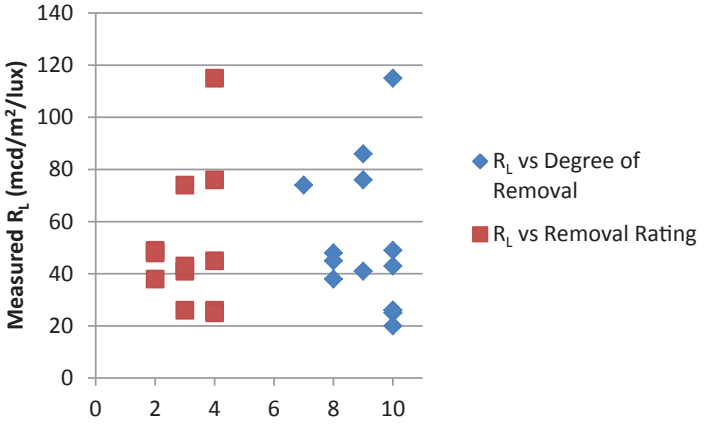


Figure D-5. Closed-course test deck retroreflectivity vs qualitative assessments.

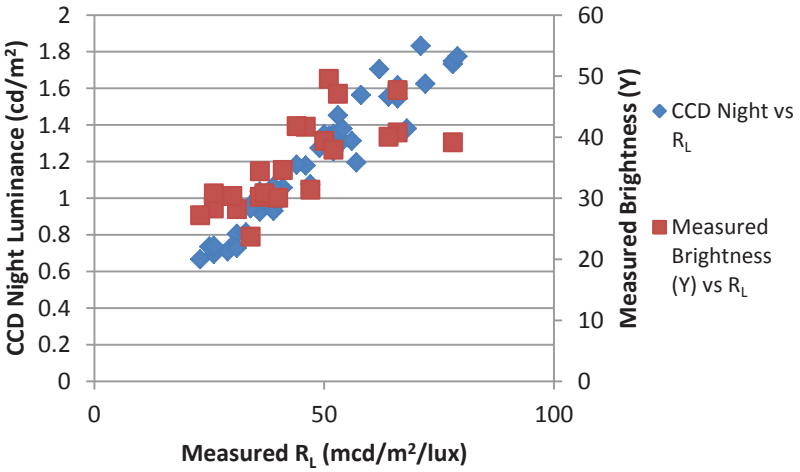


Figure D-6. PCC test deck comparisons to retroreflectivity.

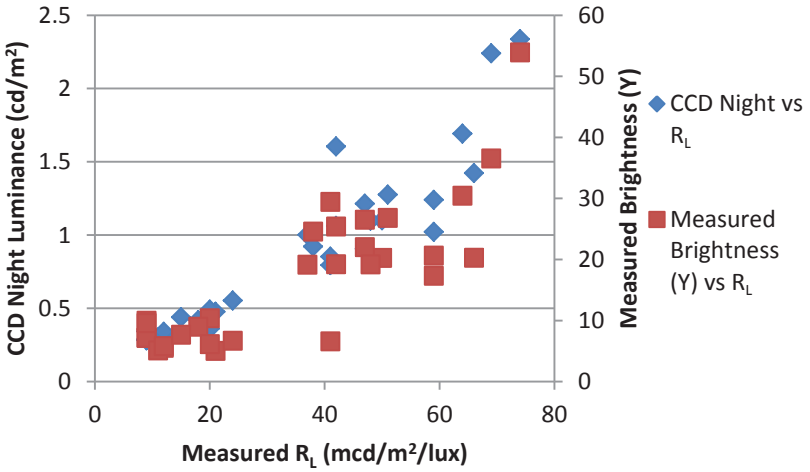


Figure D-7. Asphalt test deck comparisons to retroreflectivity.

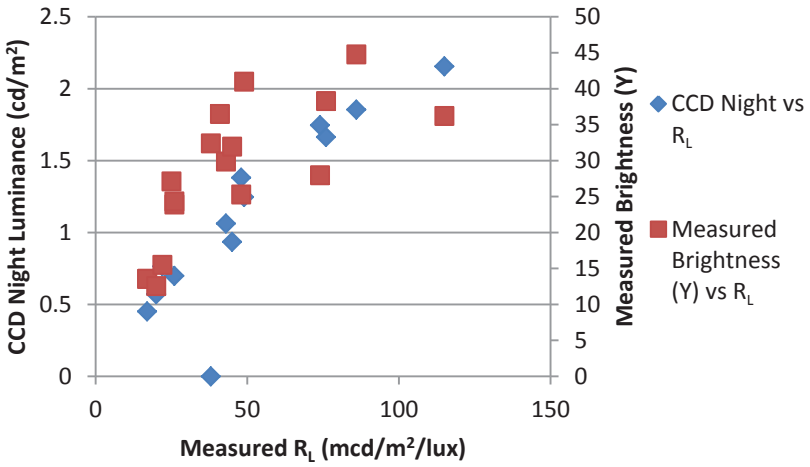


Figure D-8. Closed-course test deck comparisons to retroreflectivity.

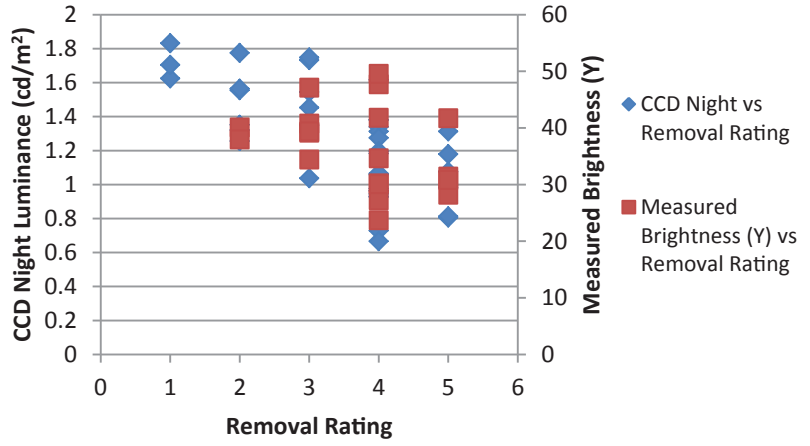


Figure D-9. PCC test deck photometric measurements vs removal rating.

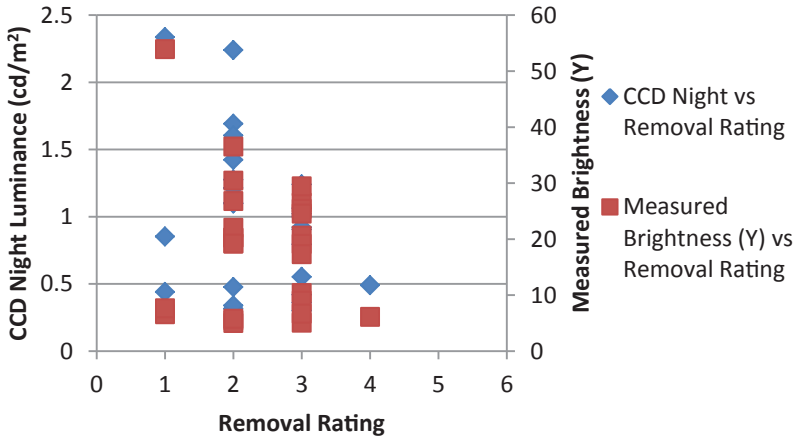


Figure D-10. Asphalt test deck photometric measurements vs removal rating.

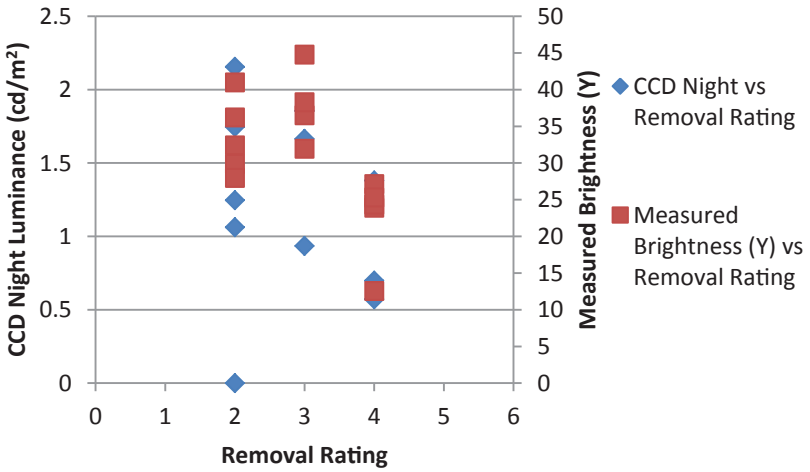


Figure D-11. Closed-course test deck photometric measurements vs removal rating.

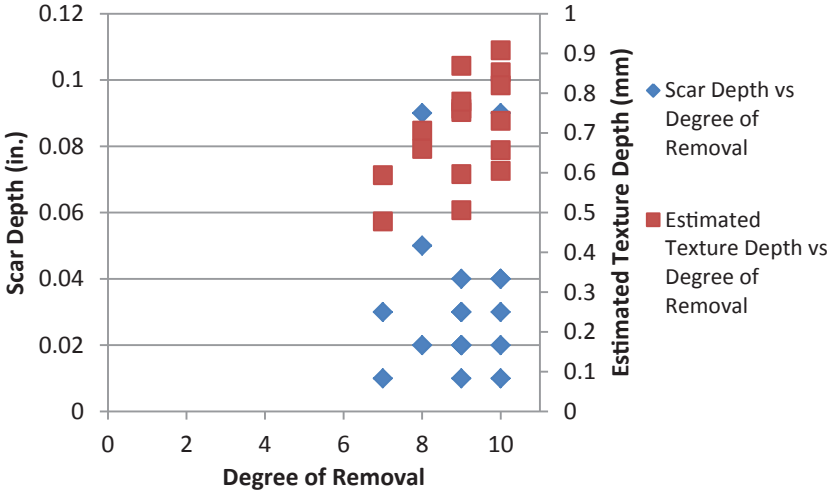


Figure D-12. PCC test deck comparisons to degree of removal.

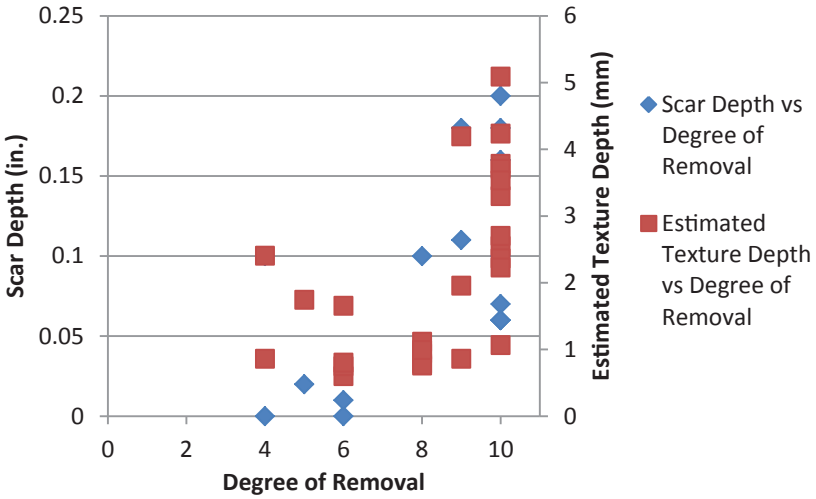


Figure D-13. Asphalt test deck comparisons to degree of removal.

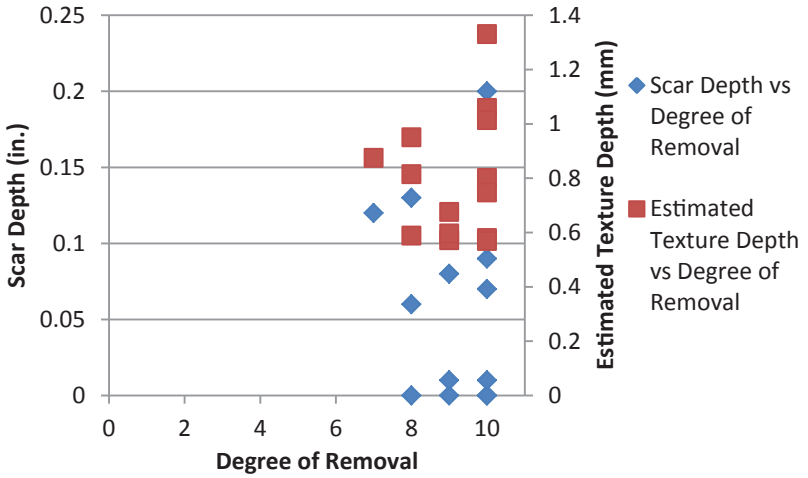


Figure D-14. Closed-course test deck comparisons to degree of removal.

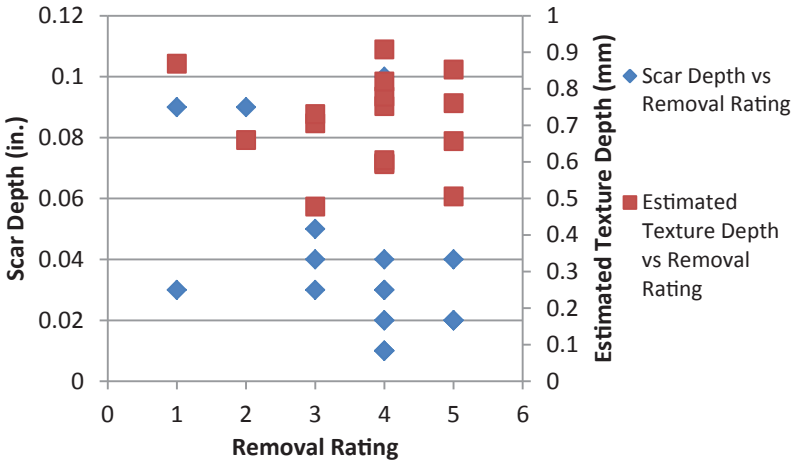


Figure D-15. PCC test deck surface damage measurements vs removal rating.

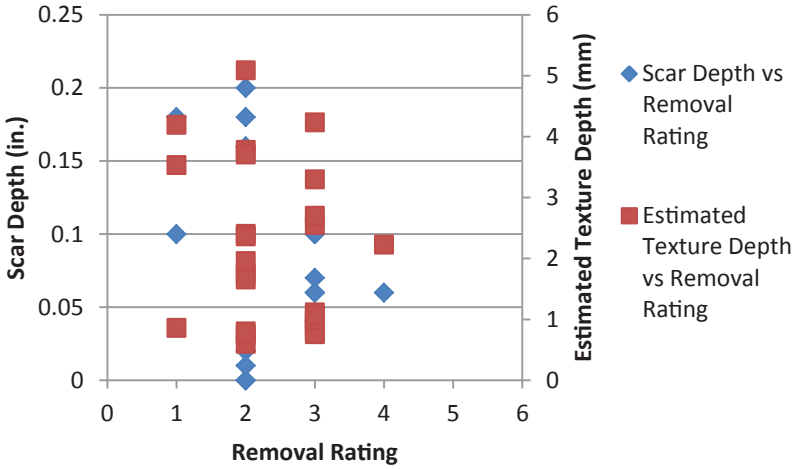


Figure D-16. Asphalt test deck surface damage measurements vs removal rating.

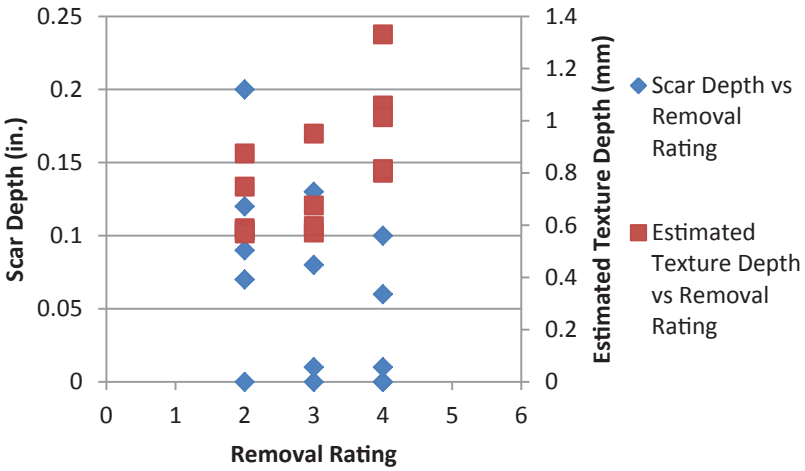


Figure D-17. Closed-course test deck surface damage measurements vs removal rating.

APPENDIX E

Standalone Pros and Cons of Each Removal Process Including Effectiveness with Respect to Pavement Marking Materials

Removal Method	Advantages	Disadvantages
Grinding	• Fast and economical • Depending on the system configuration (effective vacuum system installed to remove dust), dust created by removal can be contained • High availability • Effective at reducing the thickness of thick marking materials such as thermoplastic or multiple layers of paint prior to restriping	• Damage to pavement surface • Scarring with full marking removal • Minimizing damage to roadway may leave marking material behind • Orbital flailing may result in less noticeable scarring than drum flailing due to tapered edges • Non-vacuum systems can create dust clouds and be hazardous • Tape removal can be messy
High-Pressure Water	• Byproduct does not create dust and is contained within the equipment • Little to no scarring on good PCC • With the exception of drying time, the pavement surface is prepped for pavement marking reinstallation • Relatively fast for a blasting method especially for thin marking materials • Large vehicle mobile systems available with additional utility carts for smaller nearby areas	• Limited to above-freezing conditions • May polish surface aggregate and/or clean the surrounding pavement, creating a color contrast • May remove some surface asphalt and fines that could lead to water penetration • Potential for damage to pavement joints • Proper equipment operation critical to achieve good results • Currently not widely available, higher costs
Sand Blasting	• Minimal pavement degradation • Little to no scarring • Hand-operated precision • Effective on thin markings	• Creates considerable byproduct • Creates considerable dust • No current large vehicle mobile system, therefore slower than mobile methods • Health hazards depending on blast media • Less effective on thick markings
Shot Blasting	• Minimal pavement degradation • Little to no scarring • Minimal byproduct • Byproduct does not create dust and is contained within the equipment	• Shot recovery can be problematic especially on uneven surfaces • Cannot be used in wet conditions • Can be slow especially for thicker markings • Can cause pavement damage on non-smooth surfaces • Limited availability of equipment

Removal Method	Advantages	Disadvantages
Other Media Blasting (Dry Ice, Soda, etc.)	• Minimal pavement degradation • Little to no scarring • Minimal environmental concerns with respect to debris generated • Marking can be completely removed • Hand-operated precision	• Can create a moderate amount of byproduct • Can create considerable dust • Can be slow especially for thick markings • Only useful on some markings, typically paint only • Dry ice is a difficult medium to handle and store • Very noisy • No current large vehicle mobile system
Chemical	• Byproduct does not create dust • Can get complete removal without scarring	• Potential to damage pavement surface if incorrect removing agents are used • Requires at least one additional pass to remove residue • Slow, need to wait for chemical to react then proceed with removal • Some chemicals may pose an environmental risk • No current large vehicle mobile system • Only useful on some markings, typically paint
Masking	• No damage to road surface • Existing markings can be temporarily covered with tape that matches the road surface color and texture, and later reused when the tape is removed • Removed areas can be masked to help blend in scarring or surface color changes • Can be used in lane-shift areas to reduce driver confusion due to ghost markings or scarring	• Can be expensive • Material may wear away, exposing the markings being covered • Difficult to match color and texture with tape • Tape is for temporary purposes only • Cannot use marking materials other than tape to cover a marking

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation