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Current and Future Best Practices for Pothole Repair in Illinois

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16. Abstract

This report presents a review of flexible pavement pothole-patching materials, equipment, and techniques within Illinois Department of Transportation as well as other transportation agencies in the United States. The research team conducted a literature review to examine recent studies and available state department of transportation guidance on pothole patching. Overall, this review revealed a lack of recent studies on this topic, and a greater need for them. The review also revealed that most states do not have centralized guidance for pothole repair best practices. The researchers also met with all nine Illinois Department of Transportation districts to determine their current state of practice for pothole patching. The meetings revealed a wide range of materials and techniques in use among the nine districts as well as areas where improvements can be made. The final chapter of this report includes overall recommendations for improvement.

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EXECUTIVE SUMMARY

The Illinois Department of Transportation (IDOT) spent upwards of $25 million in fiscal year 2019 on pothole repairs. This represents a significant portion of all activities done by IDOT work crews. At the same time, there is a lack of centralized best practices within IDOT for performing pothole patching activities. Therefore, this study was conducted to determine the current state of practice within IDOT as well as other transportation agencies in the United States.

The first stage of this research study involved a literature review to determine the type of guidance available in each state regarding pothole patching and what previous research studies have found on the subject. The state-by-state review revealed an overall lack of documented best practices, likely because pothole patching is decentralized in most state agencies. A review of research studies indicated that while temporary, low-quality patching solutions are highly popular and result in recurrent failure of sections with potholes. Therefore, the literature generally recommends the use of higher quality patching materials such as hot-mix asphalt (HMA) and proprietary cold patching mixes. Proper cleaning of potholes, proper compaction, and effective training efforts are also crucial to achieving long-lasting pothole patches.

The second stage of the present study consisted of meetings with each of IDOT's nine districts, which represent different geographical regions of the state of Illinois. A series of two-hour meetings were held to determine each district's current state of practice with respect to pothole patching materials, equipment, and techniques. The meetings revealed that current practices vary greatly not only between different districts, but also between different yards in each district. Regarding materials, proprietary cold mixes are preferred over general cold mixes in nearly all districts. Four out of nine districts (Districts 2, 4, 8, and 9) use HMA extensively when it is available. However, HMA is not available year-round, and questions persist about the best mix types for use in pothole patching. Out of the nine districts, only District 9 does not use the spray injection method for patching potholes, while all districts use cold mixes in throw-and-go or throw-and-roll procedures at least at some point throughout the year.

For the final stage of this project, the research team made recommendations to IDOT based on the above two tasks. The research team recommends that HMA be used as frequently as possible when available and that proprietary mixes are strongly preferred when cold mixes are used. The throw-and-go method should not be used except in cases where worker safety would otherwise be compromised. Cleaning and water removal as well as appropriate compaction of patching materials should be prioritized. However, there is not enough information to provide a thorough best practices document, and more study is required on the cost-effectiveness of these materials and techniques. There are, however, four practices that are immediately implementable as a result of this study: (i) improvements to the Asset Management Program system for tracking activities performed by each district, (ii) coordination between districts to share their experiences, (iii) more hands-on workshops rather than online trainings, and (iv) BMP posters for yards. Recommendations for future studies and guidance for eventually developing best practices are also presented.

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CHAPTER 1: INTRODUCTION

Potholes in asphalt pavements appear frequently, which causes significant safety concerns for the traveling public and a substantial financial burden for the agencies responsible for maintaining these pavements. In a 2016 survey from the American Automobile Association (AAA), almost 16 million drivers in the United States suffered vehicle damage from potholes serious enough to require repair. In Illinois, which is located in a wet–freeze region of the United States, pothole formation is one of the most prevalent surface distresses that leads to vehicle damage and requires a large portion of the operations and maintenance budget to repair. In fiscal year 2019, the Illinois Department of Transportation (IDOT) spent more than $25 million repairing potholes and had already spent more than $12.5 million halfway through fiscal year 2020. On average, state departments of transportation (DOTs) spend more than $5.5 million per year on pothole repair (Dong et al., 2014c).

It is possible that multiple mechanisms contribute to pothole formation, as no single mechanism can always explain them (Siew et al., 2005). However, a typical driver of pothole formation is freeze and thaw cycling. Asphalt-surfaced pavements are typically comprised of binder and surface layers. All asphalt layers can be designed and compacted to be resistant to the penetration of moisture. However, stress due to the weather or traffic loading on the roadway have the potential to promote the development of cracks. Water often penetrates through the cracked surface layer into the underlying layers, freezing and expanding when the temperature drops. As the temperature again rises, the underlying ice melts and water flows to other areas of the pavement structure. This action in the pavement leaves holes in the surface layer where the water again becomes trapped and freezes. Stress from traffic loading on the roadways has the potential to further widen previous cracks, increasing the opportunity for freeze–thaw cycles to cause pavement damage (Biswas et al., 2018). Freeze–thaw cycles are generally considered the largest contributor to pothole formation, followed by traffic loading and pavement age (Biswas, 2016). In wet climates, the formation of potholes can also occur as a result of stripping of the asphalt binder from the aggregate due to the infiltration of moisture, even in the absence of freezing temperatures. (Park et al., 2017).

To repair potholes, many branches and local engineers within state DOTs and local agencies have developed strategies for pothole maintenance. However, the impact of this strategy is often limited due to the recurrence of potholes, which can be a result of the method used to patch them, as discussed later in this report. In addition, strategies among different agencies, and often even within a single agency, can vary greatly depending on geographic location, climate, budget, available manpower, traffic, engineering judgement, and many other factors. The large number of potholes to patch often results in the use of cheaper materials and quick repair strategies, despite previous studies indicating that the use of proper training, high-quality materials, and standardized equipment results in longer lasting pothole patches (Thomas & Anderson, 1986). Pothole patching is also difficult because the best patches are performed in warm, dry weather, but most new potholes occur during wet, cold weather (Eaton, 1989). While a few studies have focused on providing guidelines for choosing materials and/or techniques for pothole repair (Nicholls et al., 2016), most of the decision-making has remained in the hands of local agency officials and workers (Dailey et al., 2017). Therefore, there are not currently many well-documented best practice guidelines for pothole repair. To better understand how agencies currently address this problem and to investigate the most suitable practices for IDOT moving forward, a full review of the literature, including existing specifications within each state's specifications and maintenance manuals, was determined to be necessary by the research team and Technical Review Panel.

In addition, there is a lack of documentation of best practices within IDOT regarding pothole repair to assist districts and maintenance crews in decision-making. To better determine how the nine districts in Illinois address the issue and further develop a comprehensive pothole-patching maintenance strategy for IDOT, the present study also included meetings with operations supervisors, field engineers, and lead workers from each district to gain a strong understanding of their current state of practice.

The objective of this study was to conduct a fact-finding mission regarding pothole repair strategies within and outside of the state of Illinois in terms of materials, techniques, manpower, and equipment. This consisted of a two-pronged approach that included a literature review and IDOT district interviews.

CHAPTER 2: LITERATURE REVIEW

Although there are limited studies performed on pothole patching methods, a review of the existing literature was conducted as part of this study. This chapter provides a review of previous studies and existing specifications within many agencies. Based on the scope of this study, the reviewed studies describe materials, techniques, and equipment currently and previously used for pothole patching, including test methods used for pothole patching materials. In addition to national reports and published research articles, the present study includes a review of available practices within all 50 states in the United States as well as Puerto Rico and Washington, DC.

POTHOLE PATCHING MATERIALS

Based on the design mixing and placing temperatures, bituminous patching mixes are generally categorized into three broad categories: hot-mix asphalt (HMA), cold-mix asphalt, and spray injection materials. The first type, HMA, is a mixture of asphalt binder and mineral aggregates. HMA typically has better mechanical properties than cold mixes and spray injection materials (a single size aggregate and liquid asphalt, which are discussed later in this chapter), and a longer lasting patch is expected. Cold mix usually consists of liquid bituminous emulsion and mineral aggregates. These mixes can be placed in all seasons, including cold weather. Cold mixes are typically found to have worse performance compared to HMA (Maher et al., 2001). In terms of weather, in wet–freeze locations, HMA is often used for more permanent patching during the summer, while cold mix is used when asphalt plants are closed in winter. Cold mixes and spray injection patches are usually thought of as temporary repairs until a more permanent patch can be performed or resurfacing is completed, but on some occasions, cold mix can be utilized as a permanent patching solution (Diaz, 2016).

Hot-mix Asphalt

HMA is considered the best material for patching potholes (Dong et al., 2014b; Eaton, 1989; Smith et al., 1994). HMA mix design for pothole patching typically follows the requirements of HMA surface course or binder course mixes provided in state design and construction specifications. For instance, Arkansas DOT requires surface course mixes for patching potholes (ArDOT, 2014), while Washington DOT recommends asphalt concrete Class B, which is a dense-graded 5/8 in. nominal maximum aggregate size (NMAS) HMA mix (WSDOT, 2000). For the use of HMA, temperature is an important consideration, and most states have temperature requirements. For example, Pennsylvania DOT suggests HMA is heated to 300°F before dumping the material (PennDOT, 2016). HMA is typically utilized in warm seasons due to availability but can occasionally be used in winter with the help of hot boxes or small recycling equipment (Eaton, 1984). Note that HMA is prone to thermal segregation during transportation due to duration of travel, weather conditions, or other factors, which can lead to premature patch failure (Byzyka et al., 2017). This can also create density and permeability issues.

Cold-mix Asphalt

Generally, cold mix is grouped into three subgroups: cold mix produced by local plants, cold mix produced according to agency specifications, and proprietary (patented) cold mixes produced by local plants into bulk and stockpiles (Berlin & Hunt, 2001; Ghosh et al., 2018). Generally, no compatibility testing is performed for the first type, but previous studies have recommended conducting acceptance tests before utilizing materials of the last two types in order to ensure the quality of cold-mix products (Wilson & Romine, 2001). Specifically, for cold mixes, the most important properties include resistance to draindown, resistance to stripping, cohesive properties, and workability, as well as compatibility with an existing HMA layer (Berlin & Hunt, 2001). Table 1 mentions some methods for testing these properties based on previous literature. Note, however, that some work on such methods are largely out of date due to a lack of recent studies. It is also notable that some studies suggest heating cold mixes using portable machines, which can increase the effectiveness of cold-mix patches (Berlin & Hunt, 2001; Eaton, 1989).

Table 1. Testing Methods for Cold-mix Properties

Property	**Test Methods**
Draindown	Placing mix on a plate and observation of draindown of binder to plate (Anderson et al., 1988; FHWA, 1999)
Workability	Penetration resistance (Anderson et al., 1988; FHWA, 1999) (AASHTO TP43)
Cohesion	Rolling sieve test (described in detail in FHWA, 1999) (AASHTO TP44)
Stripping	Observation of 90% coating of aggregate before and after moisture conditioning (FHWA, 1999) (AASHTO TP40)

(Berlin & Hunt, 2001)

Proprietary cold mixtures are utilized commonly due to wide availability and relatively better performance. Many of them also exhibit advantages such as less need for tack coat application before placement and the lack of compaction required to prevent premature failure of the patch. In general, proprietary mixes are thought to result in a cost-benefit due to their extended life compared to the other types of cold mixes (Thomas & Anderson, 1986). Eaton et al. (1989) also emphasize the importance of gradation with regard to cold mix, although many studies a few decades ago found that it is often just obtained from local plants without regard to gradation (Anderson & Thomas, 1984; Berlin & Hunt, 2001). A few of the main types of proprietary cold mixes are discussed below.

UPM (UNIQUE Paving Material) is a proprietary cold mix made up of specially formulated binder and local aggregate. The binder that forms UPM is a proprietary cutback asphalt with a modifier that controls the viscosity, leading to good workability. UPM can usually be divided into winter UPM and summer UPM. Winter UPM requires open-graded aggregate and can be applied below 40°F, while summer UPM is formulated with dense-graded aggregate and can be applied between 60°F–80°F (Ghosh et al., 2018). Ghosh et al. (2020) demonstrated that winter UPM has higher strength than summer UPM. This is due in part to the gradation, but it should be noted that it is likely the binder used between the two mixes is different as well, based on the workability differences.

Perma-Patch is a type of proprietary, “self-sealing” cold mix comprised of liquid asphalt and aggregate, which is used in Minnesota. The weight of bituminous material in Perma-Patch is 5%–6% of the total weight of the mix, which is similar to that of UPM (Maher et al., 2001; Ghosh et al., 2020).

However, in a recent study, winter UPM was found to bond better than Perma-Patch with HMA (Ghosh et al., 2020).

QPR (Quality Pavement Repair) is another proprietary cold mix made up of special binder and crushed limestone or an approved equivalent aggregate (Maher et al., 2001). The mix gradation for this mix should generally comply with ASTM C-136 (Maher et al., 2001). The QPR website indicates that there is typically no need to sweep water from the patching area if it is free of debris.

PennDOT 485 and PennDOT 486 are two cold mixes produced in Pennsylvania at asphalt plants according to their state specifications (Wilson & Romine, 1993). Note that the studies focused on these materials are largely outdated and mainly took place 30 years ago or more. Since that time, the technologies used have evolved into more modern materials. The main difference between these two mixes is that PennDOT 486 includes additives of polypropylene or polyester fibers (Wilson & Romine, 1993). The state specification includes gradations for both fine and coarse mixes using these materials. Other fiber mixes have also been shown to perform strongly, including mixes that utilize cellulose-based fibers (Ferrotti et al., 2014).

IAR (Innovative Asphalt Repair) is a high-quality repair material composed of binder and aggregate blended in a HMA plant. The aggregate gradation is checked using the procedure outlined in ASTM C-136 and uses 100% limestone or an equivalent aggregate (Maher et al., 2001). The binder is a modified cutback meeting the ASTM requirements (Maher et al., 2001). This patching material can be applied at temperatures as low as 14°F (−10°C), at which it remains cohesive and flexible (Biswas, 2016).

Wespro is another cold-mix material made of specially formulated binder and local aggregate. The aggregate is composed of limestone or other approved aggregate meeting ASTM C-136. The liquid binder is comprised of a special asphalt and pressure-sensitive plastics and chemicals (Biswas, 2016).

EZ Street is a proprietary cold-mix material frequently used in the state of Illinois, as mentioned in Chapter 3. This proprietary mix uses polymer-modified emulsion and is meant to work in all weather conditions without a need to clean the hole. It is also meant to be environmentally friendly due to its inclusion of biofuel.

A recent Canadian study performed an investigation in which local agency officials were surveyed among Canada's six providences to determine their state of practice using cold-mix materials (Biswas et al., 2018). Their study showed wide prevalence of QPR within Canada, but both QPR and IAR had issues with stability and inadequate adhesion and cohesion. In general, they demonstrated that Canadian provincial agencies were mainly using cold mixes and proprietary mixes.

Spray Injection Materials

Spray injection material is typically comprised of crushed aggregate and emulsified asphalt. After transfer to a jobsite, aggregate and emulsion are mixed on site in spray injection equipment. A single size aggregate allows a uniform thickness of asphalt to be coated onto aggregate particles (Wilson & Romine, 1993), although the thickness of the coating or degree of coating can vary based on the operator and equipment (Kwon et al., 2018). Note that the equipment is of utmost importance for spray injection patching. This is discussed in a later section.

Reclaimed Asphalt Pavement Material

Reclaimed asphalt pavement (RAP) material theoretically benefits the patching operation by lowering the required usage of binder if the RAP is heated to an appropriate mixing temperature. This is considered economically efficient, as the binder is typically the costliest component of any asphalt mixture. Kwon et al. (2018) demonstrated less abrasion loss based on the wet track abrasion test as well as good stability and adhesion performance when using spray injection patching in conjunction with RAP. From Montana DOT, RAP is prepared in three ways for patching: wind-rowed millings shot with emulsion; millings run through a pug mill, which leads to a more thorough mixing; and millings run through a HMA plant at hot mix temperatures, as part of an HMA mix design, and placed with a paver when partial or full-depth patching is performed (MDOT, 2002).

Novel Materials in the United Kingdom

A recent study in the United Kingdom (McHale et al., 2016) demonstrated the efficiency of resin-based mixtures as an alternative patching mixture. This was considered especially viable for local agencies in Scotland, which deal with very low temperatures in winter. Additionally, the researchers found that concrete and hydraulically bound mixtures work as alternative permanent repair materials aside from common options. The procedure is carried out as follows:

1. Stir resin and mix resin with hardener for 2 to 3 minutes.
2. Pour the required amount of mix and aggregates into a bucket.
3. Pour the mixture and spread it in the potholes.

Though it is considered a permanent repair, the material cost is high compared with conventional materials. Among the materials evaluated by McHale et al. (2016), only water-setting mixes had higher costs than these.

Additives

Stripping is a primary concern when using patching materials. Therefore, anti-stripping additives are suggested to prevent premature failure, including 1% hydrated lime by weight in some cold patching mixes (Chatterjee et al., 2006). Patel et al. (2018) indicated that Organosilane, produced by inorganic and organic reactivities based on silicon chemicals, can be beneficial in both HMA and cold mix as chemical additives. The use of these compounds improves the bonding capability, prolonging the life of patches.

Laboratory Material Quality Tests

Many agencies require quality control and quality assurance tests on samples of patching materials. In general, these are more common than field tests, which are not frequently performed on pothole patches. These tests can include both acceptance and compatibility tests. Acceptance tests are related to overall material quality, while compatibility tests are related to the compatibility between a specific binder and aggregate. These tests are typically specified due to their relation to field performance. Although the relationships between these acceptance tests and field performance are not perfect, they provide some prediction of the material's field behavior. Some laboratory tests for patching materials are summarized in the following paragraphs.

Wilson and Romine (1993) claim that viscosity, penetration, ductility, and softening point tests should be performed on extracted binder from patching materials. Although these tests are currently outdated in the United States, it is important to note that the need to consider binder properties is not. For aggregates, sieve analysis should be performed to check gradation. For mixtures, a stripping test is highly recommended because the anti-stripping properties of a mix are suggested to be related to long-lasting pothole patches. The Hamburg wheel tracking test has previously been used for this purpose (Chatterjee et al., 2006).

Based on the main causes of patch failure, the Marshall stability test can be utilized for both HMA and cold mix (Maher et al., 2001). The rolling sieve and adhesiveness tests are recommended to evaluate bonding within materials and to the existing pavement (Biswas, 2016). This test "involve[s] rolling a compacted briquette in a 19.0 mm (3/4 in.) square opening sieve of 305 mm (12 in.) in diameter. Except the freezer unit and/or a large metal tray, all of the equipment involved is common items in an asphalt laboratory. The sample is prepared by using a Marshall hand-held hammer and mold and compacted at −10°C (140°F). The percentage of materials retained on the sieve after rolling is called the cohesion index. The higher the index, the better is the cohesion" (Tam & Lynch, 1987, as cited in Maher et al., 2001, p. 6). Moreover, through short- and long-term laboratory verification, Huang et al. (2020) found the abrasion rate is correlated to the asphalt film thickness. Aside from film thickness, the gradation is also correlated to the abrasion rate even though the coefficient of correlation is relatively low (Huang et al., 2020).

Workability is also critical to achieve proper density during compaction of the patch. To evaluate workability, researchers in Texas developed the cold-patch slump test, which is adopted from the slump test for Portland cement concrete (Chatterjee et al., 2006). In this test method, a cylindrical specimen is conditioned at a high temperature and then placed in a containment cylinder of larger diameter. The time to fill the larger diameter specimen is considered a measure of workability. Within the Ontario Ministry of Transportation, blade resistance was also employed to evaluate workability (Maher et al., 2001). This method uses a blade to penetrate the mix for 30 seconds at a rate of 50 mm/min; the measure of penetration is used to quantify the workability, by the logic that it is similar to a shovel penetrating mix in the field.

Finally, a note should be made about liquid bituminous emulsions and cutbacks frequently used in pothole patching applications. While acceptance tests are typically performed, the research team found these tests do not vary much from agency to agency, and the following are typically performed:

- Flash point (AASHTO T48)
- Water percent (AASHTO T55)
- Distillation (AASHTO T78)
- Ductility (AASHTO T51)
- Ash Content (AASHTO T111)

SUMMARY OF TECHNIQUES

AASHTO (2011) classifies maintenance actions of transportation assets into two broad categories: proactive and corrective. Proactive maintenance includes actions taken to prevent the failure of pavement structures and to extend the service life of the structure in the future (Cui et al., 2020) and can be subdivided into preventive and predictive maintenance (Karimzadeh & Shoghli, 2020). Corrective maintenance aims to fix the functional elements in pavements in which distresses have already occurred; the broad range of pothole patching generally falls into this category.

Pothole repair techniques generally can be classified into one of the following categories: throw and roll, throw and go, semipermanent, edge seal, spray injection, permanent patching, and other patching techniques, with further variations within each technique depending on the specific procedures within agencies. Note that permanent patching is outside the scope of this study, but is described in this literature review as it has great relevance and is commonly weighed as an alternative to the other techniques described here when many potholes exist in a section. In the following sections, individual procedures are described; however, note that each agency has slight variations, which are described later in this chapter. It is furthermore critical to note that even within a single agency, the practices can vary greatly, as discussed in Chapter 3.

Throw and Go/Throw and Roll

Throw and roll is a commonly used technique for temporary pothole repair. Throw and roll applies compaction after laying material, while throw and go does not apply compaction after laying material. The two techniques are grouped together in this section but are crucially different in terms of compaction and performance. This technique typically includes the following steps (ITD, 2019):

1. HMA or cold mix is placed into a pothole. (Water and debris may or may not be removed.)
2. Truck tires compact the material until a crown (between 1/8 in. to 1/4 in.) of the mixture is formed. (The compaction of truck tires is not performed for throw and go.)
3. The next pothole repair commences, while traffic opens immediately.

In terms of materials, both HMA and cold mix can be utilized in throw-and-roll/throw-and-go patching. However, for some regions, like New Jersey, cold-mix materials are used in winter as part of a temporary repair strategy, while hot-mix materials are reserved for permanent repairs because they are considered to perform better (Maher et al., 2001). However, the hot-mix materials are often more expensive. Cornell’s local roads program suggests that throw-and-roll patches using proprietary materials are generally more effective than throw-and-go methods or using nonproprietary cold mixes for throw and roll and can decrease recursion of potholes by more than 50% (Orr, 2006). For equipment needed in throw and roll, trucks are required for hauling, transporting, and compacting materials while hand tools are necessary for spreading materials.

The throw-and-roll method has the advantage of providing a convenient and quick method for patching, which increases the productivity of agencies. From Maher et al. (2001), the efficiency of throw and roll is on average 2.6 minutes per pothole, whereas semipermanent and spray injection require 13.3 and 2.8 minutes, respectively. However, the rate of failure for this technique is high. In the long run, throw and roll with poor materials and techniques is more costly, as potholes require more re-repair and replacement than more permanent fixes. This is generally a result of edge disintegration (Dong et al., 2014b), which occurs due to a loss of bond between the existing pavement and patching material. However, a stronger performance of throw-and-roll patches can be achieved with proper compaction and curing (Dong et al., 2014a).

Edge Seal

From the SHRP-H-353 report, the edge-seal method is much like the throw-and-roll patching method, but the edge-seal method requires a sealing of the interface between the patching material and existing pavement using a tack material. The typically required steps for edge sealing are as follows:

1. HMA or cold mix is applied into a pothole. (Water and debris may or may not be removed.)
2. Truck tire compaction is administered.
3. A slight crown is verified. If the depression happens after rolling, additional material is added above surrounding pavement.
4. One day is allowed for drying the patching areas. Afterward, the tack material is applied along the perimeter of the patch.
5. A layer of cover sand is placed to avoid tracking.

The materials utilized in edge sealing are cold mix or HMA as the patching material, emulsion or other tack material, and sand. Equipment needed in this technique include the truck for hauling materials, hand tools, and a broom or brush to apply the tack coat.

Similar to the throw-and-roll method, edge sealing has the advantage of low cost and reduction of required labor. However, edge seal is superior to throw and roll, addressing the issue of the penetration of water resulting in the recurrence of the original pothole failure. This is significant because recurrence of the original failure mechanism is the main cause of pothole repair failure, based on a survey from Minnesota DOT (Ghosh et al., 2018). However, some studies argue that the edge-sealing step may be more decorative than functional, as this method is not proven to be cost-effective (Anderson & Thomas, 1984). Overall, the cost-effectiveness of edge sealing is not well proven in the existing literature, especially considering the temporary nature of many patches.

Semipermanent

The semipermanent procedure is considered the best procedure aside from permanent patching. Even though semipermanent patching is much more labor intensive than the throw-and-roll method, the good performance often offsets the increased labor costs (Wilson & Romine, 1993). The effort and time put into semipermanent patching also contributes to the success rate of patches (Wilson & Romine, 1993). The general steps include:

1. Water and debris are removed from the pothole.

2. Saw cutting is used to square up the patch area so that vertical sides are perpendicular to the sound pavement. Note that there are questions about the effectiveness of using 90° angle corners (Dailey et al., 2017). Debris and water should be removed after saw cutting as well.

3. Patching material is applied. The patching material should be mounded in the center of the hole and tapered to the edge to meet the existing pavement.

4. Vibratory compaction equipment is employed to compact.

5. Traffic is open when patching is finished.

For materials utilized in semipermanent patching, different manuals suggest different materials. In general, both cold mix and HMA can be used for the semipermanent procedure. Cold mix is mostly used in the winter, as the materials are obtained locally from asphalt plants and shipped to field sites (Johnson, 2000). Equipment required to implement this technique includes a truck carrying materials, hand tools, compaction devices, an air compressor for cleaning dirt or particles, and a pavement saw.

The semipermanent method benefits from the longevity of the repaired patch in performance. The drawbacks of this procedure are lower productivity as well as higher labor and equipment costs. Semipermanent is also not feasible in adverse weather because more preparation and compaction are required for this method. In contrast, using high-quality materials in adverse weather for throw-and-roll or spray patching practices is recommended due to high productivity (McDaniel et al., 2014). Because of high manpower requirements for semipermanent repairs, it is critical to provide crews with specific guidelines to achieve maximum efficiency (Thomas et al., 1984), including proper training on cutting, materials, compaction, and tack application.

Spray Injection

Spray injection is a useful method for repairing transverse cracks and potholes. It is one of the most cost-effective patching procedures, in part because the spray injection technique does not require compaction (ITD, 2019). According to NCHRP Synthesis 463, 27 states report using spray injection patching, 26 of which do it in house rather than by contract (McDaniel et al., 2014). Based on this report, the degree of success varies greatly. For example, Georgia reports problems with materials and equipment, including lack of density, clogging of equipment, and difficulty spraying aggregate. Meanwhile, Indiana reports nearly permanent repair using spray injection. Another study (Kuennen, 2004) indicated that South Carolina bought 57 spray patchers in 1997, which reduced the need to repatch a hole by more than 50%. This method is broadly performed with specialized pavement patching machines, which can spray both emulsion and mineral aggregates. The general steps for spray injection include (Orr, 2006):

1. Water and dirt are removed from the pothole.

2. A tack coat of binder is sprayed on the sides and bottom of the hole.

3. Asphalt and aggregates are sprayed into the target area.

4. A layer of cover aggregate is placed to avoid tracking.

The materials (both aggregate and asphalt binder) depends on specifications and available local materials. Besides patching asphalt pavements, spray injection is used for patching Portland cement concrete pavement (PCCP) by some states, as well as in PCCP for repairing spalling areas, corner breaks, and transverse cracking. For patching asphalt-surfaced pavements, spray injection can also repair fatigue cracking, transverse cracking, rutting, and edge breaks (Griffith, 1998).

Care should be given to the aggregate delivery system within the unit when using spray injection equipment. An improper delivery system may wear out the auger due to abrasive aggregate. Therefore, when choosing between a hydraulically driven auger and low-pressure air system, Griffith et al. (1998) recommends an air-driven delivery system unit because of less abrasion. Additionally, spray injection requires well-trained operators. In most cases, an operator needs 4 to 6 weeks to get comfortable using the equipment (Griffith, 1998). Based on the Minnesota practice handbook (Johnson, 2000), spray injection functions best in spring compared to winter seasons.

Permanent Patching

Permanent patching (which is often used interchangeably with full-depth patching in the literature) is used for pavement where the potholes are larger and/or deeper than surface distress, when material and labor resources for large patching operations can be obtained. Note that the typical difference between these methods are both the method used for excavating the old pavement (see step one below) and the depth of patching. Although it is not a main focus of this report, it is important to discuss the typical permanent patching procedure. The permanent procedure for good patching includes:

1. The area to be patched is marked before construction, outside the worn area. The outline of the area is cut with the milling machine, saw cut, or jackhammered.

2. Unstable surfacing materials and weak base layer are excavated down to a stable base. (some subgrade material may be removed). The surface of excavation shall be firm and strong enough after trimming and compacting the base layer or subgrade layer. Also, the vertical sides faces should be confirmed.

3. Tack coat is applied to vertical faces while a prime or tack coat is applied to the base of the hole.

4. Asphalt mixture is filled back in the hole. Mix is shoveled against the edge immediately after the truck lays it down. Care should be taken to avoid segregation.

5. The maximum lift thickness of each lift depends on the type of mixtures and compaction equipment. After vibratory or roller compaction, the grade of patched area should be the same as the existing pavement. If the edge needs more material, then the material should

be directly deposited and excess material should be removed using a shovel (Johnson, 2000).

Anderson and Thomas (1984) also emphasize the importance of marking, which is defining the amount of material to be removed. This procedure provides for more efficient repairs. It is also critical to dig to the base because, as Minnesota DOT states, some potholes are caused by unstable base or subgrade problems (Ghosh et al., 2018).

From the *Alaska Highway Maintenance and Operation Handbook* (McDonald & Sperry, 2014), material used in permanent repair is always HMA. Note that permanent patching is utilized as the major maintenance method in Alaska. In Alaska, permanent asphalt maintenance in winter is seldom done, and potholes are patched using cold mix for temporary repairs. Like in most cold weather areas, potholes are not repaired by HMA until spring or summer. The equipment required for permanent patching includes a truck, hand tools, compaction devices, milling machine, saw cut, or jackhammer.

Other Techniques

Surface Patching

Alaska uses a temporary cold-mix patching technique, which they refer to as surface patching. In general, it is very similar to throw and roll, but the manual from Alaska (McDonald & Sperry, 2014) suggests correcting the possible drainage problems that may cause failures of patching materials before placing new materials.

Inlay Patch Repair

Idaho Transportation Department (2019) suggests inlay patch repair in addition to common methods such as throw and roll, semipermanent, and spray injection repair. Inlay repair involves excavating and replacing the roadway surface with premix. The detailed procedure includes:

1. Unstable material, including influenced base layer, are milled out or broken up at least 1 ft along the perimeter of the cracked area.
2. The area to be patched is squared up until the vertical sides are formed.
3. Light and uniform tack coat is applied.
4. Mix is placed not exceeding 3 in. per lift.
5. Each layer is compacted with a vibratory compactor.
6. Traffic is open when the maintenance workers are withdrawn.

Even though this inlay patching procedure has a similar procedure to permanent patching, the material they are using is premix rather than conventional HMA, which makes it slightly different.

Miscellaneous Procedures

Sometimes, local roads are maintained by contractors rather than the state agencies; in many cases the contractors provide some special techniques focusing on pothole distress. For example, in Florida, a contractor (Asphalt365 Inc., 2020) suggests surface patching, mill repair, and demolition repair (similar to a permanent patch) based on the severity of potholes. Surface patching is employed for minor repairs and involves adding appropriate amounts of patching material and compacting. Mill repair is used for damage within the base course and is performed by milling the damaged potholes and placing new asphalt mix. Demolition repair requires comprehensively removing the asphalt and aggregate base or subgrade layer and placing new materials.

Based on a New Jersey DOT report, which conducted a literature review, agencies in Illinois and Oregon have distinct pothole repair procedures that differ from those mentioned above (Maher et al., 2001). In Illinois, this method involves placing patching materials into potholes and compacting. When compacting, a slight crown should be confirmed. If it is not, more material should be added to create such a crown, slightly above the surrounding area. After this, bituminous material is applied to cover the patched surface, preventing tracking. The technique is also called surface sealing by the Federal Highway Administration (1995) and is similar to edge sealing. Note that in the district meetings described in Chapter 3, many IDOT districts described using spray patching equipment to perform this type of patching after cold-mix materials are placed.

From the same New Jersey DOT report, Oregon has a special technique to patch potholes in which the first step is to remove water and debris from potholes. Then, asphalt emulsion is placed as a tack coat, which is heated by a propane torch causing the emulsion to break faster. Cold mix is then heated and placed in the potholes. A truck tire is then used to compact the patching materials. Next, the patch is checked to ensure a crown exists; if not, additional material is required to level the surface up to and slightly above the surrounding areas. This is also called the heat-and-tack technique by FHWA (1995). The overall performance of cold mix can be improved by this technique, so it can be used for regions with poor cold mixes. However, it can also still be used in conjunction with good-quality cold mixes.

Infrared Heating Technology

Infrared heating technology has been used in pavement engineering for 30 years and is commonly used for repairing longitudinal cracking and small potholes (Uzarowski et al., 2011). Using reclaimed asphalt pavement (RAP) materials and rejuvenators, this technique is said to create longer lasting patches than patching procedures described above due to thermal bonding (Freeman & Epps, 2012). One of the application examples is in a Canadian airport. With RAP materials and rejuvenators, this technique creates a strong thermal bond between the existing pavement and the patched section. The process of infrared pavement patching is as follows (Speller et al., 2019):

1. The damaged area is heated with an infrared heating machine.
2. Heated asphalt is removed and mixed with virgin asphalt binder and rejuvenator.
3. The mixture is returned to the hole left by its removal and graded.

4. The rejuvenated material and virgin material are compacted into the hole.

The cost of employing this technique is comparable to traditional patching methods because much of the material is recycled. Thus, the material cost is only derived from the rejuvenators and any virgin asphalt used. In many cases, the use of virgin asphalt is not necessary. Moreover, some researchers employed the induction heating method, which is made possible when asphalt mixture with steel fibers is inserted at the bottom layer, providing better bonding and durability (Obaidi et al., 2017).

After identifying a disadvantage of infrared heating unevenly heating the asphalt material, the infrared heating technology procedure was optimized by Leininger (2015). This study demonstrated that a two-stage heating scheme improved heat penetration into the asphalt mat (Leininger, 2015). Specifically, the heating involves heating the existing asphalt as usual but with scraping off the charred surface for 1/2 in. or 1 in., then exposing the surface for 6 minutes to cool down, followed by adding virgin HMA and heating again (Leininger, 2015). The two-heating stage has the advantage of heating deeper material more evenly, which facilities the bonding of new patching material with existing material.

To further develop better solutions to pavement pothole patching, Byzyka et al. (2020) developed a transient thermal HMA repair model. They ran finite-element models for the cases of (1) HMA placed in the pothole with ambient temperature, (2) dynamically preheated pothole excavation without applying HMA, and (3) preheated repair with HMA using dynamic heating, which is the combination of (1) and (2) (Byzyka et al., 2020). The results show a good correlation between patch performance and measured temperature, which helps provide further insights into the heat flow within the air-pavement heater system.

Another recent study explored the use of microwave technology in conjunction with 100% RAP in Minnesota as a proof of concept (Clyne et al., 2010). This technique used a 915 MHz microwave source to heat RAP and the existing hole to 240°F with a total patch time of 50 minutes. Overall, performance of these patched sections was regarded to be similar or slightly better than traditional methods; however, the time to patch was too long. One potential solution proposed by the authors was the use of taconite aggregates for faster heating. Other studies also evaluated taconite-based repair methods and found that the microwave patch method could be suitable not only for RAP materials, but also materials using reclaimed asphalt shingles (Zanko, 2016).

Summary of Pothole Patching Techniques

When choosing a pothole patching method, manpower is a major concern, which is discussed more in Chapter 3. Regarding manpower, semipermanent patching generally needs four workers patching in addition to the workers responsible for traffic control (which is mostly dependent on the route type and number of lanes), whereas the throw-and-roll, edge-seal, and spray injection methods need two workers for patching in addition to the labor required for traffic control (Wilson & Romine, 1993). Table 2 includes a full summary of all techniques, including the manpower requirements associated with each one.

In terms of life expectancy, cold-mix asphalt is anticipated to perform well for one year, although this varies greatly, while HMA is expected to remain in good condition for 3 to 6 years, with great variation (Johnson, 2000). If these procedures are completed correctly, HMA patches can last 15 years or more (Johnson, 2000). For spray injection patching, the expected life depends on the density achieved and patching area condition. Short life may be caused by a lack of density. Poor mix design (meaning the aggregate to binder ratio leading to inconsistent coating) or wet conditions (or a wet aggregate) often also results in shorter life of a patch. However, if done well, spray injection patches can last 5 years or more (Johnson, 2000).

Productivity of pothole techniques are a major concern of agencies. A previous study by FHWA investigated the productivity of various techniques (Wilson & Romine, 2001). In general, throw and roll is the fastest method for hand patching, though using spray injection can be more productive in practice, meaning it may be faster with good training. Edge seal is also a productive method, but edge sealing only reached 50%–60% of productivity levels of the most efficient throw-and-roll patching. Semipermanent is the most efficient method of pothole patching but takes the most time.

EQUIPMENT

From the perspective of equipment involved in patching, maintenance methods are classified into two types: manual patching and spray injection patching. Manual patching often aims at patching discrete potholes. For different patching procedures, the equipment employed differs, as discussed above in detail.

The typical tools used by maintenance crews for manual patching include a dump truck, a pickup truck, shovels, tampers for achieving density, a broom or brush for tack, and air compressors or leaf blowers for cleaning holes prior to patching. From Montana DOT, specialized tools used in hand patching include a jack hammer, a pavement saw, and a roller for compacting (MDOT, 2002). Thomas and Anderson (1984) described an edge-straightening device that is used to ensure vertical sides in holes when doing semipermanent patching.

In the coming years, it is expected that innovations in pothole repair equipment will continue to grow. A variety of techniques have already been developed to automatically detect potholes (Buza et al., 2013; Jo & Ryu, 2015; Kang & Choi, 2017). In addition, one study from Texas A&M focused on the development of an intelligent pothole repair vehicle, which could automatically detect and fill potholes without inputs from an operator (Adarsh et al., 2018). The below paragraphs of this review, however, focus on more recent innovations in pothole repair.

Table 2. Summary of Pothole Patching Techniques

Techniques	Material	Equipment	Labor (excluding Traffic Control)	Suitable Seasons	Productivity	Life Expectancy
Throw and go	Cold mix or HMA	Truck, hand tools, shovel	2 workers	All seasons		A few hours – 1 year
Throw and roll	Cold-mix or HMA	Truck, hand tools, shovel, tamper	2 workers	All seasons	1.98 ton/hr	Cold mix: expected 1 year; HMA: expected 3 to 6 years
Edge seal	Cold-mix or HMA, tack material and sand	Truck, hand tools, shovel, tamper, broom or brush	2 workers	All seasons	1.1 ton/hr	Cold mix: expected 1 year; HMA: expected 3 to 6 years
Semipermanent	Cold-mix or HMA	Truck, hand tools, compaction device, air compressor, and an edge-straightening device (either a jack hammer with spade bit attachment, pavement saw, or cold milling machine	4 workers	Warmer seasons, not suitable for adverse weather	0.36 ton/hr	Cold mix: expected 1 year; HMA: expected 3 to 6 years
Spray injection	Spray injection materials	Spray injection device	2 workers	All seasons	2.09 ton/hr	Almost 5 years
Surface seal	Available cold mix	Truck, hand tools, shovel, tamper, broom or brush	2 workers	NA	1.1 ton/hr	Expected 1 year
Heat and tack	Available cold mix	Truck, hand tools, shovel, tamper, broom or brush	2 workers	NA	0.484 ton/hr	Expected 1 year
Permanent	HMA and tack materials	Truck, hand tools, compaction device, air compressor, and an edge-straightening device (either a jack hammer with spade bit attachment, pavement saw, or cold milling machine	NA	Only warmer seasons	NA	15 years or more
Infrared heating technology	Rejuvenator	2 3/4 ton pickup trucks; skid steer loaders; 3 trailers (for transportation of equipment); 2 10-yard dump trucks; 1 arrow board; 2 HeatWurx generator and heater elements; 1 processor for scarifying, milling, mixing, and shaping; 1 small vibratory roller	8 to 9 workers	All seasons	3.0/hr	NA

Hot Boxes

In pothole patching applications, hot boxes are generally used to keep materials and heat them to a workable temperature. Generally, there are two types of hot boxes. The first type is a holding box, which is designed to hold HMA without an internal energy source; therefore, it is only suitable for projects that will take place within a few hours. The other type is a hot box reclaimer, which can maintain the temperature over time because it is thermostatically controlled as an infrared unit (Heydorn, 2010). Moreover, the heating system can be diesel based, propane based, or electrical, depending on the manufacturer. Heydorn (2010) indicates that diesel hot boxes can more quickly increase the workability, whereas propane-run hot boxes are cleaner in terms of energy.

Spray Injection Equipment

The spray injection patcher is a major piece of equipment used for spray injection patching. It carries virgin aggregate and asphaltic material (usually emulsified) to pothole locations. After blowing out debris and water to clean the hole, the aggregate and asphalt are sprayed into holes, resulting in a patch (Wilson & Romine, 1993). In recent years, automated patching machines have been increasingly utilized; these machines automate parts of the spray patching process, including cleaning the hole and applying emulsion and aggregate. (Lofton et al., 2014).

FIELD PRACTICE IN THE UNITED STATES

One important aspect of this study was to investigate the existence of specifications within different agencies for pothole patching. It is important for state agencies to offer some type of guidance to local engineers regarding best practices for patching potholes. In the United States, some states have manuals that specifically focus on pavement surface maintenance. These often contain guidelines for patching potholes. Meanwhile, some states do not have such specific manuals, but instead include information about patching potholes within standard specifications. Furthermore, some states do not have publicly available information regarding pothole patching practices. A review of available information online led the authors to conclude that approximately 24 states and Washington, DC had some form of information publicly available online to guide engineers in terms of pothole patching practice.

Note that a lack of availability of such information online does not mean that such best practices guidance does not exist within an agency, only that it has not been codified and made available to the public. Figure 1 indicates which states have such available manuals or specifications online. In addition, it should be noted that many states have qualified producer lists for patching materials available online, but these were not included in this review due to their importance being largely local.

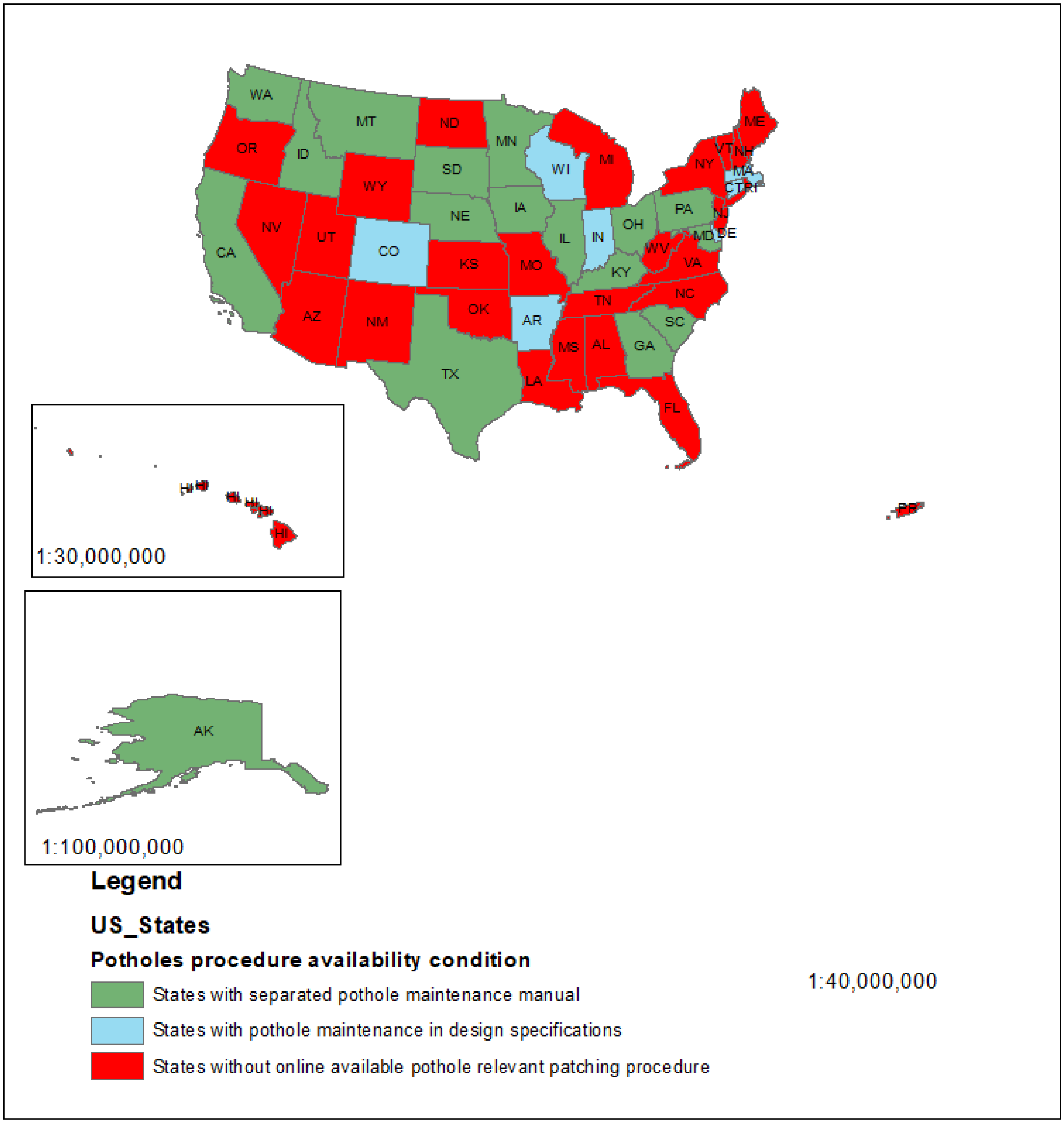

Figure 1. Map. Pothole repair guideline availability by state.

Alaska

Asphalt roadway repair and rehabilitation guidelines, including intersection, roadway, drainage system, roadside, and bridge maintenance, are described in the Alaska operations handbook. In asphalt repair, the main approaches to pothole repair are surface patching and full-depth patching. The difference between the two approaches is described earlier in this chapter. This handbook specifies that deterioration that spans more than 25% of the total pavement thickness requires full-depth repair rather than a surface patch (McDonald & Sperry, 2014).

Surface patching serves as temporary patching until more long-lasting patching activities are scheduled. Preparation for surface patching includes traffic control before construction, correction of drainage issues that may be the cause of potholes, and cleaning the area to be patched, making sure that target areas are free of water and loose particles. The procedure then includes filling the potholes to the point that patched areas are higher than the surrounding area, smoothing the area with a shovel, applying a truck or rollers to compact, and cleaning remaining debris from the area (McDonald & Sperry, 2014).

For material requirements when patching, all-season patch material performs well but dry material is better. Special materials are also recommended for cold weather as fast curing and extreme weather–resistant material. The equipment used for surface patching is listed in Table 2.

Arkansas

Asphalt concrete construction procedures and relevant material and equipment are introduced in Arkansas' standard specifications. However, specific maintenance strategies for potholes are not included, which is typical for most agency construction and design specifications (ArDOT, 2014). Materials for patching in Arkansas should generally conform to asphalt concrete hot-mix surface course (9.5 mm or 12.5 mm NMAS) requirements; the asphalt concrete hot-mix binder course (25 mm NMAS) or cold plant mix, which could include MC-250, MC-800, MC-3000 emulsion; or inverted emulsion type asphalt (ArDOT, 2014). In terms of QC, Arkansas requires asphalt content (either by extraction or nuclear gauge) and gradation (AASHTO T 30) checks (ArDOT, 2014). The required gradation is in Table 3.

Table 3. Arkansas Cold-mix Gradation

Sieve (mm)	Percent Passing (%)	Mix Tolerance (%)
0.5″ (12.5)	100	
#4 (4.75)	60–80	+/−7
#8 (2.36)	43–63	+/−5
#50 (0.3)	15–28	+/−4
#200 (0.075)	4–10	+/−2

To construct the HMA patches, the specification requires the removal of loose debris and unstable areas, with the goal of providing a stable and firm bottom surface. A tack coat is applied to vertical sides of the holes. The application of asphalt binder or surface course is performed and followed by compaction to make the surface smooth and level (ArDOT, 2014).

California

Pothole patching in California is divided into small patches and large patches, according to the size of holes; however, California did not provide instructions distinguishing between small and large holes.

In California, for small patches, hand patching and directly laid material are permitted for some instances, but clean and dry pothole preparation is required before patching begins (Caltrans, 2014).

The procedure for both types of patching consists of removing the loose materials before work, shaping out the target areas by sloping sides, priming the bottom and sides of the hole with emulsion or liquid binder, and filling the hole with premix material while slightly higher than surrounding pavement. All patches require square and straight ends and edges for a finished appearance (Caltrans, 2014). For materials used when patching, special premixes are introduced in the specification where potholes are not necessarily dry or are not primed; in general, these mixes last longer but are more expensive than conventional premix material (Caltrans, 2014). Cold mixes in California are generally proprietary and their use is based on manufacturer's specifications, while HMA is generally specified based on Caltrans' dense-graded asphalt concrete specification (Caltrans n.d.).

Washington, DC, Colorado, Connecticut, Massachusetts, and Delaware

For Washington, DC, Colorado, Connecticut, and Delaware, the standard specification does not have a specific procedure for dealing with potholes. However, there are some requirements for HMA patching. Washington, DC standard specifications propose that removal of defect areas are necessary before patching (Nicholson et al., 2013). Colorado standard specifications require that areas for repair shall be squared up (CDOT, 2019). Then, emulsified asphalt as a tack should be placed on the existing pavement. Connecticut standard specifications suggest that before placing the materials, the area must be free of dirt or other particles (CTDOT, 2018). For compaction, the expertise from engineers plays a key role in approving the packing method. Massachusetts standard specifications indicate that cold-patch mixes for temporary repairs should only be used when HMA is unavailable (MassDOT, 2020). Delaware standard specifications state that to perform patching, pavement must be saw cut using a cutting machine to develop a groove with a straight line when using HMA (McCleary, 2016). Cold mix in Delaware must use CRS-2P emulsion and meet the gradation requirements in Table 4. It must also pass the laboratory tests in Table 5 to be utilized for patching.

Table 4. Delaware Cold-mix Gradation

Sieve (mm)	Percent Passing (%)
0.375" (9.5)	100
#4 (4.75)	55–90
#8 (2.36)	10–25
#200 (0.075)	0–3

Table 5. Laboratory Tests in Delaware

Lab Test	AASHTO Protocol	Specification Limit
Coating Test	TP 40-94	> 90% Coated
Stripping Test	TP 41-94	> 90% Coated
Draindown Test	TP42-94	< 8%
Workability/Storageability Test	T43-94	< 3 @ 40°F
Asphalt Content/Gradation Test	T-308	See JMF

Georgia

The pothole patching section in a newsletter from Georgia DOT explains the mechanism and observed types of pothole deterioration (GDOT, 2014). Based on this newsletter, Georgia DOT uses throw and roll, semipermanent repair, and spray injection for patching potholes. Georgia's cold-mix specification requires CMS-2 emulsion, MC-250 cutback, or a blend of PG 64-22 asphalt and fuel oil. Table 6 lists the required gradation.

Table 6. Gradation for Cold Mixes for Bituminous Plant Mixtures

Sieve (mm)	12.5 mm SuperPave	9.5 mm SuperPave (Level B)	9.5 mm SuperPave (Level A)
0.75″ (19)	100		
0.5″ (12.5)	90–100	100	100
0.375″ (9.5)	70-89	90–100	90–100
#4 (4.75)		55–75	65–85
#8 (2.36)	34–39	42–47	53–58
#50 (0.3)	8-27	8-27	10–35
#200 (0.075)	3.5–7	4–7	4–7
Percent residual AC by weight of total mix	4.3–6.5	4.3–7.0	4.5–7.0

Idaho

Idaho Transportation Department's maintenance manual provides procedures and management guidance involving traffic services, pavement, as well as bridge and roadside maintenance (ITD, 2019). Throw and roll, semipermanent, and spray injection are common choices in the operations manual for repairing potholes. This manual suggests that throw and roll is the most suitable method for winter and indicates semipermanent is a low-productivity procedure, though it does result in a firmly compacted patch. The manual recommends that spray injection can be used in temperatures below freezing by heating CRS-2 emulsion. Moreover, inlay patch repair is also indicated as a type of remedy for pothole clusters.

Florida

In general, Florida is a warm weather area that does not experience many freeze–thaw cycles, which are often the cause of potholes, anywhere in the state. Therefore, there is little information in Florida's specifications regarding pothole repair. However, local contractors do perform some pothole patching and provide information available online related to it.

These contractors (Asphalt365, 2020) provide the causes of potholes, pothole repair types, and the proper procedure for repairs. The repair techniques generally include surface patching, mill repair, and demolition repair. Surface patching is applied to minor repairs. For damage down to the base layer, mill repair is applied, which mills 2 to 3 in. of asphalt and places new material. However, the distinct difference between minor and major potholes is not clear. The key steps for patching include traffic control, area marking into a square or rectangle, removing the damaged materials, applying the tack coat, filling the area with new materials, and sealing the edges of the new asphalt patch. The sealing step is important for avoiding future failure of patching because the channels of water penetration, which is typically at the edge between the surrounding pavement and the new material, is seamless.

Illinois

IDOT's Bureau of Operations *Maintenance Policy Manual* (2002) divides pavement repair into three types: partial depth, full depth, and emergency. However, it is critical to note that individual pothole patching techniques are not discussed. If the distress is confined to the top third of the asphalt layer, partial-depth repairs are appropriate. Full-depth repairs are performed when damage is more than one-third deep within the asphalt layer. In emergency cases, cold mix is often the main choice of patching material.

The Chicago Department of Transportation (2010) performs 3,800 miles of pothole repairs year-round. It classifies December to April as the key season for potholes reoccurring frequently. To monitor potholes, the Chicago Department of Transportation uses computerized map tracking and records reported potholes. Repair crews in Chicago consist of seven-day-a-week workers. In terms of materials, high-quality cold-patch materials are assigned to winter while HMA materials are arranged for spring, summer, and fall. In terms of materials used in Illinois, typical IL-19.0 and IL-25 (with the numbers representing NMAS) mixes are standard for HMA patching materials (IDOT, 2002). Note, however, that IL-25 is now removed from the standard specifications. For local roads and streets, IDOT recommends HMA mixes including N30 and N50 mixes, plant-produced cold mixes according to the bituminous mixture for maintenance use specification, and various proprietary mixes (IDOT, 2017). An extensive review of pothole patching within IDOT is available in Chapter 3.

Iowa

The Asphalt Paving Association of Iowa (APAI) (2007) provides information related to materials and techniques used within Iowa. Their guide discusses two methods for pothole repair. The first method aims to repair potholes on the surface of the pavement. The general procedure has a similar methodology to semipermanent repair, but the wet base layer must be removed before placing new material. In addition, priming holes is required before filling them. The second method is for full-depth asphalt repair, which describes the same procedure outlined above for permanent patching. Iowa DOT also requires checking of vertical alignment and smoothness with a straight edge (AIPI, 2007).

Kentucky

Kentucky has guidelines for maintenance of a pavement's surface, shoulder, and roadside (Organization Management Branch Office, 2017). Importantly, pothole patching is introduced as one of the chapters in the guide. Specific materials guidance is not presented, but a specific procedure similar to semipermanent repair is described. It is worth noting that the guide emphasizes that the pothole should be completely dry before construction and that a quality check is important before leaving the work site. For equipment used for patching, a pickup truck, truck-mounted attenuator (TMA), and distributor are recommended. Kentucky generally allows a wide range of cold mixes but requires 100% crushed aggregate with a soundness requirement of 12% for cold-patch mixes.

Maryland

A report from the Maryland State Highway Administration of Maryland DOT (n.d.) answered questions related to the causes of potholes and patching procedures. Generally, the maintenance methods include cold patching and hot patching corresponding to temporary patching and permanent patching, respectively. The recommended technique is similar to the semipermanent method. This can take anywhere from less than one hour to most of the day depending on the size of the pothole area. Maryland's qualification documents state that proprietary cold patching materials must meet the requirements in Table 7.

Table 7. Job Mix Formula Requirements for Maryland Cold Patching Mixtures

Test	AASHTO Designation	Specification Limits
Gradation	T30	Based on Job Mix Formula
Particle Coating	T195	>95%
Asphalt Content	T308	5–9%
Draindown	T305	<=8%

Minnesota

Minnesota DOT has perhaps undertaken the most extensive research of any state agency into pothole patching thus far. Apart from the common temporary, semipermanent, and permanent patching, Minnesota DOT has the option of patching with slurry or microsurfacing materials, meaning an emulsion, mineral filler, and aggregate typically used to seal cracks, though specific procedures for pothole repair with these materials are not available (Johnson, 2000). More recently, a Minnesota DOT–sponsored research study (Ghosh et al., 2018) suggested mechanical tests for selection of patching materials and a system for classifying the different materials. Their suggestions included three broad material categories for patching materials: (i) materials for emergency repairs, which are intended as a stop gap material until a more permanent patch can be applied; (ii) medium-term materials, which can last 1 to 3 years until the pavement is resurfaced; and (iii) long-term patching materials. Their work also demonstrated the inherent weakness of cold-patching materials, which are not heated externally, and suggested new material types that could be used as other solutions. These, however, are expensive and require extensive training and up-front investment in equipment. From a mechanical perspective, they did finite-element method (FEM) analyses to investigate the effect of geometric shape of potholes on stress distribution under loading. They found that a circular shape is the best shape of pothole in terms of reducing local stress concentrations (Ghosh et al., 2018). Moreover, Dailey et al. (2017) developed pothole repair strategies in the form of simple decision trees, which allow for quick decision-making based on the location of the hole, the season, and the size of a specific hole.

Montana

Within the Montana DOT maintenance manual, patching is divided into hand patching and machine patching (MDOT, 2002). Hand patching is subdivided into temporary and permanent patching. The manual states that permanent patching should be used when practical, but temporary patches may be used during cold and wet weather or when time does not permit permanent methods. According to the explanation, temporary hand patching uses a procedure similar to the semipermanent procedure but uses a tack to hold the material in place (MDOT, 2002). Plant mix, cold mix, and special mix are considered viable for pothole patching in Montana. Machine patching can use HMA, cold mix, or cold-recycled asphalt pavement (MDOT, 2002).

Nebraska

Nebraska DOT recommends three methods: semipermanent repair, throw and roll, and spray injection (NDOR, 2002). The maintenance manual identifies HMA as the best pothole patching material and suggests that HMA placed in a clean, dry hole will result in the longest service life. Meanwhile, for cold and wet conditions, proprietary cold mixes are recommended.

South Dakota

The South Dakota DOT manual provides a plan and strategies for preservation and indicates that a good preservation program consists of investigation of pavement information, evaluation of the pavement status and statistics, identification of possible treatments, and development of solutions to distresses. Within the flexible pavement preservation section, spray patching is mentioned as a common technique to repair potholes. Regarding material used for this technique, aggregate and emulsified asphalt such as CRS-2 are recommended (SDDOT, 2010).

Ohio

Pothole patching information for Ohio was found in information from a workshop by their Local Technical Assistance Program (ODOT, 2019). The program identifies three methods for pothole repair: full-depth repair, partial-depth repair, and spray injection. Material availability and usage condition dictates that HMA is available for spring, summer, and fall, while cold mix is provided by local plants in winter and other seasons and should be a high-performance mix such as UPM, Perma-Patch, and QPR2000. Therefore, their practice for cold weather patching involves using a high-performance mix, removing water from holes, filling the holes, and compacting to 1/4 in. above the surrounding pavement. The practice for warm weather with HMA is similar to the edge-seal procedure described above but requires application of tack coat before placement of HMA material.

Pennsylvania

Aiming to treat potholes according to severity of the hole, patching is divided into mechanized patching and manual patching. Mechanized patching is limited to large-scale sections and requires summer or other good weather conditions to perform (PennDOT, 2016). At the same time, manual patching is mostly used for pothole repair. During winter, cold patching is used if weather permits, which makes placement with a shovel possible. This cold patching is considered a temporary repair (PennDOT, 2016). Pennsylvania also has two material acceptance tests required for patching mixes. The first is a water resistance test which involves moisture conditioning the coated aggregate in a jar of water and visually confirming that 90% of coating remains, and the second is a workability test which involves ensuring that the mix can be broken up with a spatula after it is cooled to 7°C (PennDOT, 2003).

Rhode Island

Rhode Island (RIDOT, 2015) recommends the use of 4.75 mm or 9.5 mm top size HMA for pothole patching, or the use of high-performance cold mixes in their absence. RIDOT has three performance requirements for the mix: (i) complete coating of the aggregate, (ii) checking bituminous material content and aggregate gradation, and (iii) 95% retained coating based on the boiling water test mentioned above or the static immersion test (AASHTO T182).

South Carolina

A report from Putman et al. (2016) provides information about improving the implementation of pavement maintenance strategies, in which pothole repair types are classified as surface patches and permanent patches. In this report, a "toolbox" technique is provided for efficient work repairing distresses, where full-depth patching is suggested to be utilized in permanent pavement repair.

Wisconsin

The pavement surface evaluation and rating manual from Wisconsin DOT does not provide thorough descriptions for repair of potholes, but Wisconsin does have a maintenance manual (Walker et al., 2002).

Texas

In terms of pothole patching methods, the Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges from Texas provide two methods: standard repair and saw-cut repair. Standard repair consists of removal of water, dry application of tack coat, and placement of mixture, while saw-cut repair is similar to semipermanent repair, as discussed above (TxDOT, 2014).

For material, the specification contains references for material selection guidance that met the requirements. For instance, Estakhri et al. (1999) investigated 15 districts in Texas. They found most of the districts were pleased with the pothole materials purchased according to two specifications (CMD9200.001 or 9200.002), some of which are contained in TxDOT Item 334 (which describes hot-mix cold-laid materials). Overall, good performance was reported for cold, wet conditions using these materials. In addition, most districts were pleased to use the "containerized" (premix) material as a repair material.

Washington

The maintenance manual from Washington State DOT has two procedures for repairing sections with large amounts of potholes: dig out and overlay (WSDOT, 2020). Dig out is a permanent pothole patching method and has the same operational procedures as permanent; in Washington, asphalt concrete class B is introduced as the best HMA material. The WSDOT Maintenance Manual also provides guidance for cold patching. For cold-mix patching, the use of tack is recommended for fiber-reinforced mixes and other specialized "winter mixes." If tack cannot be used, it is recommended to use a crack pouring material to bond the mix to the hole. Squaring up and heating the hole with a propane torch (to remove moisture and create a better bond with the existing pavement) are also recommended if time permits.

Summary of Practice within State Agencies

Table 8 summarizes the overall specifications and other documents provided by 22 states and Washington, DC that describe pothole patching procedures and are available online. Overall, most states do not provide extensive step-by-step instructions for pothole patching and rely on the experience of engineers and field crews to properly perform patching. Instead, most manuals focus more on permanent patching, which is outside the scope of this study. Equipment is also not generally specified, although this is not tremendously surprising, as equipment purchases are often more decentralized within agencies. Material specifications are often more detailed, and many states refer to materials requirements within their standard specifications. In general, five methods are most frequently used in the United States based on a review of practice in many states: throw and roll, semipermanent (partial depth), permanent patching (full depth), spray injection, and edge sealing. Perhaps the most critical finding within this section is that few states provide meaningful guidance in terms of the more temporary repairs, especially for localized potholes. In fact, there is little, if any, guidance in terms of choosing cold mixes, when to use specific mix types, and preparation for temporary patching.

Table 8. Summary of Pothole Patching Guidelines in Each US State Based on Publicly Available Online Resources

State	Materials	Techniques	Equipment	Resources
Alaska	Hot mix; all-season patch material; special material for cold condition	Surface patching: the same as throw and roll; full-depth patching: the same as permanent patching	Broom air hose or mechanical sweeper shovel or lute hand tamper truck tire or vibratory roller.	Alaska Highway Maintenance and Operations Handbook (2014)
Arkansas	Hot-mix surface course; asphalt concrete binder course; cold mix	Procedures for HMA paving	No equipment is mentioned.	Arkansas Standard Specifications for Highway Construction Division 400 (2014)
California	Premix and special mix	Small patches and large patching: the same as semipermanent patching	Motor grader or spreading box for large patches hand for small patches	Caltrans Maintenance Manual Chapter flexible pavement (2014)
Colorado	HMA materials for asphalt and specified material approved by engineers	No specific procedure is provided in specifications.	No equipment is mentioned.	Colorado Standard Specifications for Road and Bridge Construction (2019)
Washington, DC	Surface 12.5 mm or 9.5 mm; leveling course 9.5 mm or 4.75 mm; base course 19 mm or 25 mm	No specific procedure is provided in specifications.	No equipment is mentioned.	District of Columbia Department of Transportation Standard specifications for highway and structures (2013)
Connecticut	HMA materials for asphalt and specified material approved by engineers	No specific procedure is provided in specifications.	No equipment is mentioned.	Connecticut Standard Specifications for Road Bridge Facilities and Incidental Construction (2018)
Delaware	HMA; cold-patch material	No specific procedure is provided in specifications.	No equipment is mentioned.	Delaware Standard Specifications for Road and Bridge Construction (2016 with supplement in 2019)
Georgia	Hot mix cold laid; cold mix cold laid	Throw and Roll; throw and go; semipermanent; spray injection	No equipment is mentioned.	Newsletter from Georgia DOT
Idaho	Refer to Material Manual from IDADOT	Throw and Roll; semipermanent; spray injection; inlay patch repair	No equipment is mentioned.	Operational manual of Idaho Transportation Department (2019)
Indiana	Hot mix; cold mix; spray injection material	Temporary patching; permanent patching; spray injection sometimes as permanent patching	No equipment is mentioned.	INDOT's Maintenance Quality Assurance Process (2011)
Illinois	HMA (Class C and Class D material in IDOT specifications); cold mix	Full-depth repair for permanent patch; Partial-depth for defected area within upper third depth; emergency maintenance when required material is not equipped; Throw and Roll; semipermanent; spray injection; inlay patch repair	Corresponding tools	Bureau of Operations Maintenance Policy Manual (2002) and Materials and Procedures for Repair of Potholes in Asphalt-surfaced Pavements—manual of Practice (1999)
Iowa	Not mentioned	Surface patching: the same as throw and roll; full-depth patching the same as permanent patching	No equipment is mentioned.	Asphalt paving design guide Iowa (NA)

State	Materials	Techniques	Equipment	Resources
Kentucky	Bituminous mix; liquid asphalt (optional)	The procedure similar to semipermanent	Dump truck; pickup truck; truck-mounted attenuator (optional); distributor (optional)	Field Operation Guide Manual (2011)
Maryland	Hot mix; cold mix	The procedure similar to semipermanent; permanent patching	Saw or jackhammer wire brush hot lance or air compressor	Maryland State highway administration from Maryland department of transportation (NA)
Minnesota	Hot mix; hot mix with polymer cold mix hot sand mix high oil-content fine mix UPM fall mix	Throw and Roll; throw and go; semipermanent; spray Injection; other people mention dura patch 10% and mill-and-patch 20%	Common tools and roller	Survey Result of Current Pothole Repair Practice of Maryland Department of Transportation (NA)
Montana	Hot mix; cold mix and RAP	Hand patching(temporary) and hand patching(permanent); machine patching	Jackhammer; pavement cutter; emulsion and broom for tack application; tamper or roller for compacting; trailer; pressure/jack hammer paver; rut filler attachment; roller	Colorado Standard Specifications for Road and Bridge Construction (2002)
South Dakota	Mixture of aggregate and emulsified asphalt such as CRS2	Spray patching is suggested	Asphalite machine	Pavement Preservation Guidance in South Dakota (2010)
Ohio	High-quality material such as UPM perma-patch QPR2000; mastic products are hot applied polymer modified asphalt concrete	Full-depth patching partial-depth patching and spray injection	No equipment is mentioned	Asphalt Pavement Preservation from Ohio Local Technical Assistance Program (2019)
Pennsylvania	Hot mix as permanent; cold mix as temporary; mechanized patching for extensive potholes	Cold patch and permanent patch	Several dump trucks; a paving machine; a roller and a tack-coat applicator	Pennsylvania Department of Transportation (NA)
South Carolina	Not mentioned	Surface patch and permanent patch	No equipment is mentioned	Ranking of Pavement Preservation Practices and Methods (2016)
Texas	Hot-mix cold laid; limestone rock asphalt	Standard repair and saw-cut repair	Hand tampers; mechanical tampers; rollers	Standard Specifications “Pothole Repair” of TxDOT (2014)
Washington	Hot plant-mix such as asphalt concrete class B; asphalt pre-mix (cold mix); fiber reinforced and other specialized winter mix	Dig out similar as permanent patching; overlay patching	No equipment is mentioned	Maintenance Manual (2020)
Wisconsin	Not mentioned	Construction according to severity rate	No equipment is mentioned	Pavement Surface Evaluation and Rating Manual (2002)

SUMMARY OF LITERATURE REVIEW

In general, the literature reflects a desire to move beyond inexpensive, very temporary repairs and focus on “doing [pothole repair] right the first time” (Thomas & Anderson, 1984). The literature indicates that it is critical to repair potholes using higher quality materials, even if they are more expensive. HMA appears to be the best patching material, although high-quality proprietary cold mixes can provide long-lasting patches when HMA is not available. In terms of techniques, throw and go is found to be ineffective, and pothole performance is generally improved by practices such as cleaning holes beforehand and compacting patching material, even just with a truck tire.

However, there is ultimately a lack of detailed studies to determine the current state of practice within local branches of specific agencies. Because this information for the state of Illinois is not available in existing documented literature available to the public, the research team scheduled meetings with all nine districts of IDOT. A set of meetings was scheduled with local IDOT officials, engineers, and workers in each district. The results of these discussions are presented in Chapter 3.

CHAPTER 3: DISTRICT MEETINGS

To further understand the state of practice within IDOT, the research team held meetings with engineers and workers from all nine IDOT districts to determine their current practices with regard to patching potholes. In each of the nine districts, the research team interviewed a combination of operations engineers, operations supervisors, field engineers, and lead workers. This chapter contains a summary of the meetings conducted and information gathered for each issue discussed. A copy of the slideshow shown to the districts with all questions on it is attached in the appendix for reference.

GENERAL QUESTIONS AND CENTERLINE ISSUES

After a brief introduction to the project objectives and scope, district employees introduced themselves to the research team and vice versa. First, there was a brief discussion of the definition of a pothole, to make sure everyone was on the same page. After this, the first question posed was to rank pothole patching as a priority in three seasons—winter, spring, and summer/fall. Most districts indicated that pothole patching was their number one priority year-round, although two districts specifically indicated that it is lower on the priority list in summer. It should also be noted that snow removal takes priority over pothole patching at times, depending on severity of the potholes. The consensus was mostly that in cases where potholes are a safety issue or create a hazard, they become the number one priority.

The next topic of discussion was how each district knows there is a pothole. Districts were presented with five options—known problem areas, public complaints, reports from supervisors' driving routes, reports from other IDOT sources, and an "other" option. Most districts indicated that all of these drivers play a role in knowing there is a need. Some districts also mentioned reports from local law enforcement informing their need to patch potholes. Table 9 shows how many districts selected each option as their top driver for knowing that there is a pothole that requires patching.

Table 9. Number of Districts That Indicated the Way in Which They Most Frequently Find Out There Is a Need to Patch Potholes

Option	Number of Districts
Known problem areas	4
Reports of supervisors' driving routes	4
Complaints from public	1
Complaints from IDOT sources	0
Other	0

Next, a discussion was held about the main drivers of potholes in each district. Nearly every district indicated some combination of both localized distresses (for example, at centerlines or ends of joints) and deterioration of the entire pavement due to age, construction, or mix issues. The following specific issues are among those which were discussed in various district meetings:

- Asphalt mix segregation in construction (D4, D5, D6)
- Longitudinal joints with density issues (D4, D5, D6)
- Centerline problems due to raised pavement markers (RPMs) (D8)
- Structural issues due to base failure (D1)
- Stripping in the wheel path (D4)
- Delamination (D5)
- Flat and elongated aggregate particles (D9)
- Drainage issues (D8)

Before moving into the pothole patching practices, the research team asked a few more questions about centerline-related issues. This is one of the most frequent areas for pothole patching. Regarding centerline joints, the districts were asked their thoughts on three methods: centerline microsurfacing, longitudinal joint repair, and crack seal (with or without routing). District 2 indicated that centerline microsurfacing works well compared to crack sealing because it resolves the issues of cracks and other distresses near the centerline, but they are not doing much of it. Districts 5 and 7 also found centerline microsurfacing effective. Meanwhile, District 8 indicated that crack seal works well for tight cracks, but it is difficult to do as preventative maintenance due to constraints on using contract maintenance funds for preventative maintenance. For more robust repairs, they prefer longitudinal joint repair. District 9's feedback was similar, and both districts indicated issues with centerline microsurfacing causing problems later. District 6 also experienced some issues with water ponding due to centerline microsurfacing. District 4 does longitudinal joint repair in house (not contract maintenance) and reports good performance from it. Four out of nine districts reported doing some rout and seal work. Those that were doing rout and seal work found it effective. Of those who reported that they do not currently rout and seal cracks, some indicated that they used that method in the past. However, many indicated that they stopped or have never done it due to its perceived ineffectiveness. Many districts also stressed the importance of timing for rout and seal operations. Overall, the results were mixed and seemed to vary based on regional differences.

In addition to these techniques, some districts raised other ideas that they have been using for centerline maintenance. District 1, meanwhile, uses their self-propelled pothole patching machines for sealing longitudinal cracks. In general, most districts stressed the importance of timing regarding any centerline treatment.

TECHNIQUES

Districts were then asked which techniques they are using. Among the techniques used in each district, four prominent categories were identified: throw and go with cold mix, throw and roll with cold mix, spray injection, and HMA patching. Table 10 provides a summary of the broad techniques used by each district. Note that District 8 also mentioned using an in-house material that they call "chicken scratch" made up of liquid asphalt, coarse aggregates, and screenings, which they use in a throw-and-roll manner.

Table 10. Pothole Patching Techniques Used by Each District

District	Throw and go (cold mix)	Throw and roll (cold mix)	Spray injection	HMA
1	N	Y	Y	N
2	Y	Y	Y	Y
3	Y	Y	Y	N
4	Y	Y	Y	Y
5	Y[2]	Y	Y	N[1]
6	Y	Y	Y	Y[2]
7	N	Y	Y	N
8	Y	Y	Y	Y
9	Y	Y	N[3]	Y[4]

[1] Indicated that they do have HMA left over sometimes and use for pothole patching and that they do a lot of partial-depth patching in the summer with HMA

[2] Very rare, under exceptional circumstances only

[3] Indicated that it was previously used but no longer is due to equipment issues

[4] Also indicated using millings with a rejuvenator

In addition to understanding what techniques each district is using, it was also of interest to determine the drivers behind the use of each technique. Among the many drivers, there was often no clear main driver, as it seems that the choice of technique is quite complex and has many confounding factors. In general, some of the main drivers included:

- Season
- Equipment limitations
- Manpower limitations
- Average daily traffic
- Urgency of repair
- Route type (interstate vs. state route)
- Size of pothole
- Weather conditions
- Safety (reducing exposure)

Overall, most districts reported similar procedures with each technique. Throw and go involves placing material in a hole and allowing traffic to compact it. It was widely agreed upon across districts that this technique is the poorest, and in most cases only used for emergency repairs. Throw and roll involves placing material and then compacting it with a truck tire—in most cases the truck-mounted attenuator used for traffic control. Many districts report that they try to clean the hole before placing material, with District 1 going as far as calling the technique "prep, throw and roll" rather than "throw and roll." A few districts also reported that they sometimes use a tack to achieve a better hold of the material.

Spray injection patching is also commonly used within eight of IDOT's nine districts, with the exception being District 9. Among the districts that use spray injection patching, it appears that they find the success of the patch to largely depend on the skill of the operator, as it was often called more of an "art" than a "science." For spray patching of potholes, two main pieces of equipment are used, either a conventional spray patching machine or a self-propelled patching machine. These are discussed more in the equipment section of this chapter. Some districts also indicated that they use the spray patching machine to "seal up" cold-mix patches to get a longer life out of them. Sometimes this will be done immediately after, while sometimes they will wait a few days for traffic to compact the material first.

Finally, HMA patching of potholes is commonly performed in four of nine districts. In general, these districts find more success using HMA than other techniques. When using HMA, District 9 often mills out a section, places a tack, places the material, and compacts it. District 8 reported squaring up and cleaning holes but does not use a tack for HMA every time, only when necessary. District 4 reports that they always use tack, clean a hole well, and tamp the material down when using HMA, which they prefer to use whenever they can for longer lasting repairs.

MATERIALS

Liquid Bituminous Materials

Each district uses slightly different liquid bituminous products. Table 11 summarizes the products each district is using. Note that HFE represents high float emulsion, HFP represents high float polymer emulsion, SS-1 is a slow-setting emulsion, RC-70 is a rapid-curing emulsion, and CRS-2 is a cationic rapid-setting emulsion.

Table 11. Liquid Bituminous Products Used in Each District

Product	D1	D2	D3	D4	D5	D6	D7	D8	D9
HFE-90	■	■	■	■		■	■		
HFE-150		■			■		■	■	■
HFP					■		■		
SS-1	■								
CRS-2								■	
RC-70				■					

It was of interest to determine why each district selected particular emulsion options. In general, the selection was based mostly on previous experience and if a product was working well; the districts did not consider new options. Most districts indicated that the primary function of these materials is to use in their spray patching machines. Some districts also use a product above for priming holes before patching to ensure better adhesion of patching materials (D4, D8). District 9 generally uses liquid bituminous material only for oil and chip (chip-seal) applications. District 5 also mentioned knowing that local agencies use CSS-2 for oil and chip applications and expressed interest in learning more about that product.

District 2 and 7 both report using HFE-90 and HFE-150, while other districts choose one or the other. They both report that the choice of which product to use depends on the temperature. District 8 primarily uses HFE-150 for priming holes for patching, while they prefer to use CRS-2 for their spray injection patching because it is chemically compatible with the charge of the aggregates that are locally available to them.

Districts 5 and 7 both use polymer-modified high-float emulsions. Both reported that they request polymer-modified emulsion because it does not track as much compared with other types; however, District 7 reported some major issues with the polymer-modified product that they are currently using. They have observed that the material cannot flow properly through their patching machines and causes clogs in the hoses. District 5 reported issues with polymer emulsion setting in storage tanks, especially when switching between HFE and HFP materials. Based on this finding, a review of policy and best practices within IDOT regarding tank storage guidelines may be warranted to prevent similar issues in the future. The HFP issue also seems to be more recent, as they could previously get a longer life out of it, and warrants more investigation. They did note, however, that the material works best when used within 30 days of acquisition. It should be noted that District 7 has sent a sample of their HFP material to the supplier for testing but did not yet send a specimen to IDOT Central Bureau of Materials for evaluation.

Regarding storage of emulsion, most districts reported that available storage was not a problem. The exception was District 1, which does not have storage on hand due to their only tank being nonfunctional. As a result, they must regularly obtain materials from a supplier in their district. District 5 expressed that the major issue with storage was not using their product quickly enough and having to clean the entire tank due to emulsion breaking inside it because of the polymer issue mentioned above.

The last question related to liquid bituminous materials and training. Districts were asked if they felt more training with such products was needed. A few districts expressed that it would be good to have some training or demonstrations with new products that are available, or with things like storage.

Hot-mix Asphalt

For districts that use HMA, it was critical to understand more about their operations in terms of obtaining HMA and pothole patching with it. Overall, almost all districts generally indicated that they take whatever mix the HMA producer is making on a specific day and do not request any specific mix, besides waiting for a day in which surface mixes are being made. The districts prefer not to use binder mixes (specifically, IL-19.0) for pothole patching. In general, this is because quantities requested are very small, so no producer will make a special mix for them. A few districts even indicated that they will use binder mix if it is all they can find, because of a lack of HMA plants nearby. District 7 indicated that in some yards, when they use binder mix, they will seal back over it with a spray patching machine, similar to the procedure mentioned earlier for cold mixes. In districts where SMA is used in construction, it was determined that SMA is not preferred for pothole patching. SMA and binder mixes are not desirable for pothole patching because of their poor workability compared to the other surface mixes available. For SMA particularly, the polymer modification is a problem. In general, there were mixed responses to the question of the importance of mix type: some feel it is important, while others do not because of the nature of pothole patching. Note also that some districts do coordinate with district construction personnel to determine when they are making a specific mix type, although most types of surface mix are acceptable.

In general, polymer-modified asphalt is not well liked for pothole patching. Most districts indicated that they prefer not to use polymer-modified mixes, even if they are not being charged for it, because of the difficulties in working with it. Others indicated cost as an issue as well. The lone exception was District 7, which indicated that they prefer to patch with polymer-modified HMA mixes for interstate pothole patching. Regarding fiber-modified mixes, no district was familiar with using them or indicated that they do use them. One district indicated interest in more training about HMA mix types.

Most districts indicated that they haul HMA distances of up to 1 to 2 hours, if necessary, especially when few plants are running. In those cases, they are usually placing a tarp over the mix, and in many cases cannot use some parts of the material. This is due to parts near the top of the pile which are too cold by the time they reach the site. Only one district, however, indicated that they have a temperature check gun to measure the temperature of the mix. Note also that some districts use hot boxes to reheat the HMA to ensure workability and proper compaction.

Reporting in AMP

AMP is IDOT's operations database system used for tracking materials used by each yard within a district. Generally, lead workers are performing entries in AMP. Generally, activities related to pothole patching are reported under codes 410 ("Pothole Patching") or 510 ("Pothole Patching—Liquid Asphalt and Chips"). It was clear, however, that there are many inconsistencies within AMP and that everyone is doing things differently. Therefore, it is possible that pothole patching activities are being reported under other codes as well. In general, districts reported that 410 was the code they were using for cold mix and HMA patching, and 510 refers specifically to spray injection. However, there were sometimes errors in practice—for example, cold-mix materials being reported under code 410.

In general, most meeting attendees observed errors within AMP due to entry mistakes or lack of training among lead workers on how to use AMP. In some cases, activities unrelated to pothole patching appeared in these sections as well. One additional issue that causes many problems is the unit cost defaulting to $1.00 for many things. This results in inaccurate reports and will create difficulty for future analysis of IDOT costs.

Within the 410 code, there were three main entries used for bituminous mixtures: "Bituminous Mix, Cold," "Bituminous Mix, Hot," and "Bituminous Mix, Special." Most districts indicated that "Bituminous Mix, Cold" refers to plant cold mixes, while "Bituminous Mix, Special" refers to proprietary cold mixes. However, these definitions are not universal; for example, yards that use predominantly proprietary mixes were, in some cases, reporting all of their materials as "Bituminous Mix, Special."

Overall, the recent transition to AMP has caused much confusion, which results in poor data. Some districts expressed interest in more training with AMP, while others expressed that there was a need for the system to be better, and in many cases, more simplistic and intuitive. Some points were made regarding pricing and that in the previous system, MMI, they did not need to input prices themselves; items with standard prices should show up there priced already. In summary, there is much to be improved regarding AMP, both from a training perspective and with the software itself. There is a need for standardization, clear definitions, and better guidance.

Cold Mixes

In general, most districts are satisfied with the cold-mix products they are getting. They tend to find much better performance of proprietary cold mixes compared to nonproprietary cold mixes. District 5 mentioned that they believe cheap, nonproprietary cold mixes do not really have a place in their operations anymore and that it would be worth getting rid of them entirely from the specifications. There are sometimes issues where long travel is required and to obtain a product of the same or worse quality due to procurement requirements, which dictate that only on-contract vendors can be used. Some yards know of products that they feel have superior performance but cannot use due to cost or procurement difficulties. However, many products are currently being used with good success, including M120, EZ Street, UPM, and QPR (see Table 12). In general, when most districts are storing cold mix, they try to at least keep it covered, if not indoors entirely. Some districts indicated a need for more storage.

Table 12. Overall Majority Opinion on Different Types of Cold Mixes

Successful	**Not successful**
• M120 • EZ Street • UPM • QPR	• Plant mixes

Finally, the last topic of discussion within materials was the use of any new or novel materials, specifically if there was any desire to try out a new product. The following materials were mentioned:

- Very expensive products, which normally they could not afford, to determine if performance matches the cost.

- A novel material that flows from the machine into the hole that was demonstrated for District 2.
- Crafco material (although it appeared too labor intensive).
- Cold mixes with gradations closer to the maximum density line.
- Aquapatch (although it took too long to prep; also note it has been tried in at least one district).

Equipment

Among all nine districts, the equipment that mainly pertains to pothole patching falls into two main categories—spray injection equipment and hot boxes. Among spray patching equipment, districts usually have either traditional spray injection patching machines, or self-propelled patching machines. In general, the self-propelled patching machines are preferred in districts where a lot of operations take place on high-traffic roads in urban environments (D1 and D8, primarily). This machine reduces their exposure to traffic and is considered beneficial from a safety perspective. However, one district, District 6, expressed major issues with this piece of equipment and would prefer not to use it in the future. They also expressed concerns about the very high cost to purchase this equipment.

Many districts had a need for new or upgraded equipment. The concerns listed in Table 13 were mentioned.

Table 13. Equipment Concerns and Needs by District

District	Need
1	More self-propelled patching machines
2	In line for more hot boxes, needs more Durapatchers
3	Would like to upgrade spray patchers
4	Requested two more hot boxes for winter
5	Issues with storage tank quality
7	Wants hot box with dump body
8	Needs two more hot boxes (one for each yard)
9	More rollers

In terms of maintenance and repairs for equipment, there were not many systematic issues observed between different districts. Many districts expressed that they are able to do their necessary repairs in-house and that parts are readily available. It was mentioned in multiple meetings that hot boxes have significant issues due to their frequent use at high temperatures. It was also expressed that spray injection machines can sometimes have significant issues, in which case repairs are a bit more difficult because a major manufacturer is located out of state.

Equipment training also seemed to be relatively straightforward. In general, when districts acquire new equipment, they are able to get manufacturer-provided training. However, when new people are hired, the model is usually shifted to allow experienced workers to train newer ones. Experience seems to be most critical when it comes to spray injection patching. Most districts expressed that some operators are better than others and control the binder/aggregate ratio better, which leads to longer lasting patches.

Calibration is generally not performed for equipment. The highest extent of calibration performed seemed to be what the manufacturer does when equipment is sent back for repairs. Rather, most districts tackle problems as they notice them. Quality control and quality assurance is also not routinely performed. Some districts have observed problems in the field in terms of performance of spray patches including raveling, bleeding, and loss of the patch, however, and have attributed them to issues such as proper coating of the aggregate. These types of problems indicate that there is an equipment issue. However, they can also be due to aggregate that is not properly dried or other material-related problems as well.

MANPOWER

In general, manpower drives the techniques used in some districts, while in others it is not the main driver. However, it was nearly unanimous in all meetings that manpower was lacking and that they could use more of it. Most districts mentioned that manpower required for a pothole patching operation is dominated by traffic control, especially on high average daily traffic and interstate routes. In general, anywhere between three and nine people can be required, including traffic control. However, it varies greatly and often depends on what is available.

Excluding traffic control, District 6 and District 2 mentioned crews of three for pothole patching with hot boxes, with one blowing the holes out, one operating the hot box, and one shoveling material. In terms of spray patching, apart from at least four people for traffic control, there is a need to have one driving the truck, one supervising the workflow, and one running machines, as indicated by District 6. However, if working on an interstate highway, District 7 mentioned that nine people in total were involved in these operations, including traffic control. District 2 mentioned having at least six for interstate operations, which generally require more than other routes.

Districts were asked how long it takes to patch a 1 × 1 ft hole using each technique. The results are presented in Table 14 for districts who answered this question. Districts were also asked how long it would take to patch a stretch of road that was 0.5 miles long with 20 potholes equally spaced apart. Because of the wide variety of techniques and strategies used for pothole patching, answers to this question ranged from 30 minutes to an entire day.

Table 14. Response to Question "Approximately How Long Does It Take to Patch a 1 × 1 ft Hole?"

District	Answer
1	• 5 minutes for throw and roll • 15 minutes for self-propelled spray patching
4	• 3 minutes using cold-mix materials • HMA: 7–10 minutes • Durapatcher: 10 minutes
5	• 5 minutes maximum
6	• < 1 minute
7	• 1 to 2 minutes for throw and roll with truck-mounted attenuator behind compacting • 5 to 6 minutes for filling and sealing a hole
8	• 90 seconds
9	• < 1 minute for throw and go • A few minutes for throw and roll

PERFORMANCE, TRACKING, EVALUATION, AND FINAL QUESTIONS

All districts were asked questions related to performance, tracking, and evaluation as well as some miscellaneous questions to close out the meeting. The first question asked what is lacking overall that could improve performance. Some of the collected answers included:

- Training
- Asset Management Database (AMP needs improvement)
- Compaction
- Manpower
- Equipment

Next, districts were asked when pothole patching is most and least successful. Among the answers to when it is most successful are listed in Table 15.

Table 15. When Patching Is Most and Least Successful According to IDOT Employees

Successful	Not Successful
Hole is properly cleaned and water is removed	Hole is not properly cleaned/water not removed
Filled and sealed with spray patching machine	Patches not sealed
Clean, well placed HMA patching, squaring up and performing HMA patch, partial depth HMA	Throw and go, winter cold patching
Good compaction	Poor/no compaction

Districts were also asked what percentage of holes experienced recurrent failure, meaning they had to patch the same sections over and over again, and the reasons for it. One district mentioned that it happens often when rutting is a problem and water is trapped in the asphalt; however, they did not provide a percentage. Other districts indicated that it was around 50% or more, while one district indicated it was 100%. Some indicated that the recurrent failures varied by technique—one was at less than 10% with the Durapatcher while other techniques (throw and go) were above 75% at times. One district also mentioned that it is mainly a function of materials, especially cold mixes of poor quality.

Districts were asked if there was a need for materials specification updates. In general, they had few opinions about this, although some suggested studying it further. One district mentioned that workability needed to be considered. One district also said that they would prefer to try some finer mixes while another mentioned that they would prefer to use more coarse mixes when it comes to HMA.

Another question asked if districts were considering density at all in their patching operations. The overwhelming majority answer was that they are not, although many are making an effort to compact patching materials as much as possible. It is difficult to measure density of pothole patches; however, permeability patching may be a feasible alternative to checking density.

Another question was related to the study by Dailey et al. (2017) in Minnesota where decision trees were developed to assist with decision-making in terms of materials and techniques for pothole patching. Overwhelmingly, the people present at meetings were not supportive of the use of these types of documents, with only one district expressing interest. Reasons cited for a lack of interest were related to the diversity of work that they do and the reliance of crews upon their experience rather than explicit flowcharts. However, many districts did express interest in BMP posters of some sort as a guidance or reminder of best practices at yards.

Finally, all districts were asked about the possibility of future research studies. In general, they were highly supportive and willing to help in trialing almost anything new. This is of great benefit to IDOT and future researchers so that a wide variety of traffic levels and climatic conditions can be explored for any future study. Recommendations for future studies based on these discussions and a literature search can be found in the next chapter.

CHAPTER 4: SUMMARY AND RECOMMENDATIONS

This study consisted of three primary tasks. The first task was a literature review on the state of the art in pothole patching. The second task was a series of meetings with each of IDOT's nine districts to determine their current state of practice for pothole patching. The final task, which is described in this chapter, was for the research team to make recommendations to IDOT for future studies and best practices for pothole patching. This chapter contains a summary of the first two tasks and the final recommendations.

The literature review in full can be found in Chapter 2. A summary of important findings from this review is listed below:

1. There are four primary techniques for pothole patching that are discussed in the literature and a plethora of others that are less often used. These four techniques are the throw-and-go/throw-and-roll methods, spray injection patching, and semipermanent patching.

2. HMA is widely regarded as the best material for pothole patching of flexible pavements. However, other materials can be cost-effective, especially proprietary cold mixes, which can last for a long time. In most states, including Illinois, it is not feasible to use HMA year-round because plants are closed during the winter. However, HMA patches are shown to last longer and are often cost-effective based on this.

3. In addition to materials, it is of utmost importance to use the right techniques. Although the throw-and-go technique is considered the fastest technique for pothole patching, it results in a very short life for the patch. Meanwhile, throw-and-roll patching and spray injection patching are effective techniques, but only when done correctly. Training is of utmost importance to perform these techniques.

4. There is no "one size fits all" solution. The previous work done by Minnesota DOT and others indicates that the choice of best patching techniques and materials is dependent on weather, season, location of the hole in the lane, size of the hole, and other factors.

5. There is generally little information available online regarding the current practices within state DOTs for patching potholes. Many of the resources that exist are outdated and provide little detail. This may be because, like Illinois, pothole patching is highly decentralized within state agencies and is left up to individual districts, and even individual areas within districts.

Based on these findings, it was clear that a more in-depth study of pothole patching practices within IDOT was required. To facilitate this, meetings were held with engineers and workers from all nine districts within IDOT. The goal of these meetings was to understand the current practice and where they feel there is room for improvement. The following are the main findings from the district meetings:

1. There is a wide variation of materials and techniques used for pothole repair between different districts. These are driven by a variety of factors, including traffic level, season, weather, budget, and material availability. Not only do these vary from district to district, but also within a single district from yard to yard.

2. There is a wide variation in the amount of HMA each district is using for pothole repair. Although this method is highly recommended in the literature, HMA is often impossible to obtain in colder seasons and takes more time per hole than cold mixes. However, some districts have found great success with HMA and are using it as much as possible.

3. Obtaining the right HMA mixes can be a challenge. In general, districts request small material quantities, so they do not have the luxury of choosing a type of mix. Very often, they will just take whatever the plant is making on a given day, although most districts indicated that they do some level of coordination with construction projects, or at least will wait for surface mixes to be available. It is notable that generally, districts do everything they can to avoid working with polymer-modified mixes for pothole patching because of workability issues, although District 7 did mention an exception for interstate pothole patching.

4. Spray injection patching remains a popular method within eight of nine districts in IDOT, with District 9 not using it extensively. This method is often used for repair of shallow patches, but also frequently to seal cold patches performed in winter and spring seasons to prolong their life. Districts with many urban, high-traffic routes indicated that they prefer self-propelled patching machines because of the safety provided by them with less exposure to traffic. Other districts generally prefer standard spray patching machines, which are not self-propelled. However, most districts indicated that, regardless of the machine, spray injection patching requires strong operator knowledge of the machine and application rates.

5. Reporting of activities in AMP is a significant issue that needs to be addressed. Many workers, supervisors, and officials are unclear which option, among many, in AMP should be used for each activity that they do. Often, items are coded as the wrong activity, coded with the wrong unit price, or not coded at all. This makes it difficult to accurately determine what activities are being done and how much is being spent. Recommendations for improvements regarding AMP are made later in this chapter.

6. Generally, districts are happy with the proprietary cold-mix materials that they are using, although some expressed a desire for more flexibility. Nonproprietary cold mixes perform much worse.

7. Calibration of equipment is generally not completed in-house. Repairs are frequently needed but mostly do not present a significant impedance to pothole patching. The biggest issue equipment-wise is the need of districts to purchase new or better equipment.

8. Generally, the districts are not highly receptive to guidance such as the ones developed in a MnDOT study (Dailey et al., 2017). They feel these types of guidelines are too formulaic and do not account for differences in individual circumstances. Every pothole patching operation is different, and any guidance must reflect that.

Considering feedback from the districts and the existing literature on pothole patching, the research team makes the following recommendations:

1. Prior to patching, cleaning of holes, proper compaction, and removal of water are of utmost importance. The research team recommends that throw-and-go patching should not be used unless worker or public safety would be compromised otherwise. At minimum, a truck tire should be used to compact the material into the hole. Proper attention should be paid to cleaning and water removal when time permits, and in cases of recurrent failure, tack can be used to adhere the patching material to the hole. A combination of these practices will lead to the avoidance of recurrent potholes in the same spot. However, the extent of improvement is not yet clear and requires further study.

2. An effort should be made to use HMA more for pothole patching statewide. HMA has proven to result in long-lasting, high-quality pothole patching for flexible pavement surfaces. However, there is still little definitive information about the best mix types for pothole patching. While most districts prefer surface mixes, they will generally take any type of surface mix. More study is necessary to determine the best HMA mix gradations, as there were conflicting answers given during the district meetings. If a substantial difference in performance of different mix types can be observed, it may be advantageous to encourage districts to wait for certain mixes, to bring HMA from further away, or even to buy enough material that plants are encouraged to produce a certain type of mix for them, if possible.

3. Proprietary cold mixes perform much better than nonproprietary mixes. Even at the higher cost, it is worth using proprietary cold mixes to get a longer performance out of these high-quality materials. A significant up-front investment should be made in these types of materials. It is also necessary to understand why this is currently the case and what can be done to improve the nonproprietary mixes used including binder type and gradation. In addition, IDOT should work with districts to ensure that the best performing products are on contract and accessible without long travel distances. Currently, this relies on the experience of district employees; however, a full study of the different types of proprietary mixes is warranted, as there are few recent studies on this topic in the last decade, and the literature is not very conclusive.

4. Online training is not recommended for most issues related to pothole patching. Where possible, the use of hands-on workshops is better.

5. Much more training and guidance about AMP is needed. Overall, a simplification of the system with fewer categories and simpler inputs is necessary. In addition, it would be

advantageous to provide each yard with a summary “cheat sheet” that tells users how each activity should be coded. Items with standard prices should show up with the price there already so that an input is not required every time. A more simplistic and intuitive interface is necessary.

6. Overall, more investment is needed in equipment and manpower for most districts.

7. The IDOT “M” specification for cold-patching materials is not well known among the different IDOT districts. This specification also requires an update. The specification should be re-examined for potential revision, and then efforts should be made toward training and education on the specifications.

8. Innovative materials and techniques have not yet been widely used in Illinois. While it may be advantageous to study these, a focus should also be made to study the proven materials and techniques in parallel to improve on what is already being done.

9. Future studies should focus on materials, hole preparation, techniques, and compaction level. A combination of laboratory and field studies could yield information about the financial impact of using the preferred techniques described above. While this study results in a good idea of the best practices to produce long-lasting repairs, their feasibility in the field and resulting cost-effectiveness is still unknown. This is important to study before formal guidance is issued.

10. Formal guidance, when provided, should not result in prescriptive solutions that provide rigid instructions. Instead, it should focus on the holistic impact on IDOT if an overall move towards or away from certain techniques or materials is implemented, and how best to do this without restricting the abilities of individual districts and yards to make their own decisions.

11. More coordination and discussion between districts can tremendously help to improve pothole patching throughout IDOT. Districts should be given and take advantage of opportunities to share their current state of practice with each other and new ideas, including what is working well and what is not. This will help save time and money and will result in positive impacts on districts who are struggling and succeeding with patching potholes.

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APPENDIX: DISTRICT SUMMARY TABLES AND INTERVIEW SLIDES

SUMMARY TABLES OF DISTRICT MEETINGS

Table 16. Introduction and Centerline

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
How do you determine there is a pothole?	All + law enforcement	All	All + law enforcement	Public complaints, known problem areas	All	All	All	Public complaints, route runners	All
Main pothole drivers	Age	Bad centerline construction	Centerline and edge of joints	Freeze-thaw Age Moisture Joints; Stripping	Centerline and edge of joint Segregation Age Delamination	Deterioration Segregation Longitudinal joints	Age Mix	Seams/ centerline joints; Oxidation; Moisture	Joints Age Aggregates (flat/elongated)
Preferred Centerline Techniques	Patching Machines	Microsurfacing; Patching; Machines	Longitudinal Joint Repair	Rout and seal	Microsurfacing	Microsurfacing Patching Machines	Microsurfacing Crack Seal	Microsurfacing Crack Seal	Longitudinal Joint Repair

- Almost all districts indicate pothole patching is top priority, but sometimes surpassed by mowing or snowplow in summer/winter respectively if holes are not serious hazards.
- First question- all includes report from supervisors driving routes, public complaints, known problem areas, and other IDOT sources.

Table 17. Techniques

District	Throw and go (cold mix)	Throw and roll (cold mix)	Spray injection	HMA
1	N	Y	Y	N
2	Y	Y	Y	Y
3	Y	Y	Y	N
4	Y	Y	Y	Y
5	Y[2]	Y	Y	N[1]
6	Y	Y	Y	Y[2]
7	N	Y	Y	N
8	Y	Y	Y	Y
9	Y	Y	N[3]	Y[4]

1 Indicated that they do have HMA left over sometimes and use for pothole patching and that they do a lot of partial-depth patching in the summer with HMA.

2 Very rare under exceptional circumstances only.

3 Indicated that it was previously used but no longer is due to equipment issues.

4 Also indicated using millings with a rejuvenator.

Table 18. Liquid Bituminous

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
How are you using each liquid product (and which ones)?	SS-1 – patching machines; tack HFE-90 – patching machines	HFE-150 and HFE-90- patching machines	HFE-90- patching machines	HFE-90- patching machines	HFP-90- patching machines	HFE-90- patching machines and for oil and chip	HFE-90 and HFE-150	HFE-150- tack CRS-1- poropatch	HFE-150- oil and chip
Need additional storage?	Yes		No	No	No	No	No	No	No
Need more training on selecting liquid products?	Yes			No				Yes	No
Preferred mix type	N70, N90	Surface Mix	Surface Mix	None	Surface Mix	Surface Mix	None		Surface Mix
Do you coordinate with construction?	Not much	Yes	Sometimes		Not much		Sometimes	Yes	Yes
Using polymer? If so, where?	Yes, ramps		No		No	No	Yes, interstates	No	No
Do you pay extra for polymer?	Yes				Not sure	Based on contract	Yes	Yes (but don't use)	No
Do you use fiber?	No					No	No	No	No
How far do you haul HMA and how?		45 minutes; tarp	1 hour; hot box (small quantities)	Hot box or tarp	60 miles; tarp and insulate	25 miles; tarp or hot box (small quantities)	30 min; tarp		Tarp
Do you check temperature and how?	No		No	No	No		Thermal Gun		No
Do you use binder and when?	No	Yes, if alternative is cold patch	No	Yes, on bigger holes but cap with surface					No

Almost every district indicated little control over mix type they get.

Table 19. Cold Mix

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
Happy with cold mix	Yes		Yes	Yes	Yes for proprietary	No	Yes	Yes	Yes for proprietary; No for nonproprietary
How do you store cold mix?	Storage bin; patch carts		Outside and covered	Inside in a bay	Outside and covered	Hot box plugged in	Outside and covered, inside		

- Most districts did not want to see spec changes; only one suggested finer gradation, one suggested coarser.
- List of new materials desired to try in report.

Table 20. AMP

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
Difference between bit mix hot (ton), bit mix special (ton), and bit mix road repair?	Bit mix special = proprietary cold mix		Depends on yards	Bit mix cold = cold patch Bit mix hot = HMA Bit mix special = proprietary cold mix	Bit mix special = proprietary cold mix	Bit mix special = proprietary cold mix Bit mix road repair = error	Bit mix special = proprietary cold mix Bit mix cold = premix from plants	Depends on lead worker	Bit mix special = proprietary cold mix Ecophalt = aquaphalt
How do you determine whether to use work activity 410 or 510?		410 – pothole patching, 510 -spray patching	410 – pothole patching, 510 -spray patching	410 – pothole patching, 510 -spray patching	410 – pothole patching 510 -spray patching	410 – pothole patching, 510 -spray patching	410 – pothole patching, 510 - spray patching		Only use 410 (do not use spray injection)

- Many suggested changes for AMP listed in report; each district had something different.

Table 21. Equipment

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
What kind of calibration is done?		No formal procedures	No formal procedures	No formal procedures	No formal procedures	No formal procedures	Check temperature gauge	Not done in house	
Is there any QC/QA done for cold mix?	No	No	No	No	No		No	No	No
Which equipment requires a lot of/difficult maintenance?	None	Spray patchers	Old spray patchers	Hot boxes	Spray patchers; hot boxes	Self-propelled spray patcher		None	None

- QC/QA does not really exist for spray injection patchers except for visual check.
- Importance of keeping aggregate dry emphasized.
- Most districts indicated vendor provides training when new equipment is purchased and it's sufficient.

Table 22. Manpower

Topic	D1	D2	D3	D4	D5	D6	D7	D8	D9
Number of people needed	Spray injection—4-6 Throw and roll—3	Interstate cold patch—8 Non-interstate—6 Spray injection—5	Throw and roll—5-6 Spray injection—6-7	2 Lane cold patch—4 Spray injection—6 HMA—many	5-6 for all methods	Cold patch—8	Interstate cold patch—6-8 Spray injection—9 Rural cold patch—4-5	2-8	5-6
Time to patch 1x1 ft hole	Spray injection—15 min Throw and roll—5 min		No good estimate	Cold patch—3 min HMA—7-10 min Spray injection—10 min	Maximum 5 min	Throw and roll - <1 min Spray injection—similar	Throw and roll—1-2 min Sealing up—5-6 min	90 s	Throw and roll—1-2 min
Time to patch 0.5 mile stretch with 20 holes	Throw and roll—1.5 hours Spray patch—little longer		No good estimate	1 day	1 hour	1 hour	Minimum of half a day	30 min	1.5–4 hours
Does manpower drive technique?	No				Yes		Yes	Yes	Yes
Best platform and additional guidance needed	Hands on with a presentation, tailgate talk		Interact with other districts in training, etc.		1 on 1 or on job training	Manufacturer coming out and giving feedback		Need more guidance when there's turnover	

DISTRICT INTERVIEW SLIDES