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Synthesis Study of Best Practices for Cleaning Tools and Paving Equipment: Asphalt Release Agents (ARAs) and Asphalt Cleaners (ACs)

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Diesel has been used widely as an asphalt cleaning agent due to its effectiveness for many years. However, its negative impact on health and the environment calls for more sustainable and safe alternatives. Asphalt Release Agents (ARAs) are products for preventing or mitigating undesirable adhesion of HMA to the asphalt equipment, and Asphalt Cleaners (ACs) are products for remediation when the adhesion has already happened. In this study, commercially ARAs and ACs reported by NTPEP and U.S. DOTs are quantitatively and qualitatively examined based on the following criteria: (1) cost-effectiveness, (2) functionality, (3) environmental, and (4) safety considerations. The results provided valuable insights into cost-effective products; and ultimately led to developing an interactive decision-making dashboard to help INDOT make more informed decisions regarding testing and investing in these alternatives.</td></tr>
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EXECUTIVE SUMMARY

Introduction

Hot mix asphalt (HMA) is one of the most commonly used materials in the transportation construction industry. During paving works, HMA can stick tightly to instruments and tools. For many years, diesel was widely used as an asphalt cleaning agent to solve this issue; however, diesel also reduced the strength and quality of HMA by destroying the bond between asphalt particles. Furthermore, diesel leakage can cause lung cancer or other respiratory diseases, fire hazards, and contamination to soil and groundwater near job sites. These are the main reasons why the Resource Conservation and Recovery Acts of 1976 banned the use of diesel. There is also a risk of diesel residue being present in truck beds and paving equipment used to produce the next batch of HMA. This potential contamination may reduce the quality and durability of the HMA. Therefore, alternatives to diesel should be investigated that address safety, health, and environmental concerns while also offering the same effectiveness level.

Asphalt release agents (ARAs) and asphalt cleaners (ACs) are excellent diesel substitutes. ARAs are non-hazardous, environmentally friendly products that build a barrier between asphalt and truck beds/equipment that prevents adhesion and minimizes cleaning. In the event that paving tools and equipment are already coated in HMA, ACs can clean and safely dissolve tough asphalt spills and deposits. This study aims to evaluate commercially available ARAs and ACs quantitatively and qualitatively to provide DOTs and asphalt paving contractors with the tools and information needed to shift towards a more sustainable and environmentally friendly model.

Findings

The study findings are listed as follows.

- We developed a comprehensive scoring system to qualitatively and quantitatively evaluate the ARA products published by NTPEP in terms of their functionality, environmental impact, cost-effectiveness, and safety.
- Given that NTPEP only evaluates the ARA products but doesn't recommend them, state DOTs should establish specifications for selecting the most appropriate products to use in their states.
- We developed a comprehensive scoring system that considered environmental, economic, and safety criteria to quantitatively evaluate the AC products that were listed by various state DOTs or proposed by known manufacturers (no official organization conducts tests for evaluating the functionality of ACs). The data was derived from the manufacturers.
- A survey was developed to obtain further information from DOTs regarding their product selection process and their feedback on ARA and AC products. According to the responses, DOTS and contractors prioritized the functionality of the products over other criteria in their selection process.
- DOTs indicated the challenges they face when urging subcontractors to utilize ARAs and ACs as alternatives for diesel, because diesel is characterized by its functionality and lower price.
- We developed an interactive decision support dashboard to help INDOT make more informed decisions when selecting ARAs and ACs.

Implementation

Data Collection

To obtain the necessary information to perform the study, the research team accessed three sources: the NTPEP database, DOT-published ARA/AC lists, and data released by product manufacturers. AASHTO's National Transportation Product Evaluation Program (NTPEP) tests ARA products and publishes the results to help the asphalt industry decide which product is most suitable for their application, thus the NTPEP database was the primary source for relevant information on test data, biodegradability, and flash points. U.S DOTs published ARA lists to filter identified products. Lastly, the financial information, like the cost per gallon, was directly obtained from the manufacturer. Since there is no official list of tested AC products available, DOT-published lists were used as a primary source, and AC manufacturers were contacted to obtain all required data.

Data Processing

After obtaining all data, an evaluation system was designed to assess each identified product. Four criteria were selected for ARA evaluation—cost-effectiveness, functionality, environmental, and safety—and three criteria were selected for AC evaluation—economical, environmental, and safety. A scoring system was then designed for each criterion mentioned, which resulted in a comprehensive ARA and AC database. The database and associate weights for each product were then reassessed based on information obtained from DOT personnel and contractors that have used the products. The final results were then developed into an interactive decision-making dashboard to help INDOT make more informed decisions regarding alternatives for diesel and to conduct follow-up field testing.

CONTENTS

TABLE LIST

LIST OF FIGURES

1. INTRODUCTION

1.1 Problem Statement

HMA, a mixture of aggregates bound together by asphalt binder, has been essential for paving projects. Due to HMA's adhesive properties, it sticks tightly to truck beds, tools, and paving equipment. As a result, workers struggle to clean and remove asphalts from those contacted surfaces (Mikhailenko et al., 2016). To address this issue, through years, diesel has been used as a primary solvent by workers for decades since it can readily dissolve asphalts. However, the use of diesel endangers the workers' safety, and can enter the water supply and contaminate drinking water (Tang & Isacsson, 2006). The use of diesel as a solvent was banned by Resource Conservation and Recovery Act in 1976 due to its detriment to humans and the environment. While diesel is illegal, can potentially contaminate the environment, and exposes workers to health and safety risks, and most of the state departments of transportation typically do not allow the use of diesel fuel for cleaning and release on state jobs, workers still prefer to use it due to its effectiveness. Therefore, effective commercially available alternatives should be investigated in lieu of diesel while addressing safety, health, and environmental concerns.

1.2 Background

While diesel was considered an effective agent for asphalt removal from truck beds, tools, and paving equipment, it adversely impacts the environment, workers' health, and asphalt quality. For example, diesel leakage causes contamination to soil and groundwater in the vicinity of job sites. Even worse, paving crews who are exposed to diesel exhaust may confront health problems (e.g., lung cancer and respiratory disease) (Sobus et al., 2009). Further, diesel is flammable, and its low flashpoint (between 126°F and 205°F) potentially leads to the injury or fatality of workers. Diesel also reduces the strength and quality of HMA by destroying the bond between asphalt and aggregates. This explains why a pothole usually coincides with the spot where diesel spilled. More importantly, when diesel is used to clean truck beds and paving equipment, the remaining diesel affects the next batch of HMA, reducing HMA quality and durability.

ARAs and ACs could be used as substitutes for diesel. Although ARAs and ACs have been considerably emphasized by the National Transportation Product Evaluation Program (NTPEP) and departments of transportation (DOTs) in paving, maintenance, and operation tasks. ARAs are defined as non-hazardous (i.e., do not pose a health risk to workers) and environmentally friendly products manufactured as an alternative to diesel. Specifically, ARAs build a barrier between asphalt and truck beds or equipment to prevent adhesion and allow for little cleaning at the end of the day (Scardina, 2007). Previous studies categorized ARAs into petroleum-based, fatty-oil-based, and non-oil-based. There is a misunderstanding and confusion among paving contractors regarding diesel. While some may consider diesel a petroleum-based ARA (Tang, 2008), it cannot be regarded as an ARA based on the NTPEP's definition. To eliminate duplication of testing and auditing by the states, The American Association of State Highway and Transportation Officials (AASHTO) National Transportation Product Evaluation Program (NTPEP) tests available ARAs and publishes the results in a database called *NTPEP DataMine*. This database provides cost-effective evaluations for the state DOTs and helps asphalt industry stakeholders decide which product is more suitable for their application. Afterward, state DOTs can establish their specifications based on the ARAs posted by NTPEP and propose a list exclusive to their states.

On the other hand, the purpose of ACs is to clean and safely dissolve the tough asphalt spills and deposits. In other words, ACs are mainly used to destroy the asphalt's remnants after the adhesion. Compared to ARAs, fewer restrictions and requirements were established for ACs to conform to, and there is no official database available. While ARAs are products for preventing or mitigating undesirable adhesion of HMA to the asphalt equipment, ACs are products for remediation when the adhesion has already happened. Due to the different functions between ARAs and ACs, both of them will be investigated and included in this project to provide INDOT with a comprehensive list of available products.

1.3 Points of Departure

Given that abundant ARAs and ACs are commercially available, testing all of them to select the best option lacks efficiency and feasibility. A reasonable and efficient process of narrowing down the lists of ARAs and ACs based on the objective multicriteria method is necessary. Therefore, this study aims to evaluate commercially available ARAs quantitatively and qualitatively and ACs to help DOTs and asphalt paving contractors go green by shifting towards a more sustainable and environmentally friendly model and providing them with the tools and tools information needed. The objective of this project will be achieved by conducting the following five tasks shown in Figure 1.1. The entire process comprises of collecting data from NTPEP, DOTs, and manufacturers, analyzing data, distributing a survey, and generating a comprehensive top product list. These outcomes of these tasks are then used to develop a dashboard of ARAs and ACs for INDOT to make a thorough comparison among different products and select the products based on INDOT's requirements and priorities. The details of each task are elaborated on in the following chapters.

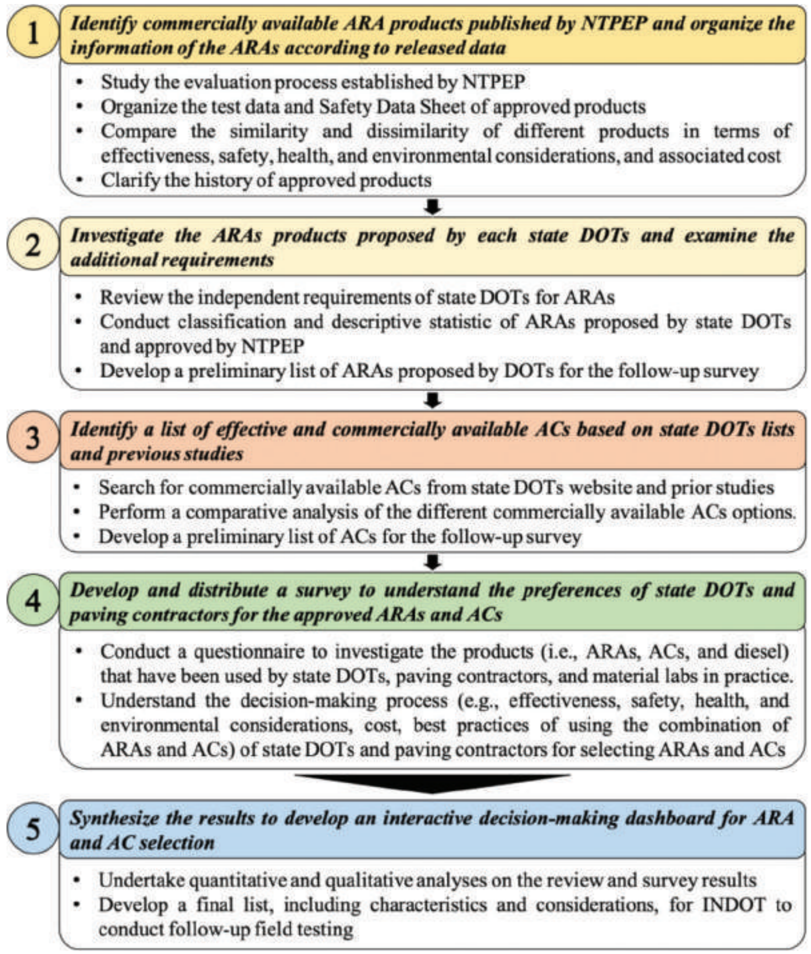


Figure 1.1 Summary of the tasks to achieve the project's aim.

2. TASK 1: IDENTIFY COMMERCIALLY AVAILABLE ARA PRODUCTS PUBLISHED BY NTPEP AND ORGANIZE THE INFORMATION OF THE ARAs ACCORDING TO THE RELEASE DATA

The National Transportation Product Evaluation Program (NTPEP) is the only program that establishes a standardized evaluation process for ARAs. Therefore, this database was considered the primary source to complete this task. Task 1 consists of understanding the NTPEP's evaluation process, specifications for ARAs, and collecting/processing/analyzing the data. Finally, a scoring system was designed and applied to facilitate a comprehensive comparison between different ARA products. Five steps were followed to accomplish Task 1, Figure 2.1.

1. Collect all information on the ARA products published by the NTPEP on their website (last updated on May 24th, 2022).
2. Contact ARAs' manufacturers to obtain additional information that NTPEP may not provide.
3. Identify the evaluation criteria based on characteristics of data and INDOT priorities.
4. Determine the scoring system to evaluate ARAs based on the specified criteria.
5. Organize the ARAs based on the method and criteria chosen in previous steps and develop a database comprehensive of all information.

2.1 NTPEP Introduction

NTPEP is the program that evaluates materials and commonly used devices in highway and bridge constructions to provide cost-effective evaluations for DOTs. To eliminate duplication of testing and auditing by the states, AASHTO NTPEP tests available ARAs and publishes the results in a database called *NTPEP DataMine*. This database provides cost-effective evaluations for the state DOTs and helps asphalt industry stakeholders decide which product is more suitable for their application.

2.1.1 NTPEP's ARA Evaluation Process

The work plan for *NTPEP Evaluation of Asphalt Release Agents* elucidates the complete NTPEP's ARA evaluation process, Figure 2.2 (NTPEP, 2022). Initially,

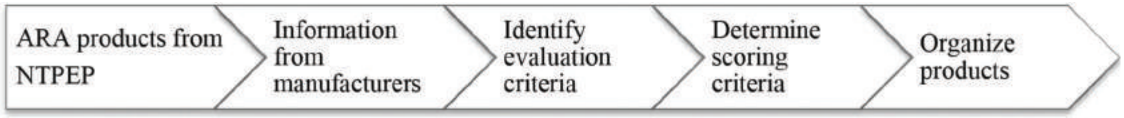


Figure 2.1 Task 1 roadmap.

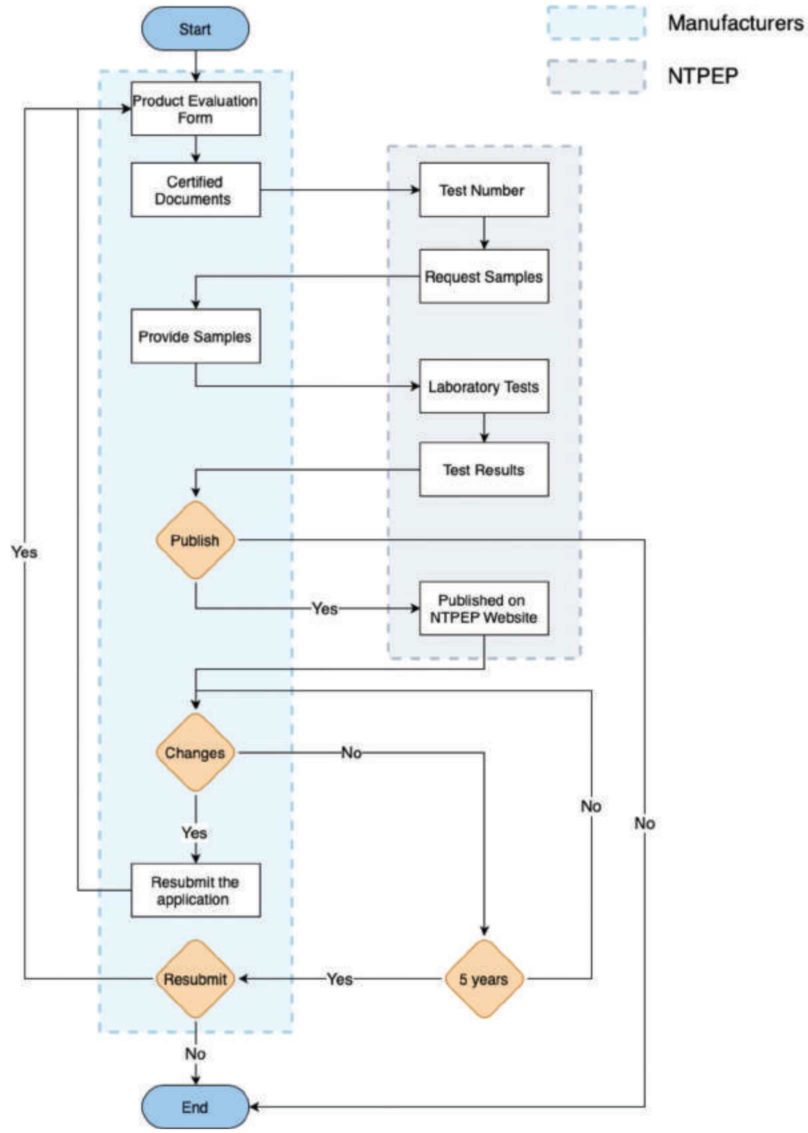


Figure 2.2 NTPEP's ARA evaluation process.

manufacturers submit an electronic Product Evaluation Form (ePEF) to the website (four submission cycles per year). Applicants are required to provide several certified documents (i.e., Rank Order List is a ranking of the programs that the manufacturer wants its product to attend, product literature, safety data sheets (SDS), flash point, infrared spectra, recommended dilution ratio, and pH test results). After the submittal, a test number is assigned to each ARA product. The test number is comprised of four types of information. The information indicates the product type, year of submission, rolling submission cycle (1–4), and sequential sample numbers. For example, the number "ARA-2022-03–12" represents an ARA product that was the 12th product submitted in the 3rd cycle of 2022. Afterward, the manufacturer is asked to provide a sample of the product. The sample should be non-diluted 2 gallons of the product. Finally, the provided sample is sent to a laboratory and tested.

NTPEP conducts three tests for ARA products: (1) Asphalt Stripping Test, (2) Mixture Slide Test, and (3) Asphalt Performance Test, as indicated in the *Standard*

Method of Test for Evaluation of Asphalt Release Agents (ASSHTO, 2021). Table 2.1 illustrates the detailed process of each test.

1. The *Asphalt Stripping Test* aims to evaluate whether ARA damages the HMA. For example, diesel is potentially detrimental to HMA because it will dissolve the asphalt binder. During the test, both diluted and non-diluted ARA are poured into containers with the presence of HMA. The weight change of the mix will be recorded to indicate the extent to which the HMA is stripped by the ARA. Also, the experimenter will visually observe the color of the solvent in the container to rate the stripping degree of the ARA product.
2. The *Mixture Slide Test* determines the susceptibility of paving mixtures for sticking to or adhering to the bed of the haul truck after adding an ARA. The tested ARA is sprayed on a metal plate identical to truck beds, and the HMA is then placed on top. Subsequently, the plate is tilted to a 45-degree angle, allowing the mixture to fall from the plate freely. The amount of binder that remains adhered to the plate demonstrates ARA's functionality.
3. *Asphalt Performance Test* is used to investigate the economic aspect of ARAs. Similar to the Mixture Slide Test, the tested ARA and an asphalt binder are placed on a metal plate. The operator repeatedly removes the binder sample and puts a new binder sample on the plate until 10% or more of the binder adheres to the plates, or seven repetitions are achieved. The pull number refers to the number of re-applying times (i.e., repetition) in the Asphalt Performance Test and will be used to evaluate ARA's economic performance.

NTPEP will then share the results of the three tests with the manufacturers, and they can decide whether to publish the results of their ARA (or ARAs) on the NTPEP DATAMINE website. The information contains the basic information regarding the manufacturer and product, SDS, technical information, and test data (the three tests conducted by NTPEP). If a manufacturer is not satisfied with the tests' results, another application can be submitted for a new product formulation. Results remain valid for 5 years. After this time, manufacturers may resubmit a new application to keep their product on the website or in case the formulation of their product has changed. Note that NTPEP will not remind manufacturers that a product is expired/will expire.

2.1.2 Specifications

The work plan for NTPEP Evaluation of Asphalt Release Agent specifies the safety and environmental requirements that ARA products shall conform to. Table 2.2 describes the specifications established by NTPEP based on Globally Harmonized System (GHS) hazard categories. Furthermore, this work plan stipulates that the flashpoint of ARAs should be higher than 400°F (204°C). If no flashpoint is observed during the test due to the ARA's boiling, the submitted documents should reveal the test procedure and the equipment used for the flash-point test. Finally, it is worth noting that NTPEP only conducts the ARA evaluations to provide references for DOTs, instead of approving or certifying the submitted ARAs. In other words, there are no NTPEP-approved ARAs or NTPEP-certified ARAs. Therefore, DOTs still need to establish their specification for selecting appropriate ARAs based on the evaluation outcomes provided by NTPEP.

2.2 Data Collection and Processing

The data were collected in two phases: (1) all test data, SDSs and other relevant information for each product available on the NTPEP DATAMINE web service was collected. On the first day of the data collection (November 1st, 2021), there was a total of 86 products published on the NTPEP website, which increased throughout the project until a total of 95 products as of May 16th, 2022. Once all information available for every product was collected, further investigations were conducted to identify the critical factors in the scoring system. The collected factors are listed in Table 2.2.

TABLE 2.1
Organization of three tests conducted by NTPEP

	Asphalt Stripping Test	Mixture Slide Test	Asphalt Performance Test
Purpose	If ARA damages asphalt	If ARA prevents the adhesion of HMA to the truck bed	If ARA is economical to use
Process	1. Place a 100 g asphalt mixture sample into six glass jars. 2. Pour 200 ml non-diluted ARA into three of six glass jars. 3. Pour 200 ml diluted ARA into the rest of jars. 4. After 7 days, the changes in jars' weights will be recorded and averaged. 5. Based on the color of the solvent, the ARA will be rated as *no stripping*, *slight stripping*, *moderate stripping*, or *severe stripping.*	1. Spray the ARA product onto a metal plate identical to truck beds and weigh the plate. 2. Pour 500 g asphalt mixture onto the plate. 3. Tilt the plate to a 45° angle and allow the asphalt mixture to slide down. 4. Repeat steps 2–3 twice without removing the retained asphalts. 5. The weight change of the metal plate will be recorded to calculate the asphalts adhered to the plate.	1. Spray the ARA product onto a metal plate and record its initial weight. 2. Place a 20 g asphalt binder onto the plate. 3. After 5 minutes, remove the binder in one continuous pull by using a small spatula. 4. Calculate the weight of the retained binder on the plate. 5. Repeat steps 2–4 until the percentage of the retained binder is at least 10% or it already releases seven times.

TABLE 2.2
Criteria selection and groups

Collected Factors	Final Criteria	Group in Scoring System
Stripping Test	Yes	Functionality
Mixture Slide Test	Yes	Functionality
Asphalt Performance Test	Yes	Cost-effectiveness
Flash Point	Yes	Safety
Biodegradability	Yes	Environmental
Dilution Ratio	Yes	Cost-effectiveness
Cost ($/gallon)	Yes	Cost-effectiveness
Melting Point/Freezing Point	No	–
pH	No	–
NFPA	Yes	Safety
HMIS III	Yes	Safety
Cold Stability	No	–
Coverage	No	–

- *Stripping Test:* Susceptibility to stripping asphalt from aggregates in a HMA mixture in slat elevators, truck beds, and other paving equipment. There should be no stripping after 7-day, either in full strength or diluted form. With this test, a sample of HMA mixture is soaked in each ARA product in the non-diluted and, if requested, a diluted strength to determine any reaction of the product against the asphalt-aggregate bond. Photographs are provided as a visual aid, while gravimetric data is provided for weight gain or loss of the mixture. The test results demonstrate how the product is detrimental to HMA, so *the lower the percent weight change, the better the ARA product*.
- *Mixture Slide Test:* Susceptibility of an HMA mixture for adhering to slat elevators, beds of haul trucks, or paving equipment after applying ARAs. With this test, the product is uniformly sprayed once onto three identical metal plates similar to the metal used in DOTs haul trucks. Next, a sample of the HMA mixture is applied to each plate to determine the release capability of the product from the metal plates. This process will be repeated three times, without reapplication of the product. *The lower the mix retained on the plate, the better performing the ARA.*
- *Asphalt Performance Test:* Susceptibility of hot asphalt binders for adhering to plant and paving equipment, rakes, shovels, etc., after using ARAs. The product is first sprayed once onto the same metal plates used in the Mixture Slide Test for this test. The same amount of hot asphalt binder is applied to each plate. Each binder patty is then pulled off from each plate. Reapplication of the hot asphalt binder and pull-off is performed until 10%, or more of the binder adheres to the plates. This test is used to find products that are more cost-effective. *The higher the pull number is, the more cost-effective the ARA.*
- *Flashpoint:* This test involves heating a small asphalt binder sample in a test container, and the flashpoint is the lowest temperature at which the test flame causes the vapors of the binder sample to ignite. The point at which it remains burning for at least 5 seconds is called the fire point. ARAs should not have flashpoint below 400°F (204°C) on the diluted product as measured by ASTM D93. The test is done in either an "open cup" or a "closed cup" apparatus, or in both, to mimic the conditions of storage and the workplace. If no flashpoint is observed due to the boiling of the material, some specific procedure must be followed (Section 8.7 of ASTM D93).
- *Biodegradability:* True ARAs are biodegradable and do not pose a health risk to workers or impact the environment. However, it is recommended that all of them be treated as chemical waste and disposed of following local regulations. Products cannot be discharged into the sewer system nor emptied into drains. For some of them, incineration is recommended.
- *Dilution ratio:* Products can be used non-diluted, but in most cases, manufacturers suggest a dilution ratio, which is the amount of water the ARA should be cut with. It ranges from 1:1 to 1:80 (for the product evaluated), with the second number being the water.
- *Cost ($/gallon):* The cost per gallon of the product. However, pricing can change based on several factors (volume, location, package size, prior customer relationship, etc.).
- *Melting point/Freezing point:* Temperature at which the product starts to freeze. Most of the manufacturers do not provide a freezing temperature. Some of them stated "Keep from freezing" in the "Cold Stability" section of SDS. Few have a freezing point between -4 and 32°F (-20 and -4°C).
- *pH:* Must comply with EPA regulations for pH levels (2–12.5).
- *NFPA:* According to the National Fire Protection Association (NFPA), the likelihood of fire and other related risks must be minimal. It categorizes a chemical from 0 (low hazard) to 4 (high hazard) (NFPA).
- *HMIS III:* Hazardous Materials Identification System (HMIS) categorizes a chemical from 0 (low hazard) to 4 (high hazard) based on four factors, including health, flammability, physical hazards, and personal protection (American Coatings Association)
- *Cold stability:* The product must be kept from freezing. For some products, if temperatures drop below 40°F, heating is required to maintain their liquid form and to prevent adverse effects of freeze-thaw weathering.
- *Coverage:* How many square footage of surface can be covered with 1 gallon of product. Nonetheless, the product's area coverage depends on the concentration used for the application and varies with how the product is applied.

Melting/freezing point, pH, cold stability, and coverage were not selected as final criteria for the product analysis. The reason behind this decision is discussed below.

- *Melting point/freezing point:* Lack of information. Also, products need to be adequately stored to keep them from freezing. Hence, a criterion that is only necessary due to poor maintenance will not be used for product evaluation.
- *pH:* All the products comply with the requirements; therefore, pH cannot be a criterion to evaluate.
- *Cold stability:* There is no robust data on how each product is affected by freezing and thawing cycles. Products need to be adequately stored.
- *Coverage:* almost no manufacturer provides this information.

Finally, all criteria were clustered in four main groups: (1) functionality, (2) cost-effectiveness, (3) environmental, and (4) safety considerations, as shown in Table 2.4.

1. *Functionality:* How effective the ARA is at creating a barrier between the asphalt and the truck and/or equipment without compromising the asphalt performance or altering its properties.
2. *Cost-effectiveness:* Calculated based on several criteria, including cost per gallon, dilution ratio, and pull number.
3. *Environmental:* Whether the product is biodegradable or not.
4. *Safety:* How safe the product is for workers considering health, flammability, and reactivity.

Further analyzing the 95 products (as of May 24th, 2022), 22 expired on the NTPEP website (meaning that the test data was older than 5 years), 30 were not commercially available, and 22 were repeated versions of the same products. Thus, the final product list comprised 54 products. After obtaining information from manufacturers, 12 products were not recommended by the manufacturers for this particular project because of the location of the project (Indiana). Therefore, 43 products (from 26 manufacturers) were included in the first analysis.

Since some information was not provided on the NTPEP website, all 34 manufacturers of listed products have been contacted to obtain information on cost ($/gallon), biodegradability, flashpoint, NFPA, and HMIS III. While the research team tried all communication channels (e.g., phone and online contact forms) to reach out to manufacturers, 52.9% of the initial 34 manufacturers did not respond to the queries or decided to not participate in this study. The research team then decided to consider the manufacturer's responsiveness level as one of the evaluation metrics to ensure that there will be no issue in future procurement (i.e., *High_3 points:* responded to all queries; *Medium_2 points:* responded to most of our questions; *Low_1 points:* partially responded but stopped responding after one or few responses; and *None_0 points:* Not responded at all). If it were impossible to connect with the manufacturer, or no information could be found on a specific product, the product was removed from the list. Figure 2.3 demonstrates the responsiveness level of all manufacturers.

Finally, the final list includes 16 products (from 13 manufacturers) that adequate data were obtained from the manufacturer or found on their website to reliably evaluate the ARAs. The list in Table 2.3 contains the manufacturing company name and product name for the final 16 products.

As can be seen in Figure 2.4, the information regarding the Stripping Test, the Mixture Slide Test, the Asphalt Performance Test data, and recommended dilution ratio were available for all the final 16 products. The missing data for some of the products are biodegradability, cost, flashpoint, NFPA, and HMIS III, for the following reasons.

- *Biodegradability:* Some manufacturers do not test for biodegradability and therefore do not have this information.
- *Cost ($/gallon):* Some manufacturers were reluctant to share the price of their products. Others did not respond at all to this question.

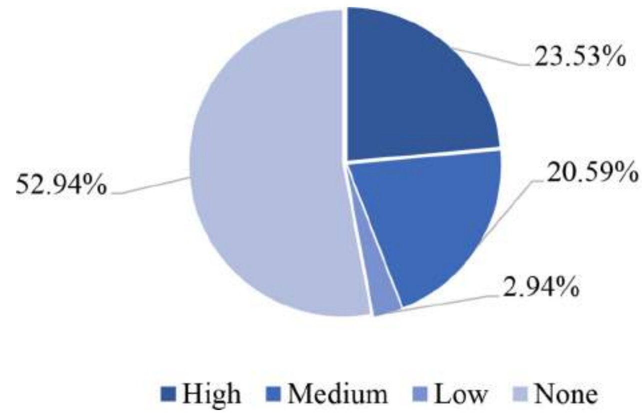


Figure 2.3 Responsiveness level of all manufacturers in Task 1.

TABLE 2.3
Final list of ARAs considered in this study

Manufacturer/Company Name	Product Name
Arrow Magnolia International	Super Slick
ChemStation	22169
	ChemStation 8442
Chem-Tech Solutions, Inc.	Westech CT-1470 PowerGlide
DeltaGreen Products, Inc.	TA-200 GS Asphalt Solutions
DuBois Chemicals	Du-Slip II
	Slick EM 5000
	Slick EM HF
Global Barrier Services	Slipcoat-IRC
Kop-Coat Protection Products	slipARAy
Lubrication Technologies, Inc.	Endurance HD
Meyer Lab	Avalanche 2020
	Super Slider
	Ultra Slider
SoySolv Biosolvents LLC	TackSolv
Zep, Inc.	BMF asphalt release agent

- *Flashpoint:* There was only one product without this information. This was because the product's boiling point is lower than the flashpoint; therefore, the test has to be stopped at the boiling point temperature, and the flashpoint cannot be measured.
- *NFPA & HMIS III:* Providing this information in a SDS is not required; therefore, some manufacturers use other labeling systems for their products.

The developed scoring system is comprised of five scores to evaluate and rank each product: (1) functionality score, (2) environmental score, (3) cost-effectiveness score, (4) safety score, and (5) final score. INDOT users can select the weight associated with each

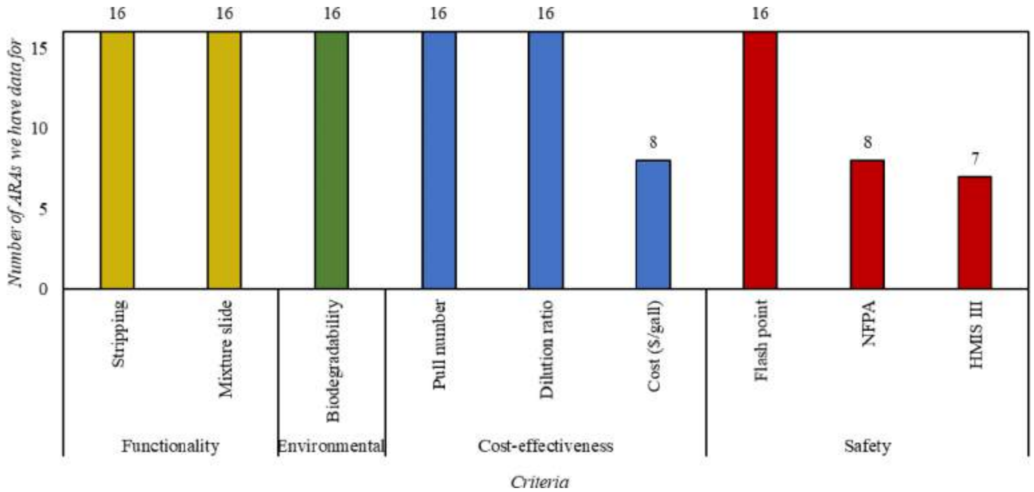


Figure 2.4 Number of ARAs with related data for the four defined criteria.

score based on their priorities, opinions, and application areas.

1. *Functionality score* is calculated based on the stripping and the Mixture Slide Test results published by NTPEP. The *Stripping Test* provides information on stripping asphalt from aggregates when using ARAs. The average diluted weight change data was used for this calculation because, as the manufacturers recommend, the product is supposed to be diluted. The results from this test vary from -3.67 g to 0.28 g for the 19 products selected, with an average value of -0.13 g and a standard deviation of 0.86 g. A change in the weight of the sample represents a chemical interaction between the asphalt binder and the ARA or stripping in the sample, both scenarios being detrimental to the asphalt. Therefore, the less change in weight or the closer the value is to 0 g, the better the ARA is, as it is not causing any damage to the asphalt. A negative value means that the ARA is stripping part of the ARA sample, so the weight decreases. In contrast, a positive value indicates that a chemical reaction generated some products (this indication was derived from the meeting with NTPEP.). Furthermore, the Stripping Test uses 100 g of sample, but only a maximum of 8% is the binder (i.e., a maximum of 8 g) can be stripped from the sample because the binder is the only component that can be stripped from the mixture (AASHTO, 2021). For this reason, the Stripping Test score is calculated as shown in Equation 2.1, where X is the diluted binder weight change in grams after the Stripping Test. Please note that if the NTPEP changes the testing procedure, the formula must be changed accordingly.

$$Stripping\ test\ score = 100 - \frac{X\ (grams)}{8\ (grams)} \cdot 100 \quad \text{(Equation 2.1)}$$

Further, the Mixture Slide Test score is based on the average amount of mix retained on the plate provided in the NTPEP test data sheet. A negative test value means that the sample has completely slid off the plate, along with part of the applied ARA. A positive value means that part of the sample was retained on the plate (AASHTO, 2021). The closer to 0 g retained, the better the ARA product, meaning the ARA effectively created a barrier between the asphalt and the truck bed and did not slide off with the asphalt sample. The test uses 500 g of asphalt, which theoretically is all susceptible to getting retained (AASHTO, 2021). Thus, this score was calculated as shown in Equation 2.2, where X is the amount of binder mixture retained in grams after the Mixture Slide Test.

$$Mixture\ slide\ test\ score = 100 - \frac{X\ (grams)}{500\ (grams)} \cdot 100$$

(Equation 2.2)

Nonetheless, it is worth mentioning that the results from this test usually are very high scores for all products, all above 99%. Considering Mixture Slide Test results are crucial for the functionality assessment of the ARA products, the research team assumed 99% as the threshold; therefore, if the Mixture Slide Test score is lower than 99, the product gets a functionality score of 0, while if it is higher than 99, then the functionality score is equal to the Stripping Test score, as shown in Equation 2.3.

$$\begin{cases} If\ mixture\ slide\ test\ score > 99;\ Functionality\ score \\ \quad = Stripping\ test\ score \\ If\ mixture\ slide\ test\ score < 99;\ Functionality\ score = 0 \end{cases}$$

(Equation 2.3)

2. *Environmental score* is determined based on whether the product is biodegradable. If so, the score would be 100 points; if not, the score would be 0; as shown in Equation 2.4.

$$\begin{cases} If\ it\ is\ biodegradable;\ Environmental\ score = 100 \\ If\ it\ is\ not\ biodegradable;\ Environmental\ score = 0 \end{cases}$$

(Equation 2.4)

3. *Cost-effectiveness score* is calculated based on the Asphalt Performance Test result (i.e., pull number), the dilution ratio, and the product cost ($/gallon), Equation 2.5 and Equation 2.6. A higher pull number, a lower cost, and a higher dilution ratio lead to a higher Y value meaning a more effective product. Then, the value of each product

is normalized, giving 100 points to the highest value and 0 to the lowest, Equation 2.6.

$$Y = \frac{Asphalt\ performance\ test}{Dilution\ ratio * Cost} \quad \text{(Equation 2.5)}$$

$$Cost - Effectiveness\ score = \text{Normalized } Y = 100 * \frac{Y - \min(Y)}{\max(Y) - \min(Y)} \quad \text{(Equation 2.6)}$$

4. *Safety score* is calculated based on flashpoint, NFPA, and HMIS III data. As the flashpoint is the most critical safety concern, it is assumed to be the score's central part. Since HMA is asphalt mixtures that are heated and poured at temperatures between 350°F to 400°F, a threshold of 400°F was set. Thus, ARA products with equal or higher flashpoints will obtain higher (better) safety scores. If the product has a flash point equal to or greater than 400°F, the safety score would be 100%. The safety score will decrease proportionally if it is lower than 400°F as a flash point. The NFPA and HMIS III labels will then be subtracted from this score. Because each label has three scores, ranging from 0 (no risk) to 4 (high risk), the minimum amount taken from the 100 points score is 0, and the maximum is 24. This will clearly distinguish products with high flashpoint but different safety issues to workers. The safety score can be obtained from Equation 2.7.

$$\begin{cases} If\ flash\ point < 400°F;\ Safety\ Score = 100 * \frac{Flash\ point(°F)}{400°F} - NFPA - HMIS\ III \\ If\ flash\ point \geq 400°F;\ Safety\ Score = 100 - NFPA - HMIS\ III \end{cases} \quad \text{(Equation 2.7)}$$

5. *Final score* is calculated based on the combination of the above-mentioned scores (i.e., functionality, environmental, cost-effectiveness, and safety scores) and their associated weights, Equation 2.8:

$$Final\ score = Environmental_{Score} * W_{Environmental} + Functionality_{Score} * W_{Functionality} + Cost - Effectiveness_{Score} * W_{Cost-effectiveness} + Safety_{Score} * W_{Safety} \quad \text{(Equation 2.8)}$$

Where, $W_{Environmental}$, $W_{Functionality}$, $W_{Cost\text{-}effectiveness}$, and W_{Safety} are the weights assigned to each category by the customer. As a default, the values for all weights are 1/4, meaning that each group is worth the same and has the same importance. However, as mentioned, INDOT users can select the weight associated with each score based on their priorities, opinions, and application areas.

Note: The products without sufficient information were penalized, Figure 2.4. For the environmental score, the products that do not provide information regarding biodegradability are penalized with a 0 score. If the cost information is not provided for the cost-effectiveness score, the cost used will be the highest cost found among all 16 products. For the safety score, if the NFPA and HMIS III labels and the flashpoint are not provided, the safety values for diesel are used. The summary of individual and final scores formulas is provided in Table 2.4.

2.3 Data Analysis

Once the data from Task 1 had been collected and processed, the developed scoring system was applied to the 16 products—see Table 2.5, Table 2.6, and Figure 2.5. The final score provided corresponds to the average value of the four criteria.

2.4 Conclusion

The first task of the project aimed to provide a comprehensive NTPEP-based ARA list and to develop a scoring system to compare products effectively and accurately. For this purpose, all the products tested and published by NTPEP were investigated, and along with the data provided by manufacturers, relevant evaluation criteria for the ARA comparison were defined. Due to the low responsiveness of some manufacturers, some products had to be penalized. The scores were divided into five categories: (1) functionality, (2) environmental, (3) cost-effectiveness, (4) safety, and (5) final scores. Regarding final score calculation, INDOT users can

TABLE 2.4
Score calculation formula for each group criterion

Scores	Calculation Formula
Functionality	$\begin{cases} If\ mixture\ slide\ test\ score > 99; Functionality\ score = Stripping\ test\ score \\ If\ mixture\ slide\ test\ score < 99; Functionality\ score = 0 \end{cases}$
Environmental	$\begin{cases} If\ it\ is\ biodegradable;\ Environmental\ score = 100 \\ If\ it\ is\ not\ biodegradable;\ Environmental\ score = 0 \end{cases}$
Cost-Effectiveness	$Y = \frac{Asphalt\ performance\ test}{Dilution\ ratio \cdot Cost}$ $Cost - Effectiveness\ score = 100 * \frac{Y - \min(Y)}{\max(Y) - \min(Y)}$
Safety	$\begin{cases} If\ flash\ point < 400°F; Safety\ score = 100 * \frac{Flash\ point°F}{400°F} - NFPA - HMIS\ III \\ If\ flash\ point \geq 400°F;\ Safety\ score = 100 - NFPA - HMIS\ III \end{cases}$
Final Score	$Final\ score = Environmental_{Score} \cdot W_{Environmental} + Functionality_{Score} \cdot W_{Functionality} + Cost - Effectiveness_{Score} \cdot W_{Cost-effectiveness} + Safety_{Score} \cdot W_{Safety}$

TABLE 2.5
Descriptive statistics of defined score results for 16 selected products

Parameter	Functionality Score	Environmental Score	Cost-Effectiveness Score	Safety Score	Final Score
Maximum	99.75	100.00	100.00	100.00	98.03
Minimum	54.13	0.00	0.00	46.00	48.79
Mean	95.77	75.00	20.26	92.94	70.99
Standard Deviation	10.26	45.24	29.70	15.72	14.04

TABLE 2.6
Defined scores breakdown for all 16 selected ARA products

Manufacturer	Product	Functionality Score	Environmental Score	Cost-Effectiveness Score	Safety Score	Final Score
Kop-Coat Protection Products	slipARAy	98.75	0.00	0.41	96.00	48.79
Meyer Lab	Super Slider	99.50	0.00	6.66	94.00	50.04
Arrow Magnolia International	Super Slick	97.50	0.00	13.85	95.00	51.59
DeltaGreen Products, Inc.	TA-200 GS Asphalt Solutions	96.50	0.00	43.79	98.00	59.57
Global Barrier Services	Slipcoat-IRC	54.13	100.00	0.00	100.00	63.53
ChemStation	ChemStation 8442	98.50	100.00	17.52	46.00	65.51
DuBois Chemicals	Slick EM 5000	98.50	100.00	1.02	95.00	73.63
Meyer Lab	Ultra-Slider	98.25	100.00	5.00	94.00	74.31
Meyer Lab	Avalanche 2022	96.75	100.00	8.97	94.00	74.93
DuBois Chemicals	Slick EM HF	99.75	100.00	7.09	95.00	75.46
Lubrication Technologies, Inc.	Endurance HD	99.75	100.00	8.59	100.00	77.09
DuBois Chemicals	Du-Slip II	99.63	100.00	16.78	94.00	77.60
ChemStation	22169	98.75	100.00	17.99	94.00	77.69
Zep, Inc.	BMF asphalt release agent	99.38	100.00	22.51	99.00	80.22
Chem-Tech Solutions, Inc.	Westech CT-1470 PowerGlide	98.63	100.00	54.01	99.00	87.91
SoySolv Biosolvents LLC	TackSolv	98.13	100.00	100.00	94.00	98.03

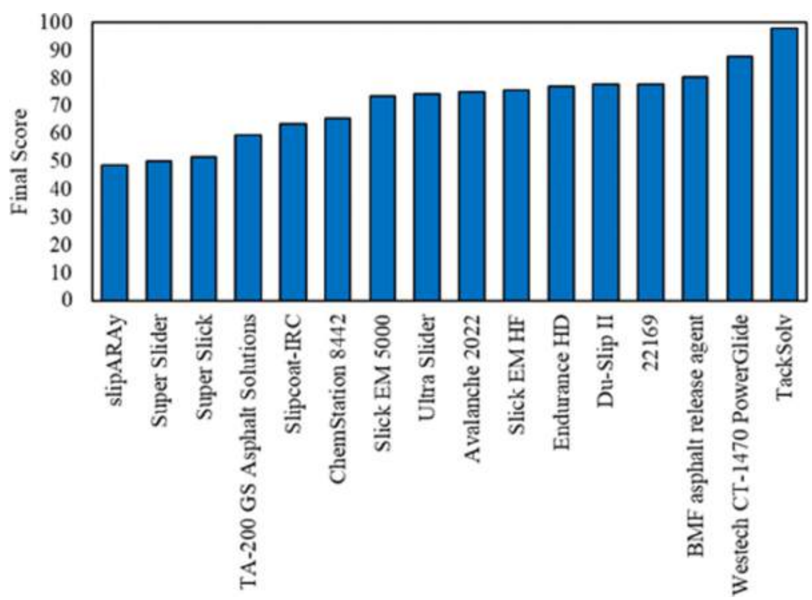


Figure 2.5 Final score distribution for selected 16 ARA products.

select the weight associated with each score based on their priorities, opinions, and application areas. The proposed scoring system is based on quantitative and qualitative data that can easily get updated in the future.

3. TASK 2: INVESTIGATE THE ARA PRODUCTS PROPOSED BY EACH STATE DOT AND EXAMINE ADDITIONAL REQUIREMENTS

Since NTPEP does not provide any ARA approval for DOTs and only tests and publishes the results, each state DOT needs to establish its own specification for ARA products based on priorities and requirements and publish an approved ARA list for potential users. The task aims to investigate the ARA products listed by state DOTs to evaluate the present status of using each product, Figure 3.1. The results from this task will then be used to develop a preliminary list of ARAs for creating a follow-up survey in Task 4.

3.1 Identify the NTPEP States

Although NTPEP is the only program contributing to ARA evaluation, state DOTs can independently determine whether to use NTPEP or other evaluation processes for testing and selecting ARAs. When state DOTs establish the specifications for ARAs, they might be based on the information accessible on the NTPEP website. For example, Texas DOT requires compliance with the following requirements: (1) ARA has no stripping on Asphalt Stripping Test, (2) ARA has a maximum of 10 g retained on the Mixture Slide Test, and (3) ARA has a minimum of three pull number on Asphalt Performance Test. In other words, Texas DOT uses the NTPEP database and adds additional restrictions on the test results based on their requirement to select appropriate ARA products.

As can be seen in Figure 3.2, state DOTs would produce a qualified list of ARAs for the users in their states, and these states can be grouped into (1) NTPEP DOTs, (2) non-NTPEP DOTs, and (3) half-NTPEP DOTs (ntpep.transportation.org). NTPEP required category represents the DOTs that only accept the ARAs that NTPEP has tested and published and related results. Also, those DOTs may add additional specific requirements for results, such as Texas DOT. On the contrary, non-NTPEP refers to the DOTs that do not use any information provided by NTPEP. Instead, they establish its evaluation process to test, evaluate, and generate an approved list of ARA products. Finally, half-NTPEP refers to DOTs that accept the ARAs listed on the NTPEP website and have another independent evaluation process. Examining these lists published by DOTs will help identify ARA products recommended (commonly used) for further analysis.

3.2 Data Collection of DOTs' ARA Lists

To collect the approved ARA lists from state DOTs, their websites were browsed to find whether they established specifications for ARAs and generated an approved list. Figure 3.3 depicts an overview of the

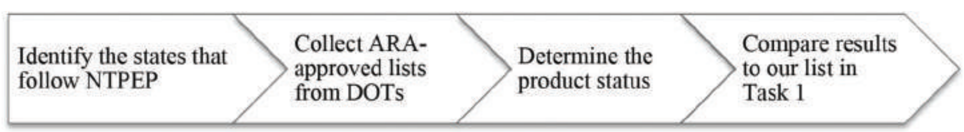


Figure 3.1 Task 2 roadmap.

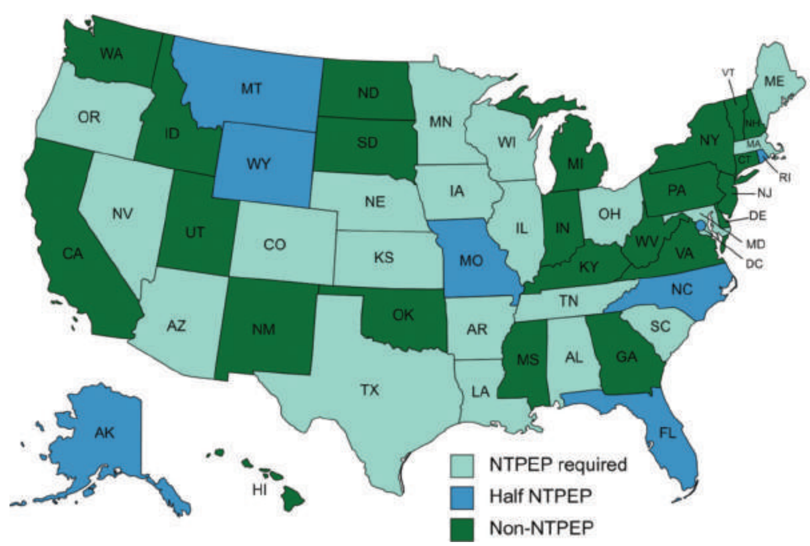


Figure 3.2 U.S map depicting NTPEP, non-NTPEP, and half-NTPEP states.

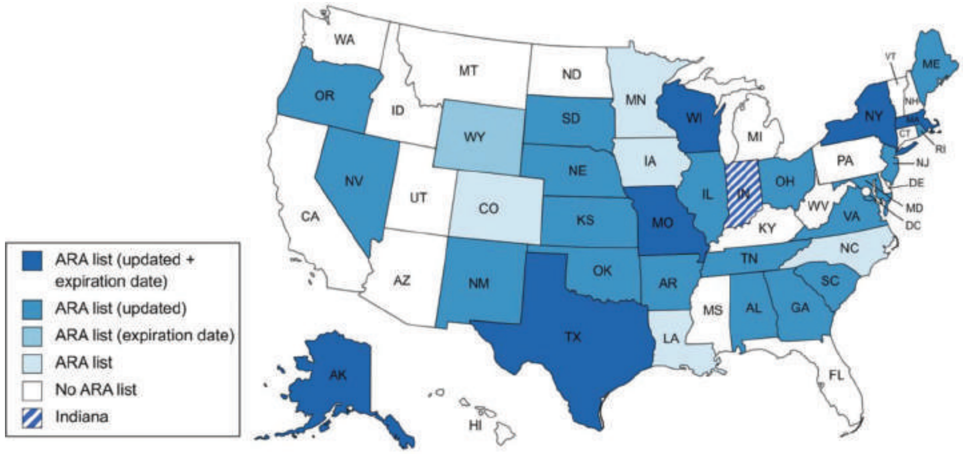


Figure 3.3 Overview of the state DOTs with or without an approved ARA list.

state DOTs with or without an approved list of ARAs. There are some observations that need to be mentioned. First, some DOTs do not include the last updated date for their lists. This information is crucial because it indicates whether the DOTs regularly update the lists so that users have access to the latest ARA information. Second, unlike NTPEP, which states all the ARAs will not be invalid in 5 years, the expiration date information for each listed ARA is not included in DOTs' published lists. This would trigger the issue when users acquire the information about the ARAs that is not commercially available any more. Figure 3.4 demonstrates a published Texas DOT's ARA list, including updated and expiration dates.

Hence, all the state DOTs are divided into five categories (see Figure 3.3): (1) has an ARA list with an updated and expiration date, (2) has an ARA list with an update date, (3) has an ARA list with an expiration date, (4) has ARA list, and (5) has no ARA list. Noteworthy, Indiana DOT (INDOT) has an approved list of "anti-adhesive materials," which includes some ARA products. In other words, Indiana DOT is a Non-NTPEP state that uses another terminology to represent ARAs and conducts its evaluation tests. Note: The following sections will compare the NTPEP tests and Indiana DOT tests. In conclusion, all the approved lists of ARAs proposed by state DOTs were collected, and two taxonomies (i.e., whether following NTPEP and whether having an ARA list, updated data, and expiration date) were used to group the DOTs.

3.3 Data Analysis

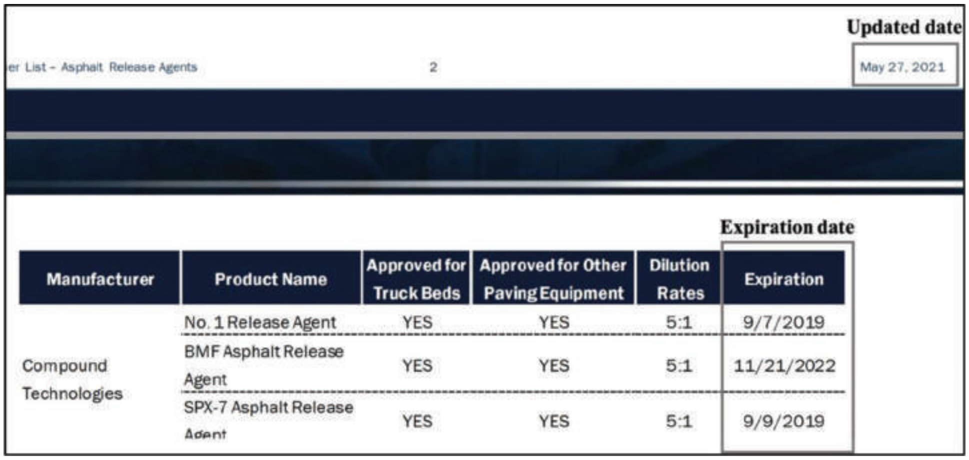
The collected data from state DOTs were analyzed qualitatively and quantitatively to provide more insights into how each DOT evaluates the ARAs and what ARAs are more frequently listed.

3.3.1 Specifications

As highlighted, NTPEP is dedicated to evaluating ARA products and providing helpful information, so NTPEP does not endorse or approve any specific ARA products. That is, state DOTs are responsible for establishing individual specifications to choose the accepted ARAs in their states. Most of the DOTs created selection criteria based on the results of the three NTPEP-conducted tests (i.e., Asphalt Stripping Test, Mixture Sliding Test, and Asphalt Performance Test). Figure 3.5 illustrates an overview of the defined requirements. Although the requirements vary from different DOTs, "no stripping," "10 g retained," and "3 pull number" has been utilized by most of the DOTs for three standard tests. As a result, this specification analysis concludes that most DOTs emphasize the importance of three NTPEP-conducted tests, especially the Asphalt Stripping Test. Further, While NTPEP specifies higher than 400°F flashpoint for ARA to ensure workers' safety, none of the DOTs considers the flashpoint as one of the evaluation criteria.

3.3.2 Anti-Adhesive Material List from INDOT

INDOT has a list of anti-adhesive materials used to prevent the adhesion of HMA. A similarity between the anti-adhesive materials and ARAs is apparently discerned, and approximately 25% of the materials listed by INDOT also appeared on the NTPEP's website. Since Indiana is a non- NTPEP state, INDOT has established an independent standard (ITM No. 576-15) (INDOT, 2015). Based on this specification, INDOT conducts two tests (i.e., film and mixture tests) to evaluate anti-adhesive materials. Both tests mainly examine whether anti-adhesive materials harden or soften the HMA. In the Film Test, after putting the tested anti-adhesive material and HMA into a jar, an evaluation of the HMA is undertaken by experimenters using fingertips, spatula, and a stirring rod to determine the impact of the anti-adhesive material on the HMA (i.e., hardening, softening, and dissolving). In the mixture test, the 400–800 g of HMA is placed onto metal plates that are covered with (1) anti-adhesive materials, (2) anti-adhesive materials (draining off the agent), or (3) tap water. After placing the plate into the


Updated date

er List - Asphalt Release Agents 2 May 27, 2021

Expiration date

Manufacturer	Product Name	Approved for Truck Beds	Approved for Other Paving Equipment	Dilution Rates	Expiration
Compound Technologies	No. 1 Release Agent	YES	YES	5:1	9/7/2019
	BMF Asphalt Release Agent	YES	YES	5:1	11/21/2022
	SPX-7 Asphalt Release Agent	YES	YES	5:1	9/9/2019

Figure 3.4 Example of updated date and expiration date from Texas DOT.

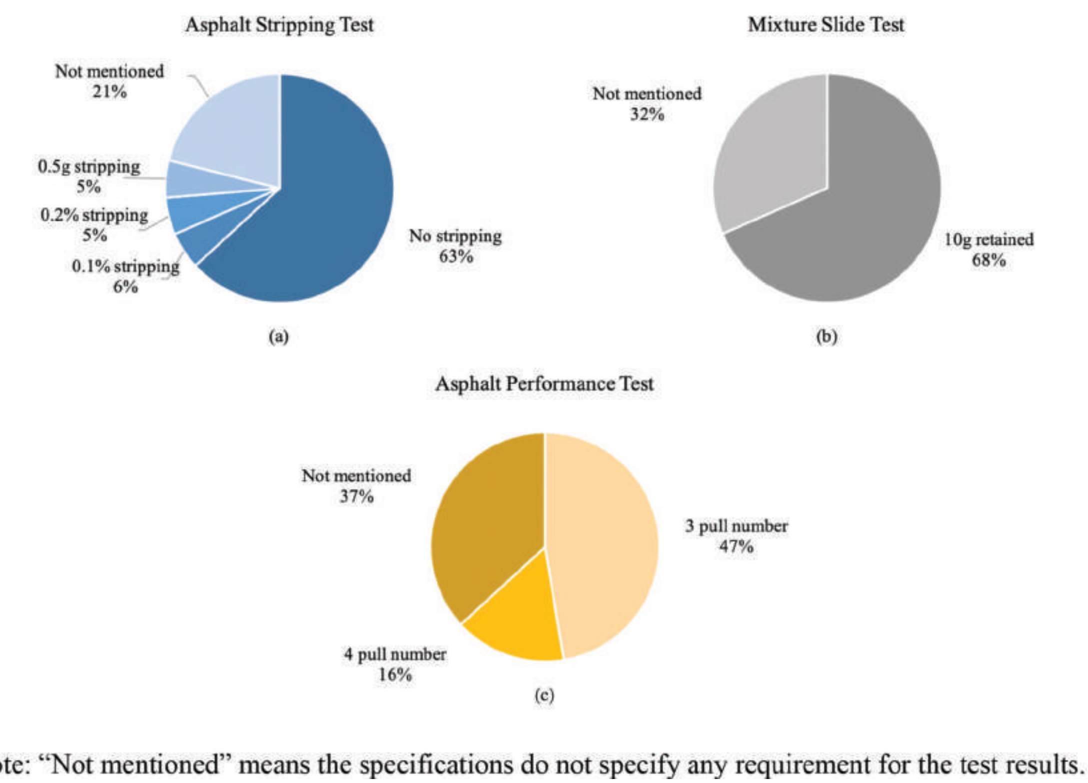


Figure 3.5 Overview of DOT's specifications for three commonly used tests: (a) Asphalt Stripping Test, (b) Mixture Slide Test, and (c) Asphalt Performance Test.

oven and cooling down. The plates will be tilted 45 degrees, and the HMA slid from the plate will be collected. A touch evaluation is also conducted to test how HMA was affected by the anti-adhesive material (i.e., slight hardening and softening of the mixture is fine, but severe changes will be reported as unsatisfactory).

Compared to the three tests included in NTPEP's evaluation process, INDOT emphasizes more on the Asphalt Stripping Test, not the mixture or performance tests. Although the Mixture Test (INDOT) procedure is analogous to the Mixture Slide Test (NTPEP), INDOT's Mixture Test does not consider the amount of HMA remaining on the plates indicating the ARA functionality. Table 3.1 and Table 3.2 demonstrate the comparisons between INDOT's and NTPEP's tests.

The primary differences in NTPEP and INDOT testing approaches lie in (1) quantitative analysis, (2) dilution, and (3) publishing of the data. First, while NTPEP produces the results of experiments based on quantitative data (e.g., grams of HMA stripped by the

TABLE 3.1
The comparison between the Asphalt Stripping Test (NTPEP) and Film Test (INDOT)

Standard	AASHTO T 383-211	ITM No. 576-15
Entity (Test)	NTPEP (Asphalt Stripping Test)	INDOT (Film Test)
Goal of the Test	To measure the susceptibility of stripping asphalt from aggregates in HMA mixture in truck beds and other paving equipment.	To determine if the anti-adhesive agent hardens or softens the asphalt binder.
Procedure	100 g of an asphalt sample are weighed before and after being added to a jar with ARA for 168 h.	Two asphalt samples of 5–7 g are added to a jar with ARA and a jar with water for 90 ± 15 minutes at 140 ± 5°F.
Measurement	A visual measure of the discoloration of the ARA, stripping based on a rating system, and weight change measure.	A touch measure of hardening or something of the asphalt or evidence of dissolved material compared to the water jar.

TABLE 3.2
The comparison between the Mixture Slide Test (NTPEP) and Mixture Test (INDOT)

Standard	AASHTO T 383-211	ITM No. 576-15
Entity (Test)	NTPEP (Mixture Slide Test)	INDOT (Mixture Test)
Goal	To measure the susceptibility of an HMA mixture for adhering to slat elevators, beds of haul trucks, or paving equipment after applying ARAs.	To determine if the anti-adhesive agent affects the adhesive property of the HMA.
Procedure	Place a 500 g asphalt mixture sample on a metal plate with an ARA diluted product applied and tilt the plate 45°. Weigh before and after. Repeat three times.	Place three 400–800 g asphalt samples on three metal plates with an anti-adhesive agent, anti-adhesive agent (draining off the agent), and water. Tilt the plate 45°.
Measurement	An averaged measure of material remaining on the plate.	A touch measure of severe changes in adhesive properties of the mixtures.

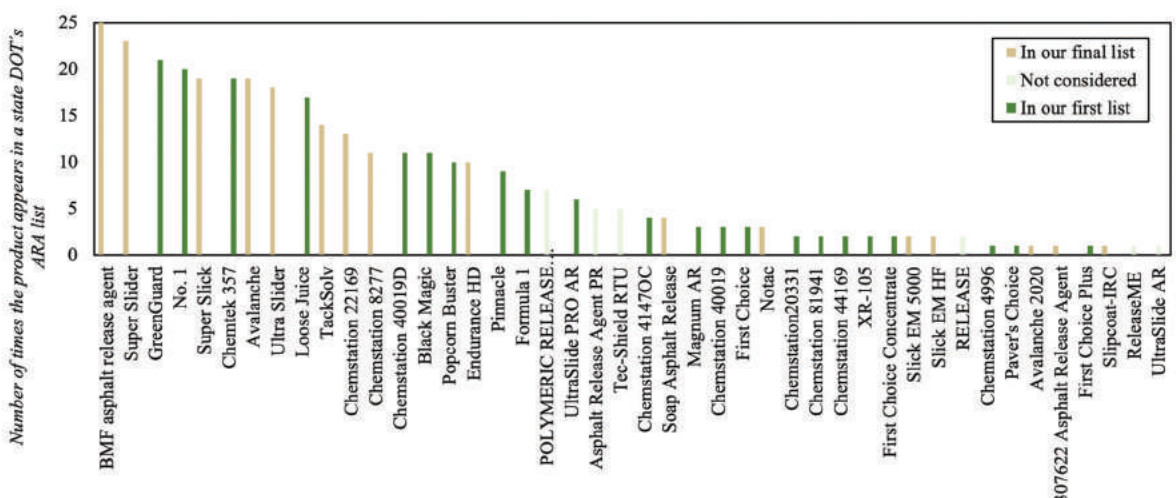


Figure 3.6 Descriptive analysis of the NTPEP ARA products listed by 32 state DOTs.

ARA), INDOT relies on a subjective touch measure (e.g., satisfactory, unsatisfactory). Second, While INDOT's standard does not stipulate any requirement for the dilution of anti-adhesive materials, NTPEP considers both non-diluted and diluted products in the evaluation. As a result, this project recommends consolidating the NTPEP filtered ARA list in combination with INDOT-specific testing and evaluation procedures to address these limitations and select the most effective ARA in the State of Indiana.

3.3.3 Descriptive Analysis

Based on the data collected from state DOTs, a descriptive analysis was conducted to identify what ARA products are being listed most frequently. Noteworthy, although some of the DOTs' listed products are not included on the NTPEP's website, the current project only focused on the NTPEP-listed ARA products because several state DOTs have widely accepted this evaluation process. Figure 3.6 illustrates the