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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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COVER IMAGE

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16. Abstract

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.

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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.

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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 nonhazardous (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.

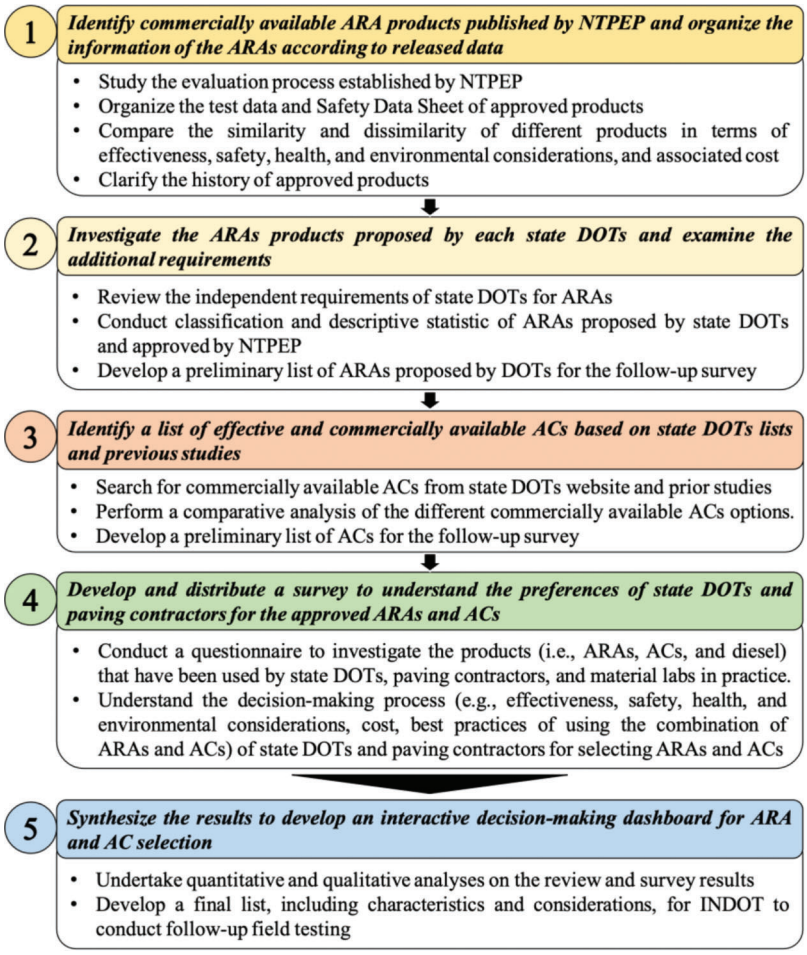


Figure 1.1 Summary of the tasks to achieve the project's aim.

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,

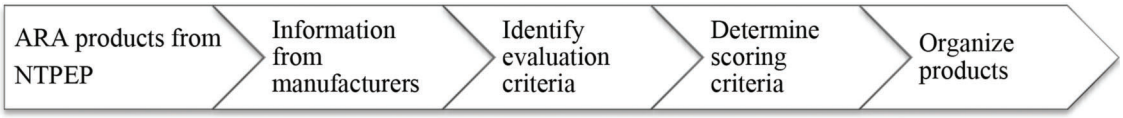


Figure 2.1 Task 1 roadmap.

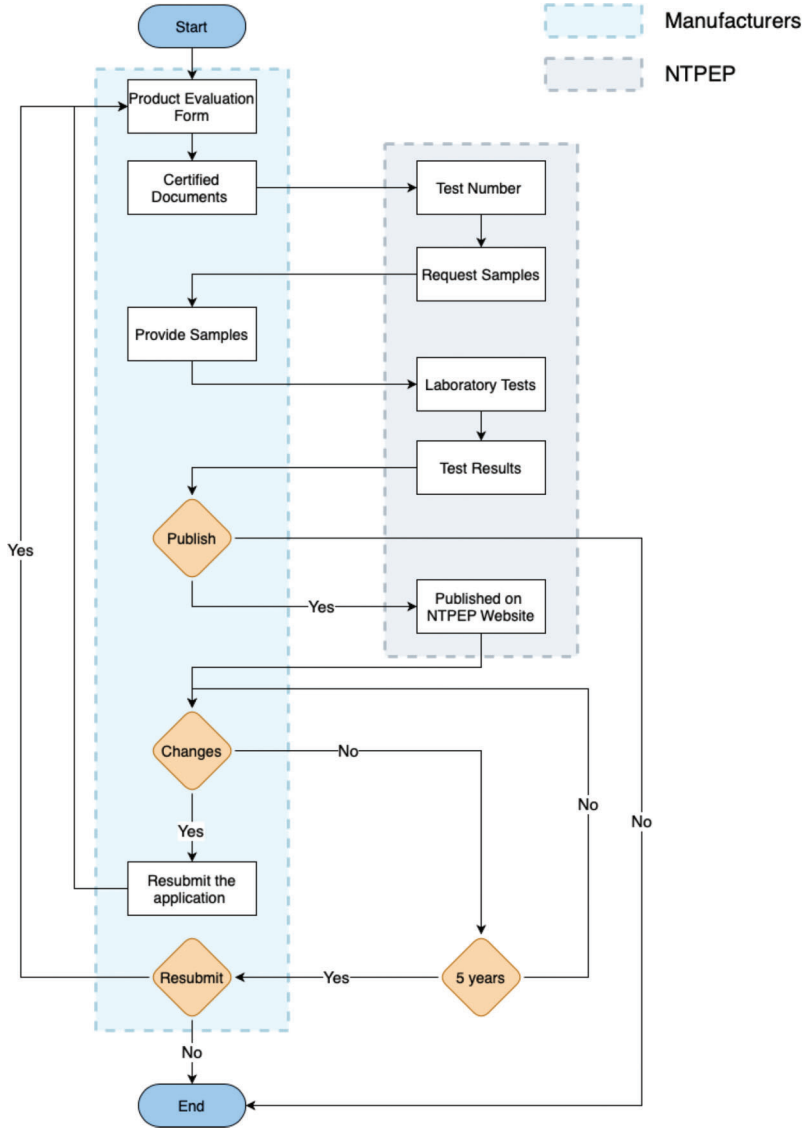


Figure 2.2 NTPEP's ARA evaluation process.

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.

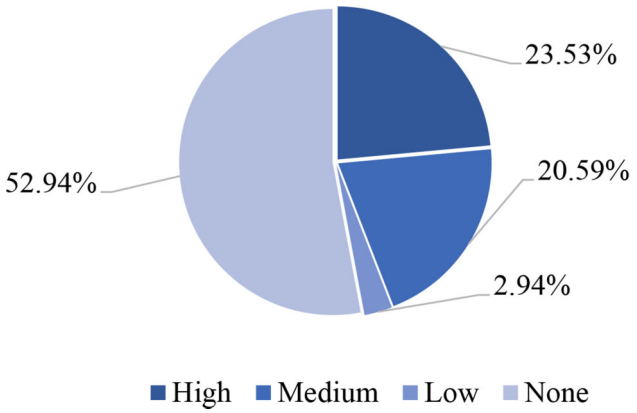


Figure 2.3 Responsiveness level of all manufacturers in Task 1.

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

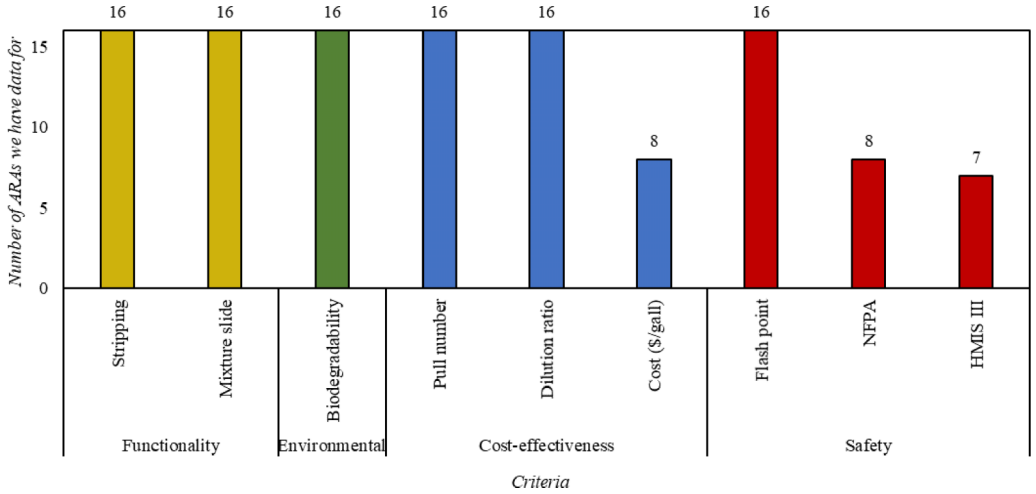


Figure 2.4 Number of ARAs with related data for the four defined criteria.

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.

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

(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.

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

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

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.

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

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:

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

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	$Y = \dfrac{Asphalt\ performance\ test}{Dilution\ ratio \cdot Cost}$ $Cost-Effectiveness\ score = 100 * \dfrac{Y - \min(Y)}{\max(Y) - \min(Y)}$
Safety	$\begin{cases} If\ flash\ point < 400°F;\ Safety\ score = 100 * \dfrac{Flash\ point°F}{400°F} - NFPA - HMIS\ III \\ If\ flash\ point \geq 400°F;\ Safety\ score = 100 - NFPA - HMIS\ III \end{cases}$
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

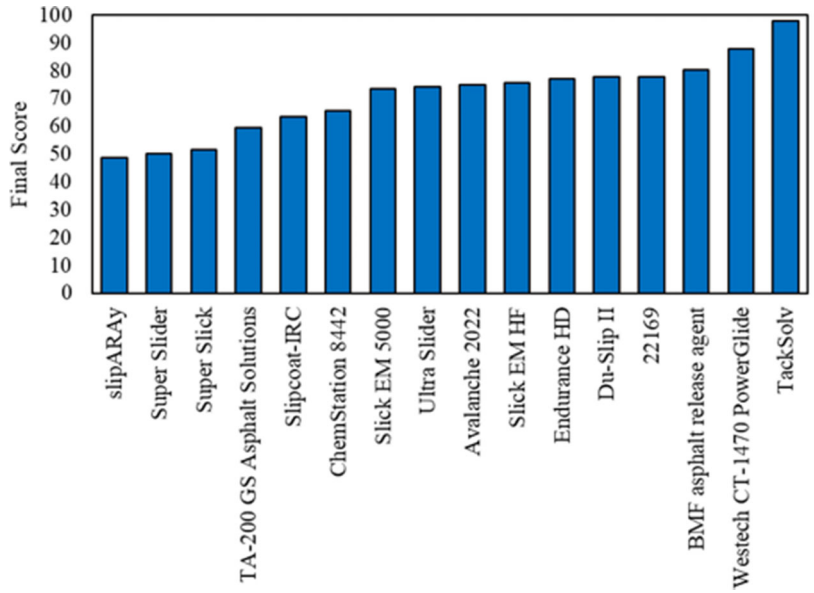


Figure 2.5 Final score distribution for selected 16 ARA products.

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.

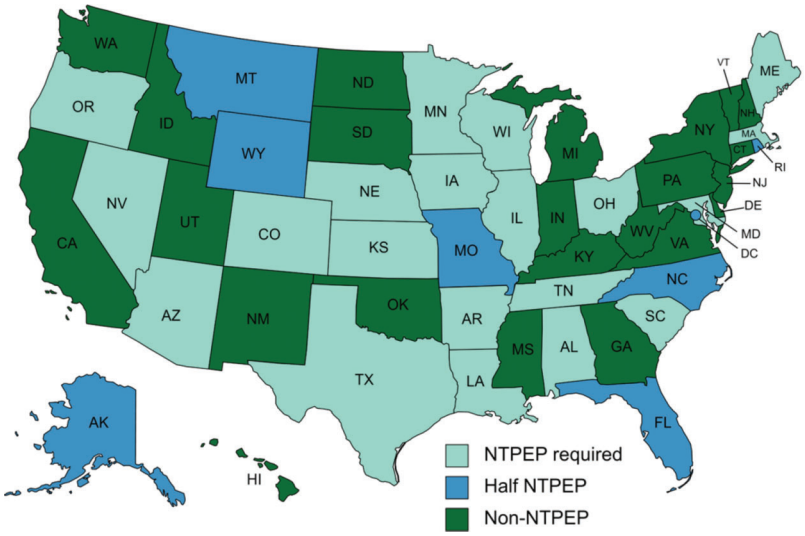


Figure 3.2 U.S map depicting NTPEP, non-NTPEP, and half-NTPEP states.

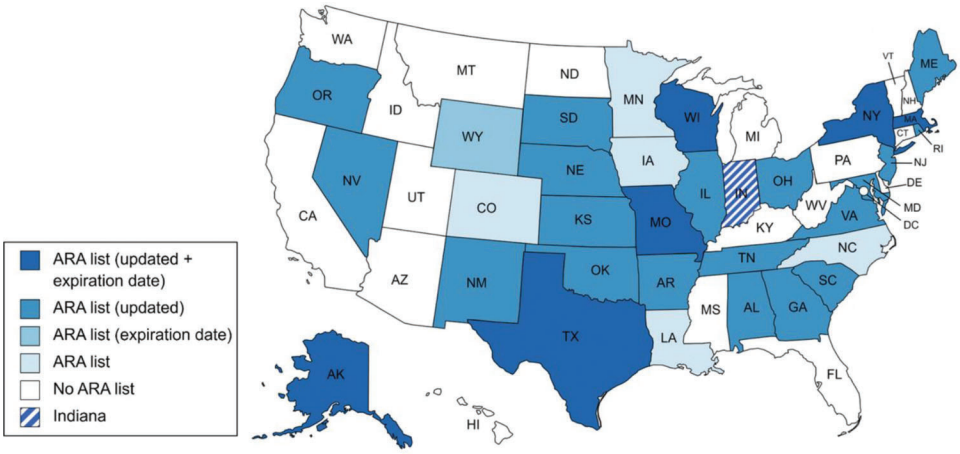


Figure 3.3 Overview of the state DOTs with or without an approved ARA list.

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

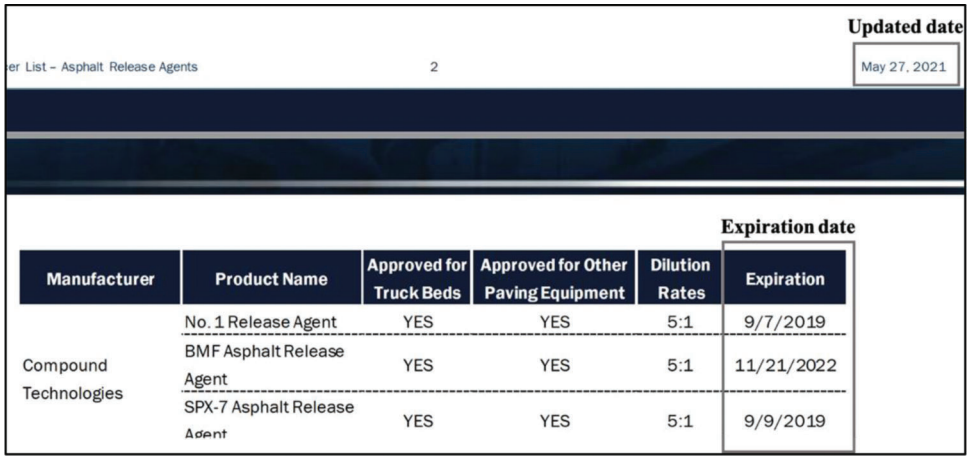
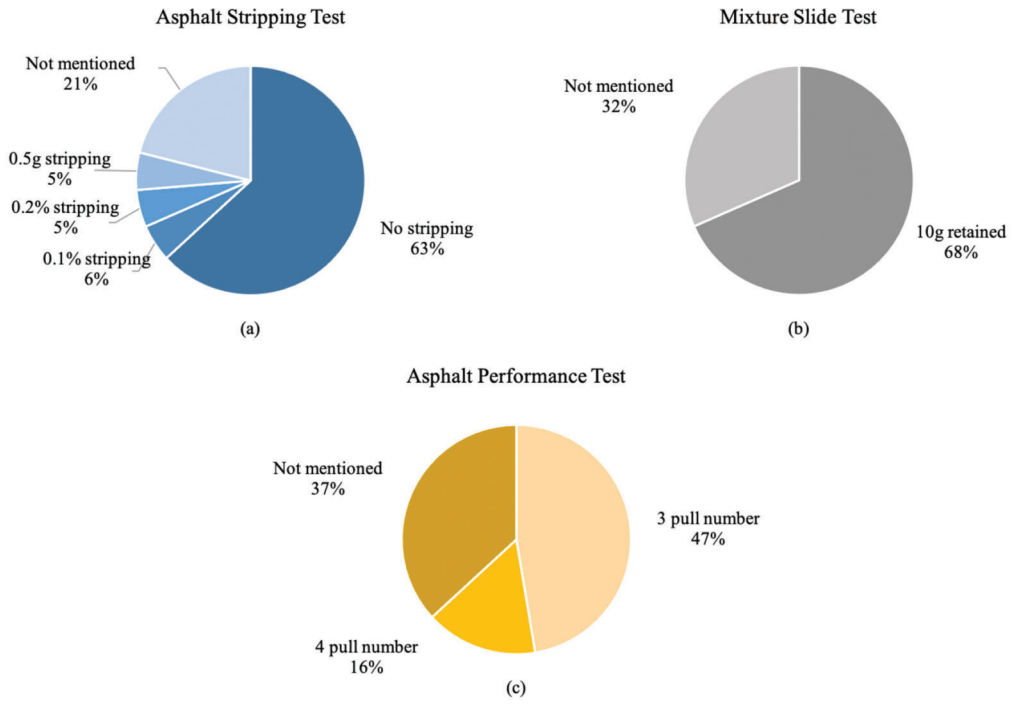


Figure 3.4 Example of updated date and expiration date from Texas DOT.



Note: "Not mentioned" means the specifications do not specify any requirement for the test results.

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.

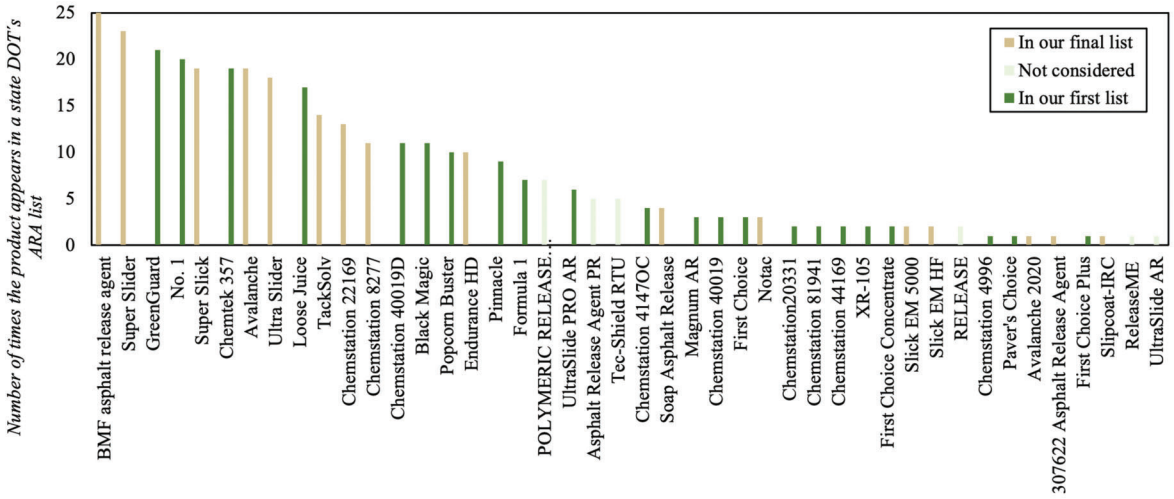


Figure 3.6 Descriptive analysis of the NTPEP ARA products listed by 32 state DOTs.

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

frequency of the 44 different NTPEP ARAs listed by 32 states. As shown, 16 out of 44 products are also included in the final list presented in Task 1. Further, 22 out of 44 products were excluded due to the insufficiency of manufacturer data. Six more products were also eliminated because they expired on the NTPEP website or aren't commercially available. The results were used to develop a survey (Task 5).

3.4 Conclusion

This chapter aimed to collect and analyze the ARAs lists from different state DOTs. The obtained lists were further analyzed to identify NTPEP ARAs and evaluate the related products based on information sufficiency. The results indicated that 32 states had published their ARA lists, and among them, only 81% included updated dates, 25% included the expiration dates and only 22% included both updated and expiration dates. This chapter also helped the research team to better understand additional tests and evaluation requirements/specifications incorporated by state DOTs. In addition, it is worth noting that INDOT has an anti-adhesive materials list that is highly similar to the ARA list; however, there are a few limitations associated with the INDOT evaluation process, which were discussed in this chapter. Finally, the descriptive analysis indicated that 16 ARAs (out of 44 listed by state DOTs) are included in the final list presented in Task 1.

4. TASK 3: IDENTIFY A LIST OF EFFECTIVE AND COMMERCIALLY AVAILABLE ACS-BASED ON-STATE DOT LISTS AND PREVIOUS STUDIES

The third task aims to collect and classify effective and commercially available ACs. To achieve this, five steps are followed, also presented in Figure 4.1.

4.1 Data Collection and Processing

The process for collecting AC lists requires more investigation than for the ARA list, as no official database is available that classifies or tests ACs. For this reason, the two sources used to collect AC products were (1) ARA manufacturers that had been responsive and selling ACs; and (2) AC lists from other state DOTs. An initial list of 45 products from 40 manufacturers was obtained from Minnesota DOT, Texas DOT, Maine DOT, Tennessee DOT, and ChemStation contact.

In addition, three selected evaluation criteria are shown in Table 4.1. Although adding a functionality criterion that measures how effective ACs are at cleaning asphalt from the equipment would be useful, no information is available regarding the functionality of ACs. The selected ACs can be purchased, and their effectiveness can be assessed through field testing.

After selecting the criteria, all 40 manufacturers were contacted, and the responsiveness level (described in Task 1) was also recorded and is shown in Figure 4.2. Due to the low responsiveness rate, for further analysis, the list was reduced from the initial 45 products to 22 products (from 18 manufacturers) (see Table 4.2). Diesel was also added to the list to create a more meaningful comparison, as it is widely used to clean truck beds and equipment from asphalt use. Diesel cost was extrapolated from the average cost of the year 2021 from the U.S Energy Information Administration gasoline and diesel fuel prices for the entire country (cost $/gallon is $3.28; not biodegradable, flash point is 126°F) (EIA, 2022; Engineering ToolBox, 2005).

The distribution of the cost and flashpoint for all 22 AC products (and diesel) is shown in Figure 4.3 and Figure 4.4. As can be seen, the costs of some AC products do not differ significantly from the diesel cost, which makes them a great alternative. Also, surprisingly, some AC products have a similar (or close) flashpoint value to diesel.

TABLE 4.1
Evaluation criteria selected for Task 3

Criteria	Variable
Economical	Cost ($/gallon)
Environmental	Biodegradability
Safety	Flash point (°F)

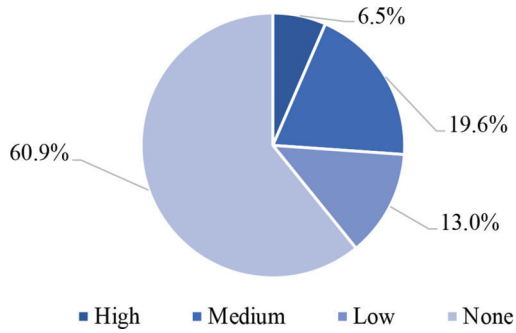


Figure 4.2 Responsiveness level from manufacturers in Task 3.

Figure 4.1 Task 3 roadmap.

TABLE 4.2
Final AC list in Task 3

Manufacturer	Product
Karnak	709 KARNA-KLEAN
CHEMSEARCH	Naturalizer VC
Acme Chemex Inc.	Chemex 602 Hi Flash Organic Asphalt Sol
Ecolink	ATR Hi-Flash
Rhomer Industries	Rhoma-Sol
Biosystems, Inc.	Bio Pro HF Citrus Asphalt Cleaner
BioSystems Inc.	BIO PRO HF
Suncoast Research Labs, Inc.	Citrus King Extraction Testing Solvent
SMC Technologies Inc.	Orange Power Plus
Franmar Chemical	BEAN.e-doo
Acme Chemex Inc.	Chemex 609 Hi-Flash
Rochester Midland Corporation	Neugenic 4175 CA
Florachem Corp	Florasolv LHF-W
Zack's, Inc.	Zacks Citrus Pine Asphalt Remover
ChemStation	ChemStation 7273
ChemStation	ChemStation 43931
Astec Corp	Hisol Plus
K & L Supply	Paversol
3236 Enterprises LLC	Orosolve Biodegradable Tar and Asphalt Solvent
JACO Industrial Supply	Citra Solv
ChemTek	PavePro Green
ChemStation	ChemStation 8286

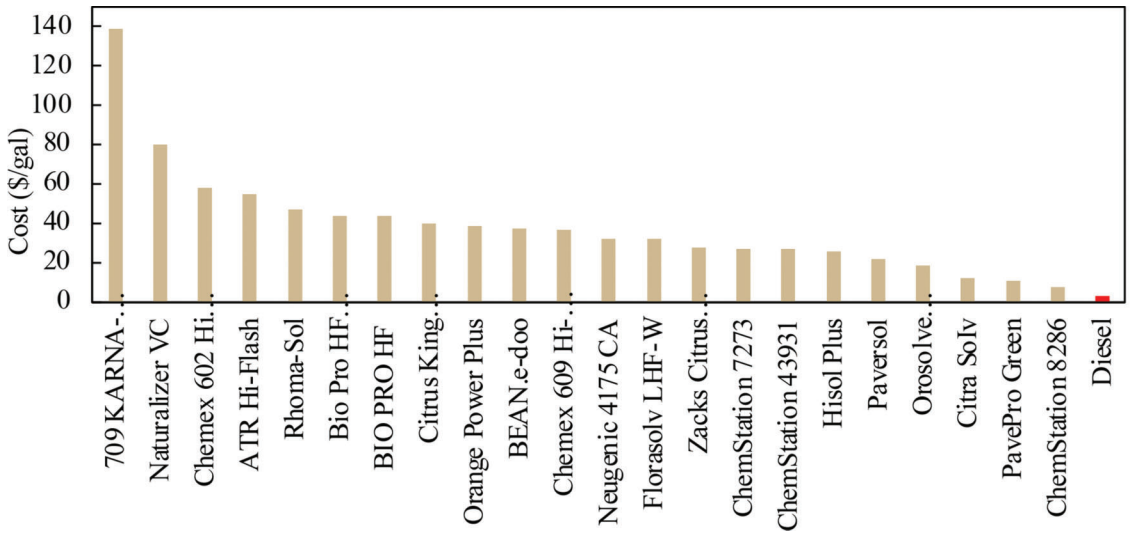


Figure 4.3 Cost distribution of the listed AC products in Task 3.

Once the data was obtained, a scoring system was developed to evaluate AC products based on economic, environmental, and safety criteria, Table 4.3. The diesel price and flashpoint were considered as thresholds. As can be seen in the table, for the final score, each score is multiplied by a weight (default is 1/3 in this case, meaning that each group has the same importance). Regarding final score calculation, INDOT users can select the weight associated with each score based on their priorities, opinions, and application areas. For the economical and safety criteria, where the cost and flash point can be a wide range of numbers, the equation presented in Table 4.3 shows only the maximum and minimum values; therefore, all values that fall in between will obtain a proportional score. In addition, if no information is provided on a specific criterion for a product, the criterion score is automatically a 0.

4.2 Data Analysis

The descriptive statistics of the score results (including diesel) of each evaluation criteria for listed AC products are provided in Table 4.4. Table 4.5 also shows detailed evaluation criteria statistics for listed AC products.

The economical and safety score distributions can be found in Figure 4.5 and Figure 4.6. The total score

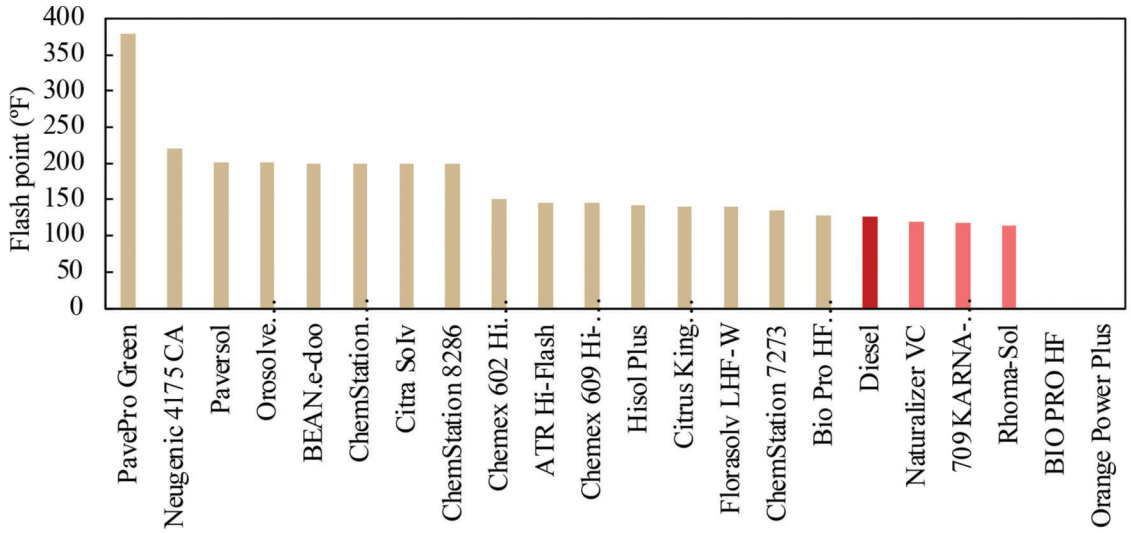


Figure 4.4 Flash-point distribution of the listed AC products in Task 3.

TABLE 4.3
Score calculation formulas for AC evaluation criteria

Group Criterion	Score Calculation Formula
Economical	$\begin{cases} 100 - \dfrac{Cost\left(\dfrac{\$}{Gallon}\right) - \dfrac{\$3.28}{Gallon}(Diesel\ cost)}{Highest\ AC\ cost - \dfrac{\$3.28}{Gallon}(Diesel\ cost)} * 100 \\ If\ cost = \text{“}not - provided\text{”},\ Cost = Highest\ AC\ cost \end{cases}$
Environmental	$\begin{cases} If\ it\ is\ biodegradable;\ Environmental\ score = 100 \\ If\ it\ is\ not\ biodegradable\ or\ information\ is\ not\ provided; \\ Environmental\ score = 0 \end{cases}$
Safety	$If\ flash\ point \le 126^\circ F\ OR\ Flash\ point = \text{“}not - provided\text{”};\ Safety\ score = 0$ $If\ flash\ point > 126^\circ F;$ $Safety\ score = \dfrac{Flash\ point(^\circ F) - 126^\circ F(Diesel\ flash\ point)}{400^\circ F - 126^\circ F(Diesel\ flash\ point)} * 100$
Final Score	$Final\ score = Environmental_{Score} * W_{Environmental} + Economical_{Score} * W_{Economical} + Safety_{Score} * W_{safety}$

TABLE 4.4
Statistical data of the score results for each group in Task 3

Parameter	Economical Score	Environmental Score	Safety Score	Final Score
Max	100.00	100.00	92.70	96.51
Min	68.54	0.00	0.00	33.33
Mean	87.77	95.45	19.27	67.50
Standard Deviation	7.35	21.32	27.09	12.98

distribution (with the same weight) is shown in Figure 4.7. As shown, diesel has the lowest final score among all products due to its non-biodegradability aspect and the safety concern, even though it scores 100 points based on economic criteria. The best product in the list corresponds to PavePro Green with a score of 96.51 points. However, this might change in the future if new products are added to the list.

4.3 Conclusion

In this task, the objective was to identify effective and commercially available AC products. An initial list of 45 products from the state's DOTs lists and manufacturers was generated, but due to the lack of responsiveness from the manufacturers, the list had to be reduced to 22 products. The evaluation criteria were defined based on

TABLE 4.5
Detailed evaluation criteria statistics for listed AC products

Manufacturer	Product	Economical Score	Environmental Score	Safety Score	Total
–	Diesel	100	0	0	33.3
Rhomer Industries	Rhoma-Sol	82.12	100	0	60.7
ChemTek	PavePro Green	96.84	100	92.7	96.5
Zack's, Inc.	Zacks Citrus Pine Asphalt Remover	89.88	100	0	63.3
Biosystems, Inc.	Bio Pro HF Citrus Asphalt Cleaner	83.33	100	0.7	61.4
Acme Chemex Inc.	Chemex 602 Hi Flash Organic Asphalt Sol	77.61	100	8.8	62.1
Acme Chemex Inc.	Chemex 609 Hi-Flash	86.21	100	6.9	64.4
Astec Corp	Hisol Plus	90.7	100	5.8	65.5
Ecolink	ATR Hi-Flash	78.82	100	6.9	61.91
Florachem Corp	Florasolv LHF-W	88.24	100	5.1	64.4
Rochester Midland Corporation	Neugenic 4175 CA	88.13	100	34.3	74.14
Suncoast Research Labs, Inc.	Citrus King Extraction Testing Solvent	84.96	100	5.1	63.4
BioSystems Inc.	BIO PRO HF	83.33	100	0	61.1
SMC Technologies Inc.	Orange Power Plus	85.44	100	0	61.8
Franmar Chemical	BEAN.e-doo	86.03	100	27	71
CHEMSEARCH	Naturalizer VC	68.54	100	0	56.2
JACO Industrial Supply	Citra Solv	96.26	100	73	89.8
K & L Supply	Paversol	92.33	100	27.4	73.2
3236 Enterprises LLC	Orosolve Biodegradable Tar and Asphalt Solvent	93.6	100	72.6	88.7
ChemStation	7273	90.29	100	3.6	64.6
ChemStation	8286	98.07	100	27	75
ChemStation	43931	90.29	100	27	72.4

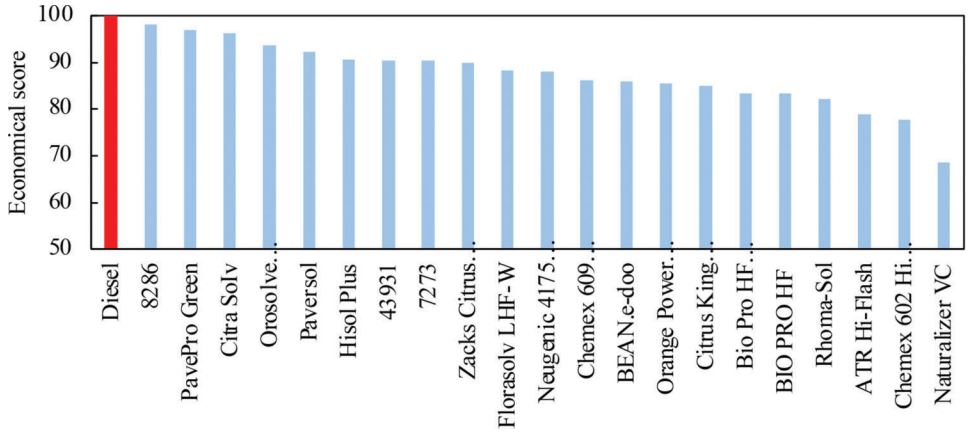


Figure 4.5 Economical score distribution of the listed AC products in Task 3.

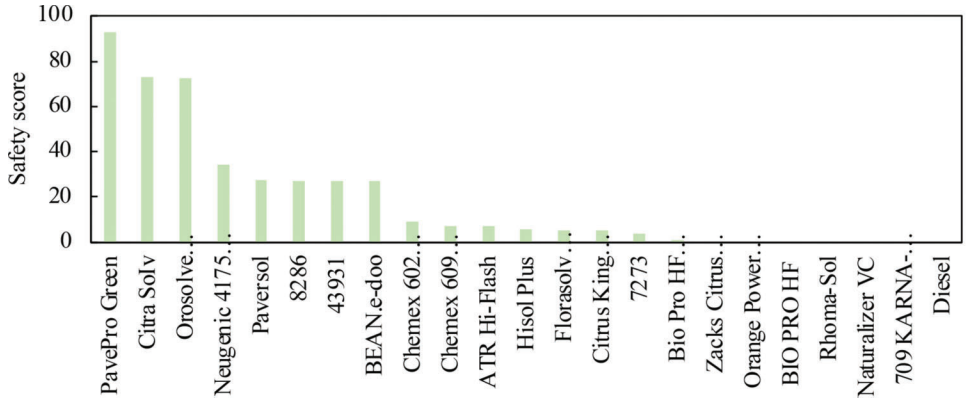


Figure 4.6 Safety score distribution of the listed AC products in Task 3.

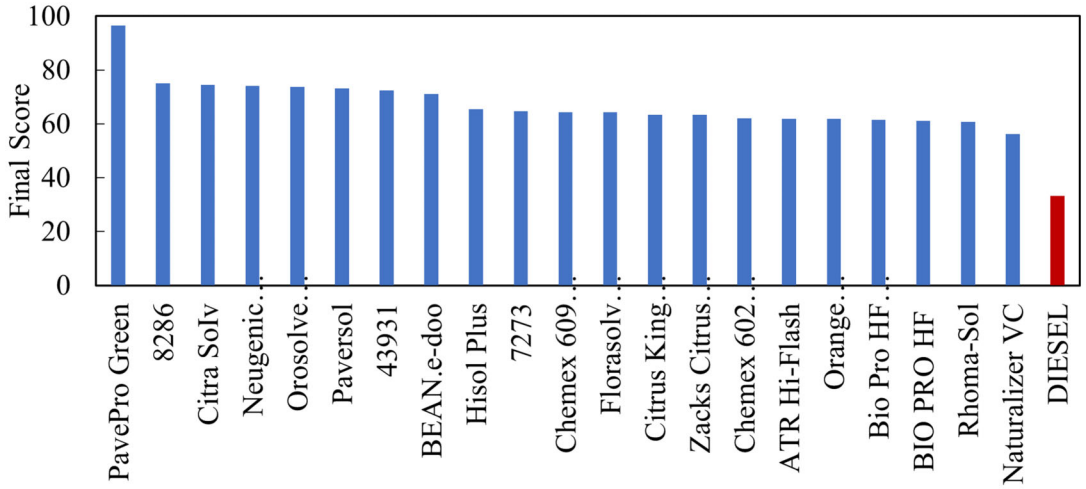


Figure 4.7 Final score distribution of the listed AC products in Task 3.

economic, environmental, and safety considerations, representing cost ($/gallon), biodegradability, and flash-point. Diesel was also added as one of the most frequently used AC products. The scoring system was then developed to identify the most effective products. The results show that diesel has the lowest value (33.33 out of 100 points) compared to all studied AC products, indicating that diesel is not the best option to choose when looking for ACs, at least in terms of the economical, safety, and environmental aspects.

5. TASK 4: DEVELOP AND DISTRIBUTE A SURVEY TO UNDERSTAND THE PREFERENCES OF STATE DOTS AND PAVING CONTRACTORS FOR THE APPROVED ARAs AND ACs

Previous tasks mainly focused on collecting related data and information about ARA and AC products from NTPEP, DOT websites, and manufacturers. This task aims to obtain feedback from users of these products. To do so, a comprehensive survey was developed and distributed among potential respondents. Figure 5.1 illustrates an overview task roadmap, including survey development, pilot testing, survey distribution, and responses analysis.

5.1 Survey Development

Based on the findings and lessons learned from Tasks 1–3, a comprehensive survey was developed to obtain user opinion and feedback on ARA and AC products that they have experience using in paving tasks within their agencies. Specifically, given that DOTs listed several approved ARAs, the company might only use a few products in practice due to their preferences or prior experiences. The survey consists of five main sections: (1) introduction, (2) demographics, (3) ARA-related questions, (4) AC-related questions, and (5) additional comment sections. The introduction section provides a brief overview of the research so that respondents are instructed and introduced to the project. After that, a few demographic questions are included to customize the following questions based on this information.

The ARAs section concentrates on the questions about the used ARAs products, the evaluation criteria, targets (e.g., truck beds, tools, and paving equipment), best practices, and the disposal and precaution practices. Sixteen selected ARA products (i.e., the most commonly listed products by DOTs as seen in Figure 3.6) are listed as options for respondents to choose from, and also they can insert additional products that are not listed. Noteworthy, due to the observed confusion about diesel application in the literature, it was intentionally incorporated into one option, even though it cannot be regarded as an ARA. Then, five suggested ARA evaluation criteria (i.e., functionality, safety, environmental, cost-effectiveness, ease of use, see Table 5.1) are involved in this survey for respondents to rank generally and concerning each selected product. Last, practiced precautions (e.g., regulatory problems and waste-stream management such as a disposal, reusing, and recycling) were investigated.

In the AC section, 21 selected AC products (i.e., most commonly listed products by DOTs—see Figure 4.7) (+ diesel) are listed as options for respondents to select, while also they can insert additional products that are not listed; and then similar questions were asked to examine user feedback regarding these products and the general opinion about the importance of listed evaluation criteria. Although ARAs are utilized to avoid the adhesion of HMA, part of HMA would inevitably adhere to truck beds or paving equipment. This common phenomenon necessitates the combination of using different products. For instance, the contractor might apply an ARA to prevent the adhesion at first and use an AC or diesel to remove the remaining HMA. The last section includes questions regarding

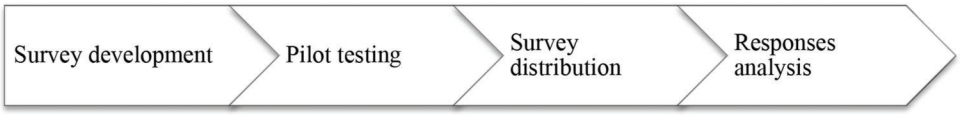


Figure 5.1 Task 4 roadmap.

TABLE 5.1
The definition of the five criteria used in the survey

Criteria	Definition
Functionality	In terms of no adhesion of asphalt and no damages to asphalt or equipment
Environment	Not detrimental to the soil, underwater, ocean, etc.
Cost-effectiveness	In terms of reasonable cost, associated dilution ratio, and the number of times the applied product can be reused (pull number)
Safety	In terms of no concerns regarding fire or other associated hazards when being used by workers
Ease of Use	The extent to how easily the product is being used and how easily the process is understood

best practices of using the combination of ARAs and ACs and additional feedback they would like to share.

The survey is developed using (survey link: https://purdue.ca1.qualtrics.com/jfe/form/SV_8AIlixW3dRhQ6H4), which is an online survey tool allowing users to build, distribute, and analyze surveys. The questionnaire is provided in Appendix B. The questionnaire and research process are approved by Purdue Institutional Review Board (IRB).

5.2 Pilot Testing

Before being sent to all respondents, the survey was pilot tested among our research team and SC members, who were asked to provide comments, feedback on the survey questions, and report any issues that needed to be revised.

5.3 Survey Distribution

The survey was distributed via email with an explanatory cover letter and a link to a web-survey, and two follow-up reminder emails were sent every 3 weeks. In addition, the research team visited the websites of the state's Asphalt Association to collect the contact information of paving contractors and material labs. INDOT helped distribute the survey to all the DOTs, paving contractors, and labs.

5.4 Response Analysis

A total of 44 responses (with 32 valid responses) were received (as of May 16, 2022). Invalid responses are from respondents who disagreed with the survey disclaimer or did not indicate their organizations. Figure 5.2 shows the organization overview of survey respondents. While DOTs' personnel were primary respondents, valuable feedback was obtained from paving contractors and other relevant companies (e.g., aramid fiber supply). Moreover, Figure 5.3 reveals the state geographical distribution of the respondents.

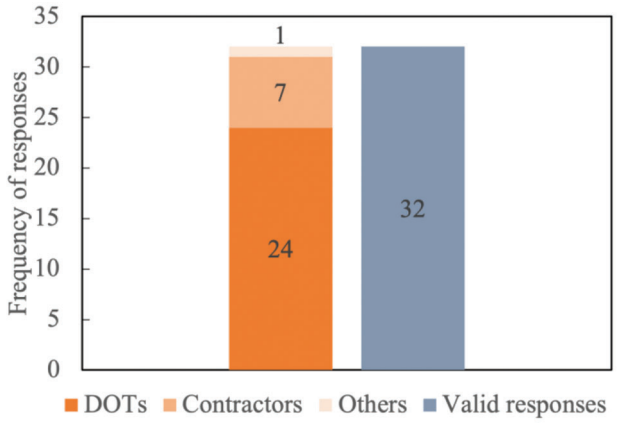


Figure 5.2 Organization overview of the survey respondents.

Noteworthy, all of the responses from Illinois varied in terms of the role of the person and the counties and were extremely helpful for this research. The survey responses were further analyzed to provide insights into the application of ARAs, ACs, and diesel.

5.4.1 ARA Products

5.4.1.1 Criteria prioritization. In the survey, respondents were asked to rank five criteria of products (i.e., functionality, environment, cost-effectiveness, safety, and ease of use) during their selection process of ARAs. Each organization might prioritize specific criteria based on its demands, requirements, and considerations. Also, this prioritization plays a significant role in the final selection of ARA products. Table 5.2 illustrates a summary of criteria prioritization by the respondents. Overall, functionality was ranked as the most important in ARA selection, followed by environmental, safety, cost-effectiveness, and ease of use criteria. This criteria prioritization genuinely reflected the decision-making of ARAs by organizations. These findings are incorporated into the dashboard development (Task 5).

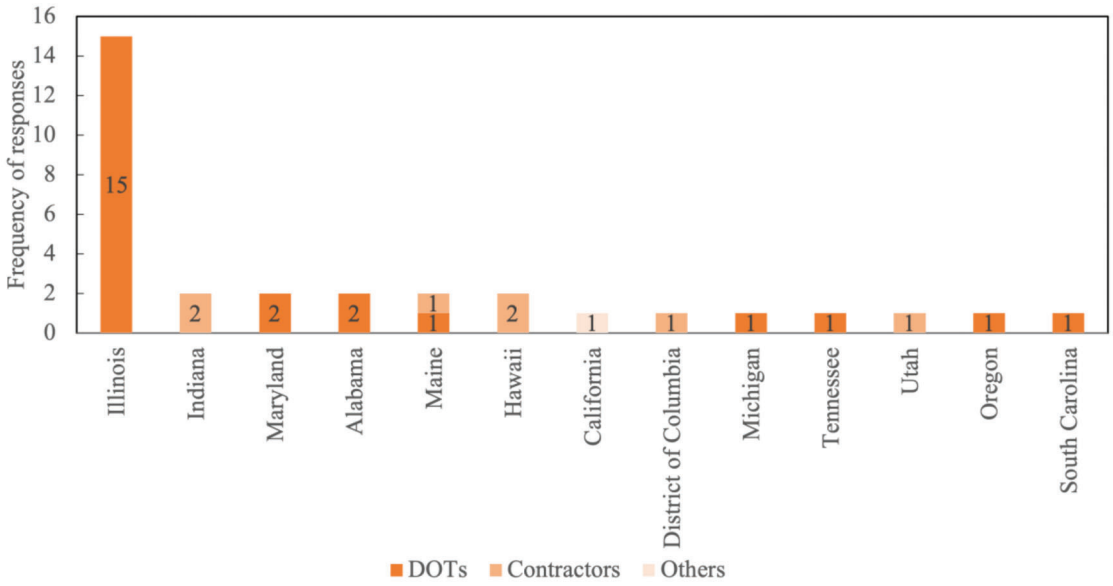


Figure 5.3 Geographical distribution of the survey respondents.

TABLE 5.2
Summary of ARA criteria prioritization by survey respondents

Criteria	Ranking 1st			2nd			3rd			4th			5th			Average Ranking		
Functionality	22^{T}			5^{T}			3^{T}			2^{T}			0^{T}			1.55^{T}		
	17^{D}	5^{C}	0^{O}	3^{D}	1^{C}	1^{O}	2^{D}	1^{C}	0^{O}	2^{D}	0^{C}	0^{O}	0^{D}	0^{C}	0^{O}	1.54^{D}	1.43^{C}	2.00^{O}
Environment	2^{T}			19^{T}			5^{T}			3^{T}			3^{T}			2.52^{T}		
	0^{D}	1^{C}	1^{O}	14^{D}	5^{C}	0^{O}	5^{D}	0^{C}	0^{O}	2^{D}	1^{C}	0^{O}	3^{D}	0^{C}	0^{O}	2.75^{D}	2.14^{C}	1.00^{O}
Cost-effectiveness	1^{T}			0^{T}			16^{T}			6^{T}			9^{T}			3.67^{T}		
	1^{D}	0^{C}	0^{O}	0^{D}	0^{C}	0^{O}	9^{D}	6^{C}	0^{O}	6^{D}	0^{C}	0^{O}	8^{D}	1^{C}	0^{O}	3.83^{D}	3.29^{C}	3.00^{O}
Safety	4^{T}			8^{T}			6^{T}			14^{T}			0^{T}			2.97^{T}		
	3^{D}	1^{C}	0^{O}	7^{D}	1^{C}	0^{O}	6^{D}	0^{C}	0^{O}	8^{D}	5^{C}	1^{O}	0^{D}	0^{C}	0^{O}	2.79^{D}	3.29^{C}	4.00^{O}
Ease of Use	3^{T}			0^{T}			2^{T}			7^{T}			20^{T}			4.30^{T}		
	3^{D}	0^{C}	0^{O}	0^{D}	0^{C}	0^{O}	2^{D}	0^{C}	0^{O}	6^{D}	1^{C}	0^{O}	13^{D}	6^{C}	1^{O}	4.08^{D}	4.86^{C}	5.00^{O}

Note: T = Total companies that reported the ranking, D = DOTs, C = Contractors, O = Other.

5.4.1.2 Product evaluation. Respondents were requested to report the ARA products that were actually being used in practice and evaluate the products based on the five criteria (i.e., functionality, environment, cost-effectiveness, safety, and ease of use). Table 5.3 provides a summary of ARA product evaluation. The evaluation represents the users' feedback on the products and is helpful for prospective users. These findings are also incorporated into the dashboard in Task 5. Six respondents mentioned using GreenGuard as ARA, but none of them reported their rationale and evaluation (the evaluation values are projected as "N/I" in Table 5.3). Interestingly, three respondents selected diesel as an ARA, indicating the confusion in the industry regarding the application of ARA and diesel. In terms of functionality, BMF asphalt release agent, 357, Ultra Slider, Loose Juice, TackSolv, 40019D, PavePro, Paverol, and Glideoff obtained higher scores. Therefore, these products could successfully prevent the adhesion of asphalts without damaging the mixture. Furthermore, BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B, Slider, DSC Asphalt Solvent, AR-125, and Bitra were less detrimental to the environment. In terms of cost-effectiveness, Super Slider, Loose Juice, 2217B, AR-125, and Bitra were evaluated to have an outstanding performance due to fair cost, dilution ration, and high pull number. In addition, BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B, Slider, DSC Asphalt Solvent, AR-125, and Bitra acquired superior safety scores. In terms of ease of use, higher scores were obtained by BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B,

TABLE 5.3
Summary of ARA product evaluation by survey respondents

Listed/Not Listed in the Survey	Product	Number of Entities that Reported the Use of the Product				
		DOT	Contractor	Other	Total	Report Evaluation
		Average Criteria Evaluation (0 not applicable/5 very high)				
		Functionality	Environment	Cost-Effectiveness	Safety	Ease of Use
Listed	BMF asphalt release agent	7 5	0 5	0 N/I	7 5	1 5
Listed	Super Slider	5 3.5	0 5	0 5	5 5	2 5
Listed	GreenGuard	6 N/I	0 N/I	0 N/I	6 N/I	0 N/I
Listed	No. 1	3 4.5	1 4	0 3.5	3 4	2 4.5
Listed	Super Slick	6 N/I	0 N/I	0 N/I	6 N/I	0 N/I
Listed	357	5 5	0 N/I	0 N/I	5 N/I	1 N/I
Listed	Avalanche	4 4.5	0 3	0 3	4 3	2 3
Listed	Ultra Slider	4 5	0 N/I	0 N/I	4 N/I	1 N/I
Listed	Loose Juice	5 5	0 5	1 5	6 5	1 5
Listed	Tack Solv	1 5	0 N/I	0 N/I	1 N/I	1 N/I
Listed	22169	5 N/I	0 N/I	0 N/I	5 N/I	0 N/I
Listed	8277	3 N/I	0 N/I	0 N/I	3 N/I	0 N/I
Listed	40019D	3 5	0 N/I	0 N/I	3 N/I	1 N/I
Listed	Black Magic	2 N/I	0 N/I	0 N/I	2 N/I	0 N/I
Listed	Popcorn Buster	3 N/I	0 N/I	0 N/I	3 N/I	0 N/I
Listed	Endurance HD	1 N/I	0 N/I	0 N/I	1 N/I	0 N/I
Listed	Diesel	2 3	1 2	0 2	3 3	2 5
Not Listed	Tuff Guy	1 4	0 4	0 4	1 4	1 4
Not Listed	ReleaseME	1 3	0 3	0 1	1 4	1 1
Not Listed	PavePro	1 5	0 5	0 3	1 5	1 5
Not Listed	2217B	1 3	0 5	0 5	1 5	1 5

TABLE 5.3
(Continued)

Listed/Not Listed in the Survey	Product	Number of Entities that Reported the Use of the Product				
		DOT	Contractor	Other	Total	Report Evaluation
		Average Criteria Evaluation (0 not applicable/5 very high)				
		Functionality	Environment	Cost-Effectiveness	Safety	Ease of Use
Not Listed	Release It	1 3	0 3	0 3	1 3	1 4
Not Listed	Formula 1	1 N/I	0 N/I	0 N/I	1 N/I	0 N/I
Not Listed	Paverol	0 5	1 4	0 3	1 4	1 5
Not Listed	Glideoff	0 5	1 4	0 3	1 4	1 5
Not Listed	Slider	0 4	1 5	0 1	1 5	1 5
Not Listed	DSC Asphalt Solvent	0 4	1 5	0 1	1 5	1 5
Not Listed	Slip-Tec	1 3	0 3	0 3	1 3	1 3
Not Listed	AR-125	1 1	0 5	0 5	1 5	1 5
Not Listed	Bitra	1 4	0 5	0 5	1 5	1 5

N/I = No information was provided by respondents.

Paverol, Glideoff, Slider, DSC Asphalt Solvent, AR-125, and Bitra. These rankings are based on the responses obtained in this study.

5.4.1.3 ARA targets and disposal approach. During the asphalt paving tasks, workers may encounter the issues that asphalts adhere to the truck bed, paving equipment/tools, and are strenuous to remove. ARA is a practical solution to tackle the problem by generating a barrier between asphalt binders and the entities. Table 5.4 indicates that ARAs are mainly used for truck beds, paving tools, and equipment targets.

In response to the question regarding the ARA disposal approach incorporated within their agencies. Most respondents revealed that their organizations did not take any proactive strategies or precautions because ARAs are assumed to be environmentally friendly. So, any overspray would be either left onsite or reused in the future.

5.4.2 AC Products

5.4.2.1 Criteria prioritization. Table 5.5 shows the summary of AC criteria prioritization by respondents. Functionality was ranked the most significant evaluation criterion for selecting AC products, followed by environment, economical, safety, and ease of use. The criteria prioritization of ACs is highly similar to the counterpart for ARAs. These findings are incorporated into developing an interactive dashboard (Task 5).

TABLE 5.4
Summary of the targets for using ARAs

Target	DOT	Contractor	Other	Total
Truck Bed	12	3	1	16
Truck Body	1	1	0	2
Paving Equipment	10	3	1	14
Paving Tool	12	3	1	16

5.4.2.2 Product evaluation. Table 5.6 demonstrates the summary of AC products evaluation. While diesel is known for its functionality and low cost, there are various environmental and safety concerns regarding its usage. Unexpectedly, its functionality and economical scores were not superior to the environment and safety scores, based on the evaluations conducted by respondents. In terms of functionality, PavePro Green, HD Cleaner, and Bio Solv obtained a higher score, which means they can be easily used to remove the adhered asphalts. HD Cleaner and Bio Solv were products with less harmful environmental impacts. HD Cleaner acquired a higher economical score, having a lower cost. Regarding safety, HD Cleaner and Bio Solv were ranked with higher scores. Diesel, HD Cleaner, and Bio Solv obtained a higher score in ease of use, representing that users can readily utilize them and realize their using processes. These rankings are based on the responses received in this study.

TABLE 5.5
Summary of AC criteria prioritization by survey respondents

Criteria	Ranking	1st			2nd			3rd			4th			5th			Average Ranking		
Functionality		28^{T}			0^{T}			3^{T}			1^{T}			0^{T}				1.28^{T}	
	21^{D}	6^{C}	1^{O}	0^{D}	0^{C}	0^{O}	2^{D}	1^{C}	0^{O}	1^{D}	0^{C}	0^{O}	0^{D}	0^{C}	0^{O}	1.29^{D}	1.29^{C}	1.00^{O}
Environment		0^{T}			24^{T}			5^{T}			1^{T}			2^{T}				2.41^{T}	
	0^{D}	0^{C}	0^{O}	17^{D}	6^{C}	1^{O}	4^{D}	1^{C}	0^{O}	1^{D}	0^{C}	0^{O}	2^{D}	0^{C}	0^{O}	2.50^{D}	2.14^{C}	2.00^{O}
Economical		1^{T}			2^{T}			22^{T}			2^{T}			6^{T}				3.34^{T}	
	1^{D}	0^{C}	0^{O}	0^{D}	1^{C}	1^{O}	16^{D}	5^{C}	1^{O}	2^{D}	0^{C}	0^{O}	5^{D}	1^{C}	0^{O}	3.42^{D}	3.14^{C}	3.00^{O}
Safety		3^{T}			6^{T}			1^{T}			22^{T}			1^{T}				3.44^{T}	
	2^{D}	1^{C}	0^{O}	6^{D}	0^{C}	0^{O}	1^{D}	0^{C}	0^{O}	15^{D}	6^{C}	1^{O}	1^{D}	0^{C}	0^{O}	3.38^{D}	3.57^{C}	4.00^{O}
Ease of Use		1^{T}			1^{T}			1^{T}			6^{T}			23^{T}				4.53^{T}	
	1^{D}	0^{C}	0^{O}	1^{D}	0^{C}	0^{O}	1^{D}	0^{C}	0^{O}	5^{D}	1^{C}	0^{O}	16^{D}	6^{C}	1^{O}	4.42^{D}	4.86^{C}	5.00^{O}

Note: T = Total companies that reported the ranking, D = DOTs, C = Contractors, O = Other.

5.4.2.3 AC targets and disposal approach. According to Table 5.7, ACs have been primarily used to clean the remained asphalts from truck beds, paving equipment, and paving tools. Regarding the disposal, respondents mentioned that the used strategies would depend on whether the AC contained dangerous materials. For example, one respondent reported that the ACs were disposed of as hazardous wastes, while others stated that the AC products could be easily washed off since they were biofriendly. While three respondents reported diesel as the main product being used, none of the respondents provided their strategies for waste-stream management.

Considering that ARAs are designed to prevent the adhesion beforehand, and ACs and diesel are used to clean the asphalt remnants after the adhesion, organizations might combine two or three products to address the problem of asphalt adhesion. Specifically, Table 5.8 indicates the summary of product combinations used by the respondents. As can be seen, diesel is still widely used in paving projects, although it is illegal and hazardous.

A few respondents willingly shared additional feedback, as shown in Table 5.9. They repeatedly mentioned the difficulty in stimulating users to utilize ARAs and ACs instead of diesel. Users insisted on using diesel due to its functionality and cheapness, although DOT respondents have endeavored to promote other alternatives. Most of the ARAs and ACs were considered either less effective or too expensive to afford for organizations.

5.5 Conclusion

This task aimed to obtain paving industry feedback on selected ARAs and ACs, and evaluation criteria. A survey was designed and distributed among DOTs and paving contractors, and the responses provided valuable insights for INDOT or prospective users to select the most appropriate ARAs and ACs. Respondents ranked functionality as the most important criterion in evaluating and selecting ARA and AC products, followed by environment, safety, cost-effectiveness, and ease of use. Among listed ARA products, BMF asphalt release agent, 357, Ultra Slider, Loose Juice, TackSolv, 40019D, PavePro, Paverol, and Glideoff were rated with the highest functionality value; BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B, Slider, DSC Asphalt Solvent, AR-125, and Bitra were rated with the highest environmental value; Super Slider, Loose Juice, 2217B, AR-125, and Bitra were rated with highest cost-effectiveness value; BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B, Slider, DSC Asphalt Solvent, AR-125, and Bitra were rated with the highest safety value; and BMF asphalt release agent, Super Slider, Loose Juice, PavePro, 2217B, Paverol, Glideoff, Slider, DSC Asphalt Solvent, AR-125, and Bitra were rated with the highest ease of use value.

Among listed AC products, PavePro Green, HD Cleaner, and Bio Solv were rated with the highest functionality value; HD Cleaner and Bio Solv were rated with the highest environmental value; HD Cleaner was rated with the highest economical value; HD Cleaner and Bio Solv were rated with the highest safety value; and diesel, HD Cleaner, and Bio Solv were rated with the highest ease of use value. However, the respondents also shared their concerns about the use of diesel by contractors /subcontractors regardless of all their efforts. They suggested considering monetary penalties and calling for products that are less costly but effective. The findings of Tasks 1–4 are then used to develop the interactive dashboard in the next chapter.

TABLE 5.6
Summary of AC product evaluation by survey respondents

Listed/Not Listed in the Survey	Product	The Number of Entities that Reported the Use of the Product				
		DOT	DOT	DOT	DOT	DOT
		Average Criteria Evaluation (0 not applicable/5 very high)				
		Functionality	Functionality	Functionality	Functionality	Functionality
Listed	Diesel	2 3.33	1 2.67	0 3	3 3	3 5
Listed	Rhoma-Sol	4 3.5	0 3.25	0 2.5	4 3.75	4 3.75
Listed	PavePro Green	2 5	1 3	0 1.67	3 4.33	3 4.67
Listed	Bio Pro HF Citrus Asphalt Cleaner	1 N/I	0 N/I	0 N/I	1 N/I	0 N/I
Listed	Hisol Plus	1 3.5	1 2	0 3	2 3	2 4
Listed	Citrus King Extraction Testing Solvent	2 4	0 2	0 3.5	2 3.5	2 3.5
Listed	Orange Power Plus	1 4	0 4	0 4	1 4	1 4
Not Listed	Solvitall ATR	1 N/I	0 N/I	0 N/I	1 N/I	0 N/I
Not Listed	PaveForce	1 N/I	0 N/I	0 N/I	1 N/I	0 N/I
Not Listed	New Pig Degreaser	1 1	0 3	0 2	1 4	1 2
Not Listed	Tuff Stuff	1 1	0 3	0 2	1 4	1 2
Not Listed	Bitu Sol	1 2	0 2	0 3	1 3	1 3
Not Listed	RTU Orange	1 2	0 2	0 3	1 3	1 3
Not Listed	HD Cleaner	0 5	0 5	1 5	1 5	1 5
Not Listed	Bio Solv	0 5	1 5	0 1	1 5	1 5

Note: N/I = No information was provided by respondents.

TABLE 5.7
Summary of the targets of using ACs

Target	DOT	Contractor	Other	Total
Truck Bed	10	2	0	12
Truck Body	3	1	0	4
Paving Equipment	8	3	0	11
Paving Tool	9	3	1	13

Note: Other = The companies that are not either DOTs or contractors.

TABLE 5.8
Summary of the product combination used by organizations

Combination	DOT	Contractor	Other	Total
ARA + AC + Diesel	7	1	0	8
ARA + AC	4	1	0	5
ARA + Diesel	1	1	1	3
AC + Diesel	0	0	0	0
ARA	1	0	0	1
AC	0	0	0	0
Diesel	0	0	0	0

Note: Other = The companies that are not either DOTs or contractors.

TABLE 5.9
Summary of additional feedback shared by survey respondents

Additional Feedbacks
"Diesel is commonly used for so long, readily available; it will be difficult to stop using. I have tried for many years to get HMA producers to switch from diesel to truck [asphalt] release with no success. Needs to be a monetary disincentive involved with diesel use."
"These [ARA/AC] products work well and are safe for the environment, but they are very expensive to use."
"We strive to find an environmentally friendly and cost-effective product that actually works. The contractors like to use diesel because it is cheap, it works, and is readily available. We do not allow it to use because of its adverse impacts on the HMA itself, but that does not stop all contractors from trying to use. I would think that if a product that is safe and just as effective as diesel was identified, most contractors would use it even if it came at a slightly higher cost."
"PavePro works the best (better than diesel) but is very expensive to use."

6. TASK 5: SYNTHESIZE THE RESULTS TO DEVELOP AN INTERACTIVE DECISION-MAKING DASHBOARD FOR ARA AND AC SELECTION

The final task of the project consisted of synthesizing the findings of Tasks 1–4 to (1) identify the top ARA and AC products that will serve INDOT as a basis to conduct field tests and (2) to develop an interactive decision-making dashboard that encompasses all findings of the project and help INDOT (and future users) to make a more informed decision regarding selecting ARA and AC products. The dashboard was developed by Excel Macros & VBA, as shown in Figure 6.1.

A dashboard is essentially a tool that was prepared for INDOT to help with the process of selecting the most effective ARA and AC products. The developed dashboard can help users obtain organized information with minimal effort, leading to better decision-making. This dashboard has two main sections: ARAs and ACs; including a general dashboard, individual product dashboard, database visualization, and a form to add new products. The user will only need to choose the desired weights for each criterion, and the scoring system will automatically adjust the products, presenting the ranking and top five products. This scoring system is explained in Chapter 2 for ARAs and Chapter 4 for ACs. The associated user guide or manual of the dashboard is provided in Appendix A (and separately).

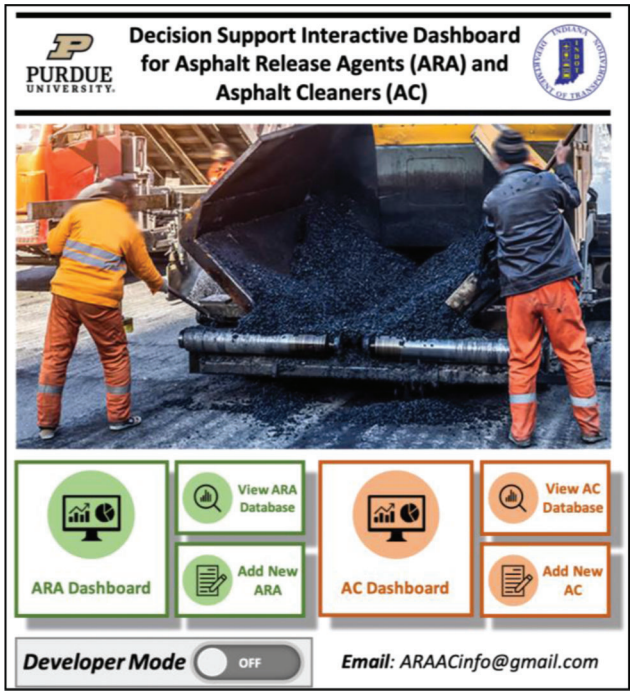


Figure 6.1 Overview of dashboard developed in Task 5 (a detailed description is provided in Appendix A).

7. CONCLUSION

HMA is a mixture of aggregate and asphalt binder extensively used for paving highways, runways, parking lots, and many other pavements. The asphalt binder sticks tightly to truck beds, tools, and paving equipment in its fresh state, making these difficult and inconvenient to clean. For this purpose, diesel has been widely used as an asphalt remover due to its low price, availability, and effectiveness. However, its use is no more acceptable due to the negative consequences it presents to the environment. Besides, even though diesel is very effective at dissolving remnants of asphalt, it must be noted that it is a solvent for the asphalt binder. Therefore, diesel is also detrimental to the performance of HMA. Indeed, the use of diesel as a solvent was banned more than 40 years ago. Since diesel is illegal, harmful to the environment, and exposes workers to health and safety risks, identifying effective alternatives is paramount. Currently, there are plenty of commercially available products that can be used in place of diesel. However, determining the most appropriate ones is not easy and needs further investigation.

Based on various qualitative and quantitative analyses, the present project provides a comprehensive list of effective ARA and AC products to help INDOT (or other stakeholders) (1) evaluate available products based on their requirements and preferences, and (2) select the most appropriate product/s on the market for follow-up field testing. The analyses were based on the information derived from NTPEP test results, DOTs websites, manufacturers' data, and surveys to obtain various perspectives of different organizations and users. Lastly, an interactive dashboard was developed to support the decision-making of ARAs and ACs for INDOT. Here, INDOT or any authorized users can assign a weight to different criteria based on their opinions/preferences and obtain a comprehensive list (with associated manufacturer's info) of the top five appropriate/effective/commercially available products. Besides, admin users can add new products, edit existing ones or delete expired products for further evaluations.

A few limitations to note—first, due to the low responsiveness level of manufacturers, the research team defined a penalization mechanism for the products without sufficient information. Second, the scope of this project is limited to products listed by NTPEP or provided by DOTs and some manufacturers. Third, while several reminder emails were sent out, some DOTs mentioned that they are not willing to participate or they do not have enough information because the contractors/subcontractors are the ones who select ARAs and ACs. To address these limitations, the dashboard includes a developer mode so the current database can be edited, or new products can be added to expand the database.

In conclusion, this study synthesizes the information from product suppliers (i.e., manufacturers), product users (i.e., survey respondents), and governmental organizations (i.e., NTPEP and DOTs). As survey results indicated, HMA stakeholders (especially contractors) are more willing to use diesel due to its lower price than ARAs or ACs, effectiveness, and availability. Although its use is not allowed by DOTs, contractors still use it because they strive to find an environmentally friendly, cost-effective, and efficient product. It was suggested to apply a monetary disincentive to stop use by HMA producers. Besides, it was mentioned that contractors could accept the use of a releasing agent as long as the cost is not significantly higher than diesel, and the product is identified as safe and effective. Thus, this study and the proposed dashboard can serve as a guide for others. Finally, it is noteworthy how the best product on the list proposed after the analysis of this study was mentioned as the product that works best among HMA stakeholders. Therefore, this synthesis provides an exhaustive comprehension of ARAs and ACs and a decision-making dashboard for INDOT to choose the most satisfactory products to use in Indiana.

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APPENDICES

Appendix A. Interactive Decision Support Dashboard for Asphalt Release Agents (ARA) and Asphalt Cleaners (AC)—User Guide

Appendix B. Survey

APPENDIX A. INTERACTIVE DECISION SUPPORT DASHBOARD FOR ASPHALT RELEASE AGENTS (ARA) AND ASPHALT CLEANERS (AC)—USER GUIDE

A.1 Introduction

This user guide is part of the *Synthesis Study on Best Practices of Cleaning Tools and Paving Equipment: Asphalt Release Agents (ARA) and Asphalt Cleaners (AC)* project (RNS Title: SPR-4652). In this project, a decision-making dashboard for ARA and AC products was developed using Microsoft Excel. This user guide aims to help the user to understand and utilize the dashboard at its full potential. For more information on this project, please refer to the full report or email ARAACinfo@gmail.com. INDOT has the authority to share, update, modify, and/or distribute the decision support dashboard generated in this study. INDOT also has full control of the dashboard's contact email address (ARAACinfo@gmail.com) and credentials for dashboard use.

A.2 Main Menu

The main menu consists of four parts: (a) ARA dashboard, (b) AC dashboard, (c) developer mode activation, and (d) contact information (see Figure A.1).

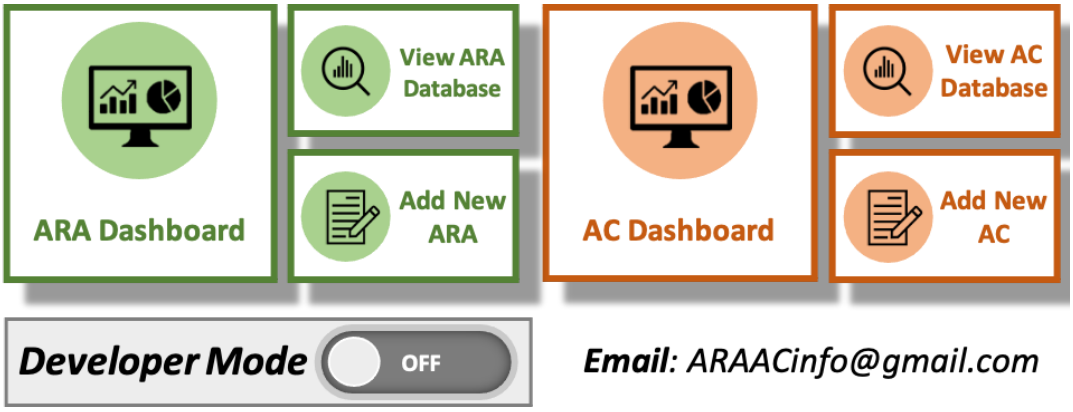


Figure A.1 Main menu.

A.3 ARA Dashboard

When the users click on the button referring to the *ARA dashboard* in the main menu, they will get redirected to the ARA dashboard. This dashboard showcases all the relevant information related to the ARA products presented in the report. The full ARA dashboard is shown in Figure A.2.

Note: Data from these products was collected from the NTPEP website, DOTs, and the manufacturers (for more information, see *Task 1–4* of the report).

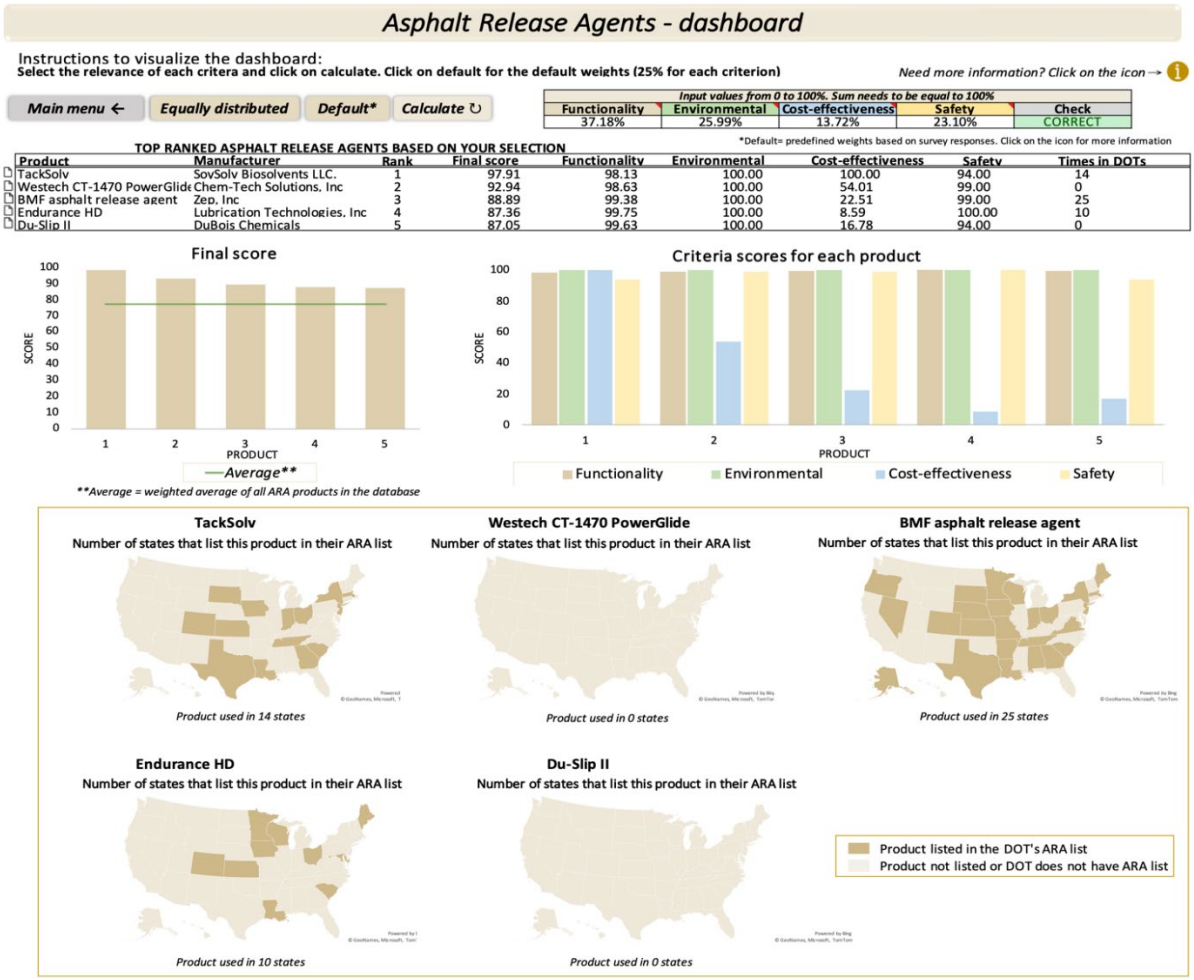


Figure A.2 ARA dashboard.

A.3.1 How to Use the Dashboard

To use the dashboard, follow the following steps.

1. *Change the weights* in the following table according to the relevance to the use.

Input values from 0 to 100%. Sum needs to be equal to 100%				
Functionality	**Environmental**	**Cost-effectiveness**	**Safety**	**Check**
37.13%	**26.71%**	**14.33%**	**21.82%**	CORRECT

Note: The percentages must sum up to 100%. Otherwise, the information on the dashboard will be incorrect.

Note: If the user hovers over each criterion with the mouse, a pop-up window will appear to explain that criteria.

2. *Click calculate* to refresh the data shown in the dashboard according to the user's weight input. The user may also *click default,* which will calculate using the default weights (Table A.1); and *equally distributed,* which will calculate with equal distribution for the weights (25% for each criterion).

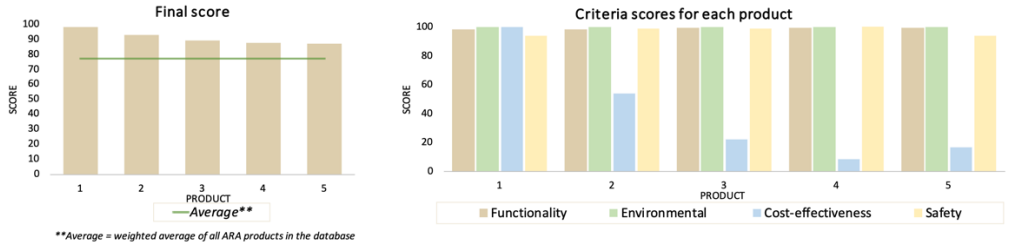
Note: There is also the "Main menu" button to go back to the main menu page.

Note: The default weights were obtained from the developed survey (*Task 4*) and are shown in Table A.1.

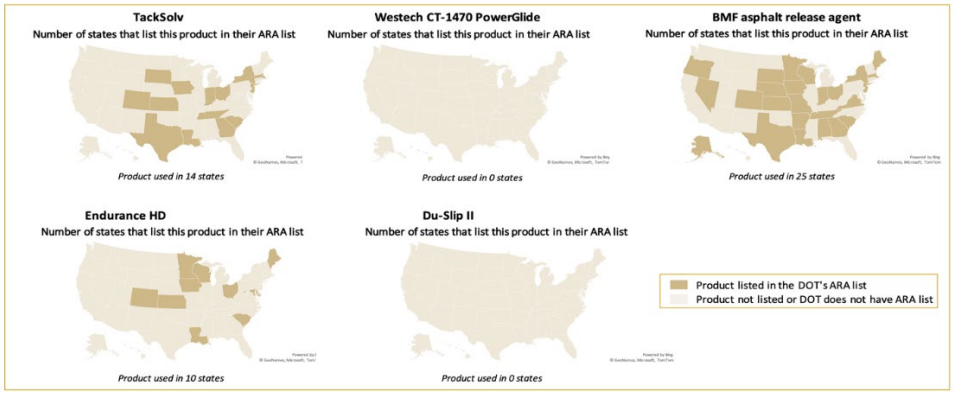
Table A.1 Default weights for the ARA dashboard

Functionality	Environmental	Cost-effectiveness	Safety
37.13%	26.71%	14.33%	21.82%

3. After calculating the desired weights, the *Top 5 Ranked ARAs* will appear as part of the results in table format. In this table, the user will be able to see the following: *product, manufacturer, rank, final score, functionality score, environmental score, cost-effectiveness score, safety score, and how many times this product appears in other DOTs' ARA lists* (see Figure A.2).
4. The information is also presented in *graphical visualizations* to facilitate comprehension. The *final scores* (on the left) for the top 5 products are shown to compare them with have threshold line of the weighted average of all ARA products in the database. Also, the four *criteria scores for each product* (on the right) are presented.



5. Underneath the graphs, the U.S. maps demonstrate the *geographical distribution* of each listed product as well as the *number of states that list each product in their ARA list*.



6. For more product information, the user can *click on the document icon on the left side of any product's name* to view the product data. This function will redirect the user to each product page, as shown in Figure A.3.

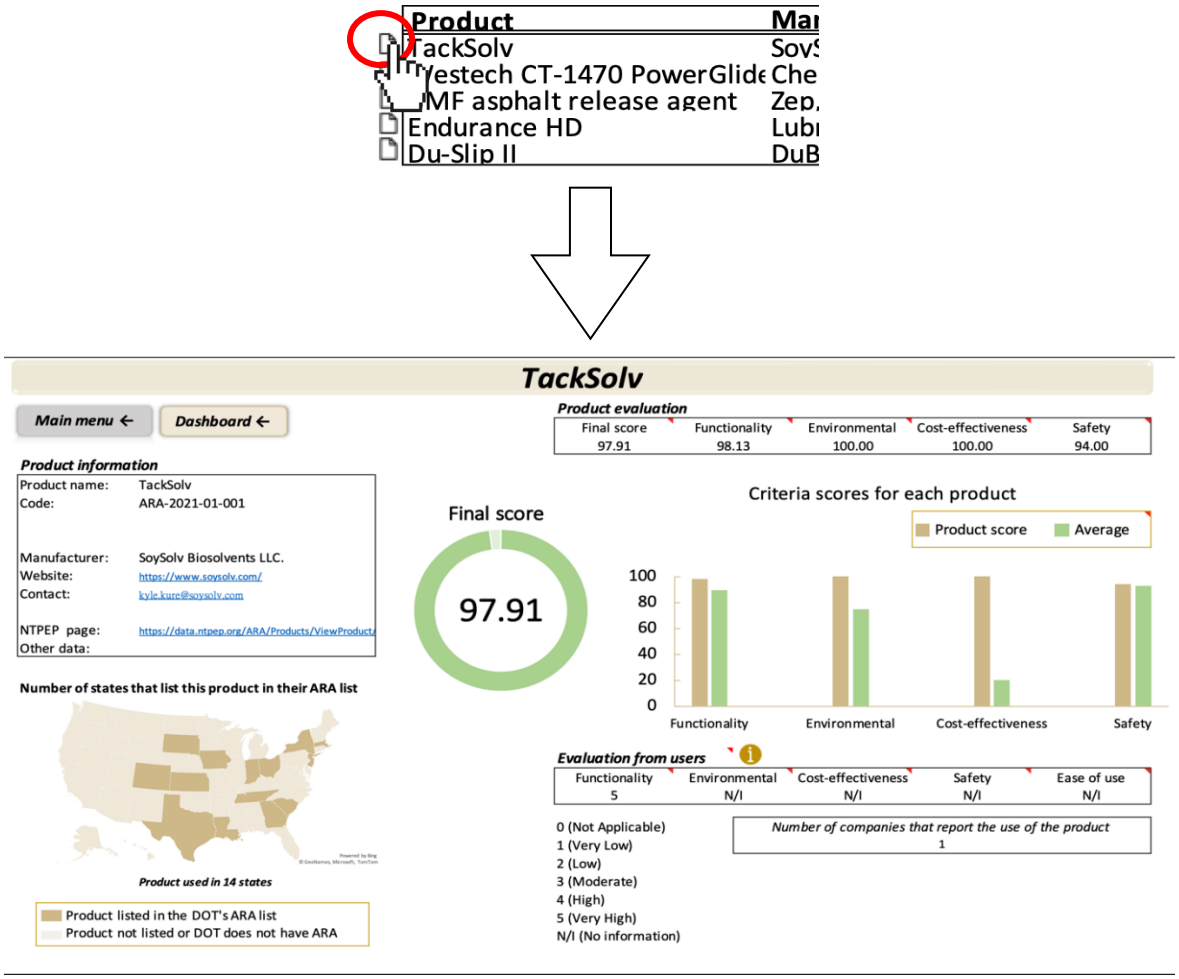


Figure A.3 ARA product dashboard.

The user can check the product evaluation on the individual product page, with the final score calculated based on the input weights; and the *assessment results obtained from the users* via the survey. Also, holistic information about the *product manufacturer, contact, websites, number of companies that report the use of the product, number of states that list the product in their lists, and NTPEP codes* are provided.

7. If the user wants to go back to either the ARA dashboard or the main menu of the program, they can do so by clicking on the top-left buttons.

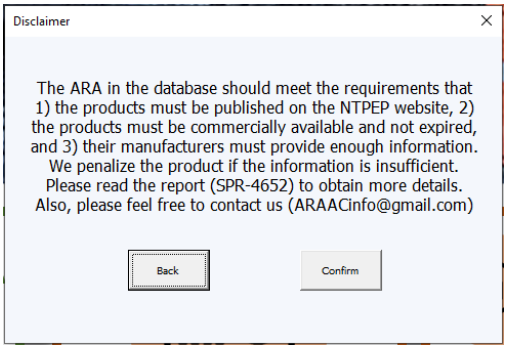
8. If the user wants more information on any aspect of the project, clicking on the information icon present on each page will redirect the user to the full report of the project, with this guide as an appendix.

9. To go back to the initial screen, the user has to click on the "Main menu" button.

A.3.2 How to View the ARA Database

To view the ARA database inside the program, follow the following steps.

1. Click on the "View ARA Database" icon on the main menu page.
2. Once the user clicks the icon, a pop-up screen with a *disclaimer* will appear. This disclaimer explains what products are eligible to be in the database and are about to visualize. If the user is satisfied with this, *click "Confirm" to continue to the ARA database.* If not, the user can *click "Back" to go back to the main menu.* In addition, this screen provides the email for more inquiries.



3. If the user clicks Confirm, they will be redirected to the *full ARA database,* where all data will be shown for visualization (see below).

Main Menu

Edit Data

Product	Manufacturer	Code	Year
Super Slick	*Arrow Magnolia International*	ARA-2019-04-002	2019
ChemStation 22169	*ChemStation*	ARA-2019-02-011	2019
ChemStation 8442	*ChemStation*	ARA-2018-04-006	2018
Westech CT-1470 PowerGlide	*Chem-Tech Solutions, Inc*	ARA-2019-03-002	2019
TA-200 GS Asphalt Solutions	*DeltaGreen Products, Inc*	ARA-2019-03-001	2019
Du-Slip II	*DuBois Chemicals*	ARA-2020-01-016	2020
Slick EM 5000	*DuBois Chemicals*	ARA-2019-02-003	2019
Slick EM HF	*DuBois Chemicals*	ARA-2020-01-001	2020
Slipcoat-IRC	*Global Barrier Services*	ARA-2020-01-008	2020
slipARAy	*Kop-Coat Protection Products*	ARA-2021-01-007	2021
Endurance HD	*Lubrication Technologies, Inc*	ARA-2019-02-001	2019
Avalanche 2022	*Meyer Lab*	ARA-2022-01-002	2022
Super Slider	*Meyer Lab*	ARA-2020-01-017	2020
Ultra Slider	*Meyer Lab*	ARA-2020-01-003	2020
TackSolv	*SoySolv Biosolvents LLC.*	ARA-2021-01-001	2021
BMF asphalt release agent	*Zep, Inc*	ARA-2021-01-010	2021

At this point, the user can scroll from left to right to view all data imported from the NTPEP (test data, codes, year, etc.), cost and other information provided by the manufacturer, contact information, the evaluation, and scores for each criterion, user evaluation, etc.

4. After visualizing the database, the user can go back to the main menu by *clicking on the "Main menu" icon* in the top left corner of the database.

A.3.3 How to Add a New ARA to the Database

There are two routes to follow in order to add a new ARA product to the database.

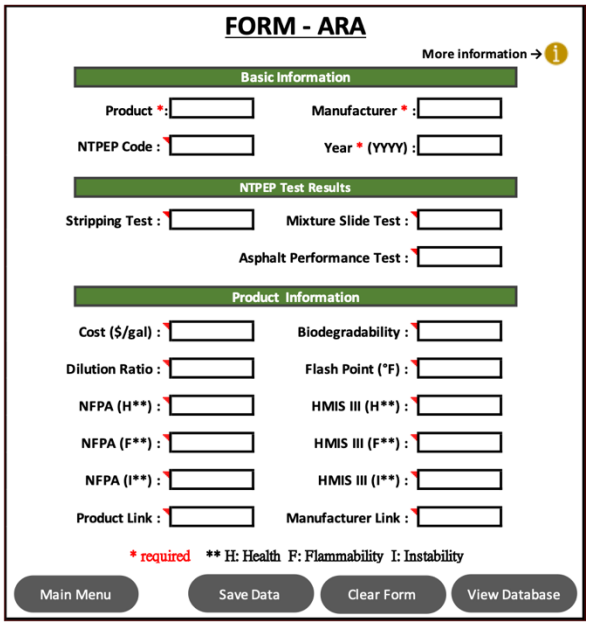
The *first* one is through the ARA database, following these steps.

1. There is an icon underneath the main menu button in the ARA database that says, *"Edit Data.*" When the user clicks, it will redirect to a login window.
2. This login window will ask for a *username* and a *password* to enable the user to freely edit the database. These credentials are *confidential (shared in a separate document with INDOT)*; please contact ARAACinfo@gmail.com or INDOT.

3. If the username and password are incorrect, a pop-up window will appear after clicking the "*Login*" button. This will also clear the text box to let the user try again. The button "*Clear*" will also clear all the textbox for easier use.
4. If the credentials are correct, the user will be redirected to the ARA database visualizer, but this time, the entire sheet will be editable. The user can now add rows or edit any aspect of any product.

The *second* way to add a new ARA product to the database is through the "Add New ARA" button.

1. First, the user must *click the "Add New ARA" button* from the main menu page. This will redirect the user to the same *user login screen* after clicking the *Edit Data* icon. Once the credentials have been verified, the system will take the user to the next screen.
2. The next screen will be a *form (ARA–see figure below)* to complete. This form includes all the needed information for the ARA database to successfully add and evaluate the new product.



The form includes *basic information, test data, and product information.*

The only *required fields* are product name, manufacturer, and year. Therefore, new products can be added without any more data being input. However, this will severely penalize the product, as the system will not be able to evaluate it properly and will take the default values (see full report for this information).

Once the information is added, the user can click on "*Save Data*" to add this product to the database.

Note: If no information is added in any non-required field, the system will automatically fill it with N/A.

3. If the user makes a mistake during the completion of the form, all cells can be cleared by *clicking the "Clear Form" button*.
4. At this point, the user can view the ARA database by *clicking "View Database."* The new product will be added to the last row of the list and all the provided information.
5. To go back to the main menu, *click "Main Menu."*

A.4 AC Dashboard

The AC (Asphalt Cleaner) Dashboard is similar to the ARA Dashboard shown in the previous section.

In order to access it, the user needs to *click on the AC Dashboard icon* located on the *Main Menu page*. This button will redirect the user to the complete AC Dashboard, including all the information needed to select most effective AC product. The AC Dashboard is shown in Figure A.4.

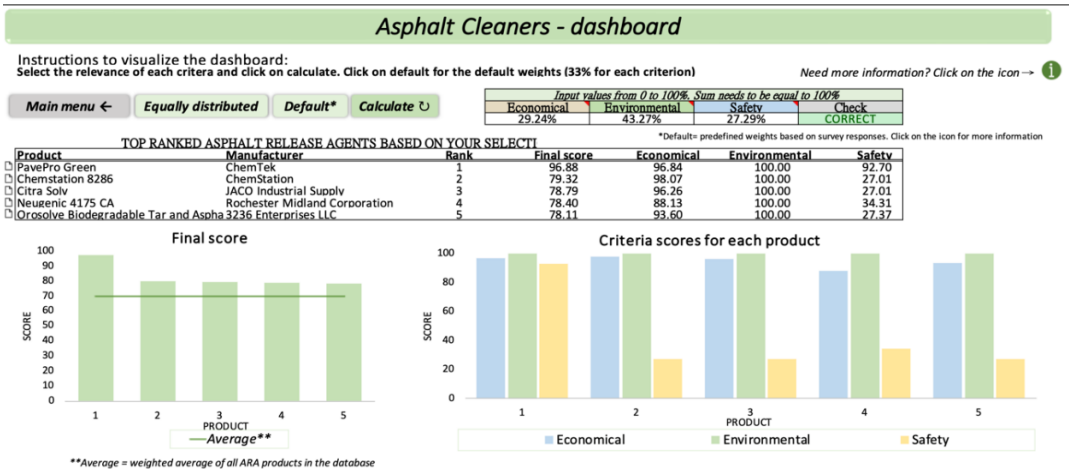


Figure A.4 AC dashboard.

A.4.1 How to Use the Dashboard

To correctly use the dashboard, follow the next steps.

1. First, *select the desired weights* from the weight table.

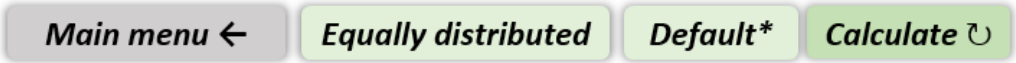
Input values from 0 to 100%. Sum needs to be equal to 100%			
Economical	**Environmental**	**Safety**	**Check**
33.00%	33.00%	33.00%	CORRECT

Note: This table requires the weight of the economic, environmental, and safety criteria. For more information on the criteria selection, please refer to *Task 3* on the report.

Note: The percentages must sum up to 100%. Otherwise, the information on the dashboard will be incorrect.

Note: If the user hovers over each criterion with the mouse, a pop-up window will appear to explain each criterion.

2. *Click calculate* to refresh the data shown in the dashboard according to the user's weight input. The user may also *click default,* which will calculate using the default weights (Table A.2), and *equally distributed,* which will calculate with equal distribution for the weights (25% for each criterion).

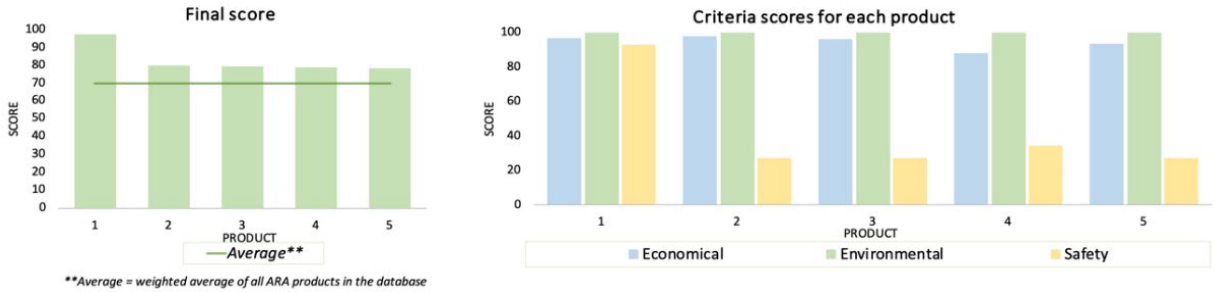


Note: There is also a "Main menu" button to go back to the main menu screen.

Table A.2 Default weights for the AC dashboard

Economical	Environmental	Safety
29.63%	43.92%	26.46%

3. After *calculating* the desired weights, the Top 5 Ranked AC will appear as part of the results in table format. In this table, the user will see *the product, manufacturer, rank, final score, economical score, environmental score, and safety score* (see Figure A.4).
4. The information is also presented in *graphical form* to facilitate comprehension. The *final scores* (on the left) for all top products are shown for comparison with the threshold line based on the weighted average of all AC products in the database. Also, the *four criteria scores for each product* (on the right) are presented.



5. For more product information, the user can *click on the document icon on the left of any product's name* to view the product data. This function will redirect the user to the individual dashboard of the product, which is shown in Figure A.5.

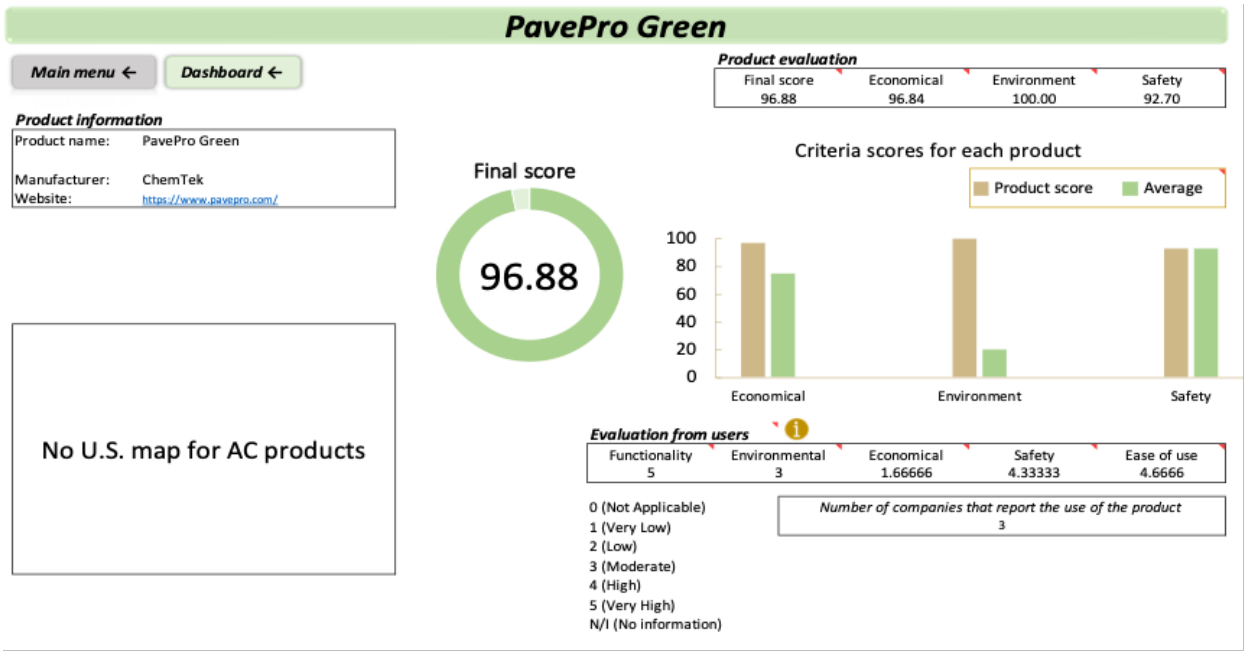


Figure A.5 AC individual dashboard.

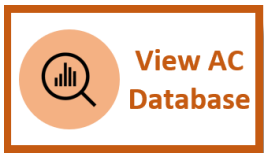
In this individual dashboard, the user will be able to visualize the *product evaluation,* with the final score calculated based on the input weights; and the *evaluation results obtained from the users* via the survey. Also, information on the *product manufacturer, websites, and the number of states that report the use of the product* are provided.

6. If the user wants to go back to either the AC dashboard or the main menu of the program, they can do so by clicking on the top-left buttons.

7. If the user wants more information on any aspect of the project, clicking on the information icon present on each screen will redirect the user to the full report of the project, with this guide as an appendix.

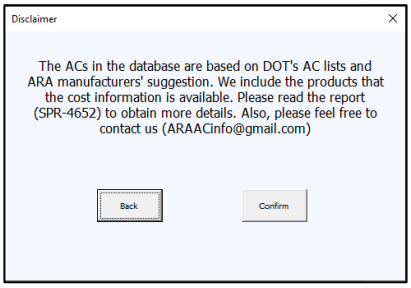
8. To go back to the initial screen, the user has to click on the main menu.

A.4.2 How to View AC Database



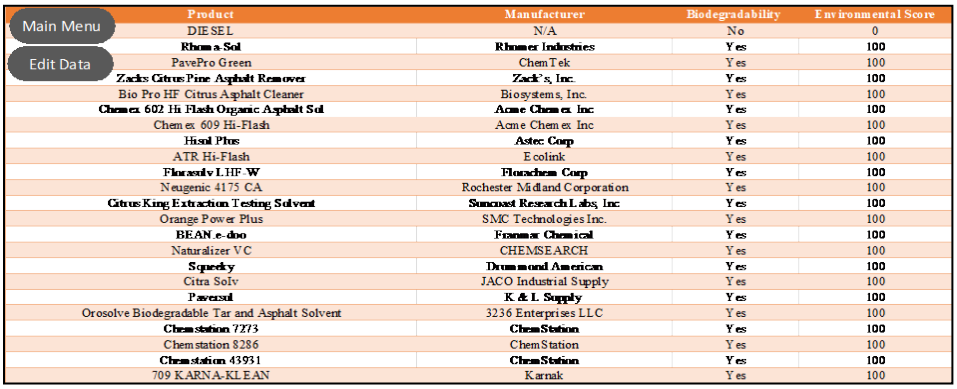
To view the Asphalt Cleaners database inside the program, follow the following steps.

1. *Click on the View AC Database* icon in the main menu.
2. Once the user clicks the icon, a pop-up screen with a *disclaimer* will appear. This disclaimer explains what products are eligible to be in the database. If the user is satisfied with this, *click "Confirm" to continue to the AC database.* If not, the user can *click "Back" to go back to the main menu*. In addition, this screen provides the email address for more inquiries.



3. If the user clicks *"Confirm,"* they will be redirected to the *full AC database*, where all data will be shown for visualization. An example of this visualization is presented in Figure A.6.

At this point, the user can scroll from left to right to view all data, such as cost, biodegradability, flash point, the evaluation and scores for each criterion, user evaluation, etc.



Product	Manufacturer	Biodegradability	Environmental Score
DIESEL	N/A	No	0
Rhoma-Sol	**Rhomer Industries**	**Yes**	**100**
PavePro Green	ChemTek	Yes	100
Zacks Citrus Pine Asphalt Remover	**Zack's, Inc.**	**Yes**	**100**
Bio Pro HF Citrus Asphalt Cleaner	Biosystems, Inc.	Yes	100
Chemex 602 Hi Flash Organic Asphalt Sol	**Acme Chemex Inc**	**Yes**	**100**
Chemex 609 Hi-Flash	Acme Chemex Inc	Yes	100
Hisol Plus	**Astec Corp**	**Yes**	**100**
ATR Hi-Flash	Ecolink	Yes	100
Fluxsolv LHF W	**Fluxchem Corp**	**Yes**	**100**
Neugenic 4175 CA	Rochester Midland Corporation	Yes	100
Citrus King Extraction Testing Solvent	**Suncoast Research Labs, Inc**	**Yes**	**100**
Orange Power Plus	SMC Technologies Inc.	Yes	100
BEAN-e-doo	**Franmar Chemical**	**Yes**	**100**
Naturalizer VC	CHEMSEARCH	Yes	100
Squeeky	**Drummond American**	**Yes**	**100**
Citra Solv	JACO Industrial Supply	Yes	100
Paversol	**K & L Supply**	**Yes**	**100**
Orosolve Biodegradable Tar and Asphalt Solvent	3236 Enterprises LLC	Yes	100
Chemstation 7273	**ChemStation**	**Yes**	**100**
Chemstation 8286	ChemStation	Yes	100
Chemstation 43931	**ChemStation**	**Yes**	**100**
709 KARNA-KLEAN	Karnak	Yes	100

Figure A.6 AC database.

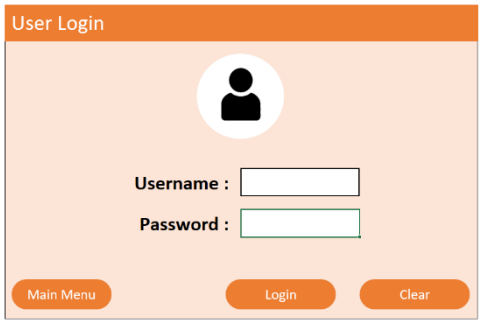
4. After viewing the database, the user can go back to the main menu by *clicking on the "Main menu" icon* on the top left corner of the database.

A.4.3 How to Add a New AC to the Database

There are two routes to follow to add a new AC product to the database.

The first one is through the AC database; the steps are the following.

1. In the AC database, there is an icon underneath the main menu button that says, "*Edit Data*" (see Figure A.6). When the user clicks, it will redirect to a login window.

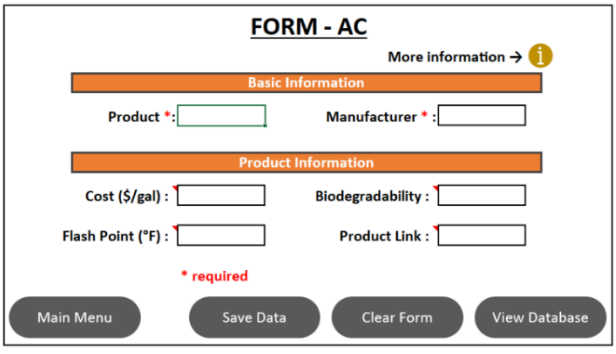


   This login window will ask for a *username* and a *password* to enable the user to freely edit the database. These credentials are *confidential*; please contact ARAACinfo@gmail.com or INDOT.

2. If the username and password are incorrect, a pop-up window will appear after clicking the "*Login*" button. This will also clear the text box to let the user try again. The button "*Clear*" will also clear all the textboxes.
3. If the credentials are correct, the user will be redirected to the AC database visualizer, but this time the entire sheet will be editable. The user can now add rows or edit any aspect of any product.

The second way to add a new AC product to the database is through the "*Add New AC button*":

1. First, the user must click the "*Add New AC*" button *from the main menu screen*. Once the credentials have been verified, the system will take the user to the next screen.
2. The next screen will be a *form (AC–see figure below)* to complete. This form includes all the needed information for the AC database to successfully add and evaluate the new product.



   The form includes *basic information, test data, and product information.*

   The only required fields are *product name and manufacturer.* Therefore, new products can be added without any more data being input. However, this will severely penalize the product, as the system will not be able to evaluate it properly and will take the default values (for more information, see *Task 3* on the report).

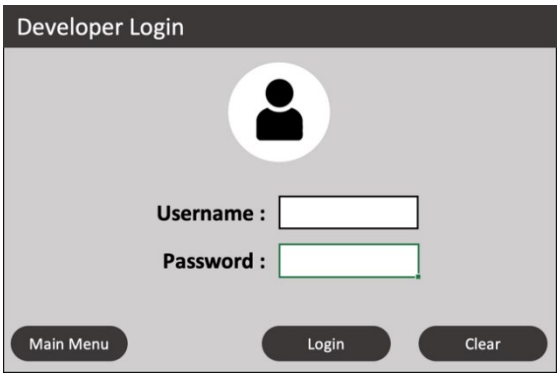
Once the information is added, the user can click on "*Save Data*" to add this product to the database.

Note: If no information is added in any non-required field, the system will automatically fill it with N/A.

3. If the user makes a mistake during the completion of the form, all cells can be cleared by *clicking the "Clear Form" button.*
4. At this point, the user can view the AC database by *clicking "View Database."* The new product will be added to the last row of the list, along with the information provided.
5. To go back to the main menu, simply *click "Main Menu."*

A.5 Developer Mode

In the Main Menu screen, there is a button underneath the dashboard controls that enables the *"Developer Mode."* By default, this mode will always be switched off to prevent users from modifying any aspect of the dashboard coding.



Note: When the Developer Mode is *off*, the user is only *allowed to edit the unprotected cells that have been pre-defined in this guide so far.* On the contrary, when the Developer Mode is *on*, the user can *fully edit the complete excel file and the coding of the dashboard.*

A.5.1 How to Turn on the Developer Mode

1. The user must click the *switch button* in the *Main Menu*. This will redirect to a login window.

This login window will ask the user for a *username* and password to activate the *Developer Mode*. These credentials are confidential, and only INDOT representatives can provide them (ARAACinfo@gmail.com).

2. If the username and password are incorrect, a pop-up window will appear stating so after clicking the *"Login"* button. This will also clear the text box to let the user try again. The button *"Clear"* will also clear all the textboxes.
3. If the credentials are correct, the user will be redirected to the "Main Menu" page, but this time, the entire excel file will be unlocked. Also, all the sheets will be viewable. The user can now entirely modify the design and coding of this decision-making dashboard.

Note: The Developer Mode is automatically switched off once going back to Main Menu.

A.6 Contact Information

Please contact the *INDOT representative listed below* or ARAACinfo@gmail.com to obtain the dashboard, login credentials, and more information. Contact information for the INDOT representatives and Purdue investigators are provided below.

INDOT

- Barry Partridge (BPARTRIDGE@indot.in.gov)
- Michael Lane (mlane1@indot.in.gov)
- Matt Kraushar (mkraushar@indot.in.gov)

Purdue University

- Sogand Hasanzadeh (sogandm@purdue.edu)
- Mirian Velay (mvelayli@purdue.edu)

Note: Please indicate your organization and the purpose of obtaining information in the email.

APPENDIX B. SURVEY

B.1 Demographic Information

Q1: Please select an organization from the following list you are working with?
- Department of Transportation (DOT)
- Paving contractors
- Material labs
- Other, please specify

Q2: Does your work position include any of the following responsibilities and/or oversight of other employees who have the following responsibilities?
Jobsite safety supervision / management
- Personally responsible
- Oversight of other
- None

Paving or other asphalt related task
- Personally responsible
- Oversight of other
- None

Q3: Which state is your company located in?
- All 50 states + D.C.

Q4: Which group does your state belong to?
- *Group 1 (DOTs with ARA list):* Alabama, Alaska, Colorado, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Missouri, Nebraska, Nevada, New, Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Virginia, Wisconsin, Wyoming
- *Group 2 (DOTs without ARA list):* Arizona, California, Connecticut, Delaware, D.C., Florida, Hawaii, Idaho, Kentucky, Michigan, Mississippi, Montana, New Hampshire, North Dakota, Pennsylvania, Utah, Vermont, Washington, West Virginia.

B.2 Asphalt Release Agent (ARA)

(This question is seen when respondents select DOT in Q1)
Q5: Are you aware of any ARA list published by your DOT?
- Yes
- No

(This question is seen when respondents select DOT in Q1 and Group1 in Q4)
Q6: Please provide the link of the ARA list.

(This question is seen when respondents select Yes in Q5)
Q7: How often does your DoT update its ARA list?
- Monthly
- Twice per year

- Yearly
- Other, please specify
- I do not know

Q8: Please rank based on the extent to which these criteria are considered in the selection process of ARA within your company/agency (With 1 as the most important selection criteria and 5 as the least important selection criteria).
- Functionality
- Environmental
- Cost-effectiveness
- Safety
- Ease of use

(This question is seen when respondents select DOT in Q1)
Q9: Which of the following ARAs are being used by paving contractors/material labs in your state? Please select all that apply.
- Super Slick (Arrow Magnolia International)
- Black Magic (BG Chemical)
- GreenGuard (BG Chemical)
- Loose Juice (BG Chemical)
- 22169 (ChemStation)
- 40019D (ChemStation)
- 8277 (ChemStation)
- 357 (ChemTek Inc.)
- Popcorn Buster (Industrial Chem Solution Inc.)
- Endurance HD (Lubrication Technologies Inc.)
- Avalanche (Mayer Lab)
- Super Slider (Mayer Lab)
- Ultra Slider (Mayer Lab)
- TackSolv (SoySolv Biosolvents LLC.)
- BMF asphalt release agent (Zep Inc.)
- NO. 1 (Zep Inc.)
- Diesel
- Other 1
- Other 2
- Other 3
- I do not know

(This question is seen when respondents DO NOT select DOT in Q1)
Q10: Which of the following ARAs are being used by your company or institution? Please select all that apply.
- Super Slick (Arrow Magnolia International)
- Black Magic (BG Chemical)
- GreenGuard (BG Chemical)
- Loose Juice (BG Chemical)
- 22169 (ChemStation)
- 40019D (ChemStation)

- 8277 (ChemStation)
- 357 (ChemTek Inc.)
- Popcorn Buster (Industrial Chem Solution Inc.)
- Endurance HD (Lubrication Technologies Inc.)
- Avalanche (Mayer Lab)
- Super Slider (Mayer Lab)
- Ultra Slider (Mayer Lab)
- TackSolv (SoySolv Biosolvents LLC.)
- BMF asphalt release agent (Zep Inc.)
- NO. 1 (Zep Inc.)
- Diesel
- Other 1
- Other 2
- Other 3
- I do not know

(This question is seen when respondents select ANY PRODUCTS in Q9/Q10)
Q11: Please evaluate the ARA product (*the product has been selected in Q9/Q10*) based on the following criteria.

	0	1	2	3	4	5
	Not Applicable	Very Low	Low	Moderate	High	Very High
Functionality	O	O	O	O	O	O
Environmental	O	O	O	O	O	O
Cost-effectiveness	O	O	O	O	O	O
Safety	O	O	O	O	O	O
Ease of Use	O	O	O	O	O	O

Q12: What targets are ARAs being used for? Please select all that apply.
- Truck beds
- Truck body
- Paving equipment
- Paving tools
- Other

(This question is seen when respondents select DOT in Q1)
Q13: What are the disposal methods for ARAs waste that contractors in your state follow?

(This question is seen when respondents DO NOT select DOT in Q1)
Q14: What strategies does your company/agency incorporate for waste-stream management (disposal, reuse, recycle, etc.)?

B.3 Asphalt Cleaner (AC)

Q15: Please rank based on the extent to which these criteria are considered in the selection process of AC within your company/agency (With 1 as the most important selection criteria and 5 as the least important selection criteria).
- Functionality

- Environmental
- Economical
- Safety
- Ease of use

(This question is seen when respondents select DOT in Q1)
Q16: Which of the following ACs are being used by paving contractors/material labs in your state? Please select all that apply.
- Diesel
- Chemex 609 Hi Flash (Acme Chemex Inc.)
- Chemex 609 Hi Flash Organic Asphalt Sol (Acme Chemex Inc.)
- Hisol Plus (Astec Crop)
- Bio Pro HF (BioSystems Inc.)
- Bio Pro HF Citrus Asphalt Cleaner (BioSystems Inc.)
- Naturalizer VC (CHEMSEARCH)
- 43931 (ChemStation)
- 7273 (ChemStation)
- 8286 (ChemStation)
- Pave Pro Green (ChemTek Inc.)
- ATR Hi Flash (Ecolink)
- Florasolv LHF-W (Florachem Corp)
- BEAN. e-doo (Franmar Chemical)
- Citra Solv (JACO Industrial Supply)
- 709 KARNA-KLEAN (Karnak)
- Paversol (K&L Supply)
- Rhoma-Sol (Rhoma Industries)
- Neugenic 4175 CA (Rochester Midland Corporation)
- Orange Power Plus (SMC Technologies Inc.)
- Citrus King Extraction Testing Solvent (Suncoast Research Labs Inc.)
- Zacks Citrus Pine Asphalt Remover (Zack's Inc.)
- Other 1
- Other 2
- Other 3
- I do not know

(This question is seen when respondents DO NOT select DOT in Q1)
Q17: Which of the following ACs are being used by your company or institution? Please select all that apply.
- Diesel
- Chemex 609 Hi Flash (Acme Chemex Inc.)
- Chemex 609 Hi Flash Organic Asphalt Sol (Acme Chemex Inc.)
- Hisol Plus (Astec Crop)
- Bio Pro HF (BioSystems Inc.)
- Bio Pro HF Citrus Asphalt Cleaner (BioSystems Inc.)
- Naturalizer VC (CHEMSEARCH)
- 43931 (ChemStation)

- 7273 (ChemStation)
- 8286 (ChemStation)
- Pave Pro Green (ChemTek Inc.)
- ATR Hi Flash (Ecolink)
- Florasolv LHF-W (Florachem Corp)
- BEAN. e-doo (Franmar Chemical)
- Citra Solv (JACO Industrial Supply)
- 709 KARNA-KLEAN (Karnak)
- Paversol (K&L Supply)
- Rhoma-Sol (Rhoma Industries)
- Neugenic 4175 CA (Rochester Midland Corporation)
- Orange Power Plus (SMC Technologies Inc.)
- Citrus King Extraction Testing Solvent (Suncoast Research Labs Inc.)
- Zacks Citrus Pine Asphalt Remover (Zack's Inc.)
- Other 1
- Other 2
- Other 3
- I do not know

(This question is seen when respondents select ANY PRODUCTS in Q16/Q17)
Q18: Please evaluate the AC product (*the product has been selected in Q16/Q17*) based on the following criteria.

	0	1	2	3	4	5
	Not Applicable	Very Low	Low	Moderate	High	Very High
Functionality	O	O	O	O	O	O
Environmental	O	O	O	O	O	O
Economical	O	O	O	O	O	O
Safety	O	O	O	O	O	O
Ease of Use	O	O	O	O	O	O

Q19: What targets are ACs being used for? Please select all that apply.
- Truck beds
- Truck body
- Paving equipment
- Paving tools
- Other

(This question is seen when respondents select DOT in Q1)
Q20: What are the disposal methods for ACs waste that contractors in your state follow?

(This question is seen when respondents DO NOT select DOT in Q1)
Q21: What are the disposal methods for ACs waste that your company or institution follows?

(This question is seen when respondents select DOT in Q1)
Q22: What are the disposal methods for diesel waste that contractors follow in your state? Please explain any waste-stream management strategies (disposal, reuse, recycle, etc.) that may be incorporated.

(This question is seen when respondents DO NOT select DOT in Q1)
Q23: What are the disposal methods for diesel waste that your company or institution follows? Please explain any waste-stream management strategies (disposal, reuse, recycle, etc.) that may be incorporated.

(This question is seen when respondents select DOT in Q1)
Q24: If diesel is being used as an AC, what preventive measures do your contractors in your state take to reduce safety and environmental concerns?

(This question is seen when respondents DO NOT select DOT in Q1)
Q25: If diesel is being used as an AC, what preventive measures does your company or institution take to reduce safety and environmental concerns?

B.4 Additional Comments

(This question is seen when respondents select DOT in Q1)
Q26: What combinations of products do contractors in your state use?
- ARAs + ACs + Diesel
- ARAs + ACs
- ARAs + Diesel
- ACs + Diesel
- ARAs (only)
- ACs (only)
- Diesel (only)

(This question is seen when respondents DO NOT select DOT in Q1)
Q27: What combinations of products does your company or institution use?
- ARAs + ACs + Diesel
- ARAs + ACs
- ARAs + Diesel
- ACs + Diesel
- ARAs (only)
- ACs (only)
- Diesel (only)

Q28: Please provide any additional information related to (ARAs / ACs) or (effectiveness / environmental /economical / safety / ease of use) criteria that you think may be of interest of this research study.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

About This Report

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