NCHRP 20-44, TASK 01

Increasing WMA Implementation by Leveraging the State-Of-The-Knowledge

Prepared for:

NCHRP Project Panel 20-44

Prepared by:

Dr. Leslie McCarthy
Myers McCarthy Consulting Engineers LLC
5 Drew Circle
Newtown Square, PA 19073

Jo S. Daniel, Ph.D., P.E.
Lee Friess
University of New Hampshire
Durham, New Hampshire

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Mr. Harold Paul, Consultant
Dr. Audrey Copeland, National Asphalt Pavement Association
Mr. Matthew Corrigan, Federal Highway Administration
Dr. Ervin Dukatz, Mathy Construction
Mr. Frank Fee, Consultant
Dr. Rebecca McDaniel, North Central Superpave Center, Purdue University
Mr. Timothy Aschenbrener, Federal Highway Administration•
Dr. Nelson Gibson, Transportation Research Board•

The project was managed by Edward Harrigan, NCHRP Senior Program Officer.

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SUMMARY

Warm mix asphalt (WMA) technologies were first introduced in the United States (U.S.) in the early 2000s and rapidly gained popularity. Industry and agencies recognized the potential benefits including cost savings from lower production temperatures; environmental benefits from reduced emissions; and construction benefits from more consistent and higher in-place density and/or extended paving seasons or haul times. Despite the significant resources dedicated to advancing the use of WMA through national level research and the Federal Highway Administration's (FHWA) Every Day Counts program, use of WMA has leveled off or declined in recent years. In response, the National Cooperative Highway Research Program (NCHRP) initiated research project NCHRP 20-44(01) to identify barriers to implementation; identify where and why tonnage has leveled off; and establish and update performance indicators for WMA implementation.

A multifaceted approach was taken to document the various efforts that have been made in recent years by federal, state, and local public agencies and the paving industry to address the impacts of WMA usage within those states. The approach to this study included: a critical review of published literature that was focused on WMA usage and implementation; surveys of both transportation agencies and members of the asphalt industry; a national level workshop involving federal, state and local agencies, industry, and academics; and follow-up surveys and local workshops and webinars. The state department of transportation (DOT) survey resulted in d a 90% response rate and the industry survey drew responses from 41 companies from around the U. S. There were more than 120 organizations that provided feedback in follow-up surveys.

One of the key findings from the project is that WMA technologies continue to be attractive to agencies and contractors for a range of reasons. The results of the literature review and surveys indicate that the overall performance of WMA is similar to HMA in the field, but that WMA has a wide range of definitions across the country. Based on discussions during various workshops and feedback from follow-up surveys, the consensus definition proposed is as follows:

> *WMA (warm mix asphalt) = Modified asphalt mixes produced with various technologies—including water foaming, chemical additives, and organic waxes— that have the capacity to be used with lower production temperatures (below 300 degrees F), but can also be used at normal production temperatures, to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance.*

Barriers or disincentives to implementation and/or increased usage of WMA were identified through the two-day workshop and feedback obtained from various meetings and surveys. These are generally categorized as:

- Restrictive or conflicting specifications;
- Burdensome certification process;
- Lack of experience and comfort level with new technologies;
- No clear quantification of savings;
- Lack of effective documentation and technology transfer; and,
- Remaining technical questions on design and performance evaluation.

Cooperative actions and future implementation efforts to address these issues were also identified through the workshops and surveys:

- Move towards the use of end-result or performance-based specifications in order to allow for more flexibility and innovation by paving contractors;
- Incentivize the use of WMA through innovative project award techniques or funding;
- Develop a database platform that supports the WMA community, perhaps coordinated with the annual NAPA-FHWA survey, which includes a template for tracking key data related to WMA;
- Develop and maintain web-based training resources including informational brief documents and recorded webinars; and,
- Support the development of a community of practice that allows for agencies and contractors to benefit from the experience of other practitioners, to problem solve, and to confidently move forward with the more routine use of WMA.

The project also identified some suggested areas for future research that include continued research on laboratory conditioning, performance testing, and tool development. The results of this study will help federal, state, and local transportation agencies and their industry partners to revisit current WMA practices and to identify joint activities which could leverage the advantages of the implementation of WMA.

INTRODUCTION

This chapter introduces background information and highlights the approach used to identify and evaluate the state-of-the-knowledge and state-of-the-practice related to the implementation of warm mix asphalt (WMA). The survey and interview processes and organization of the report will also be described.

Background

WMA technology and deployment were largely driven by the asphalt industry. Implementation progressed while a number of technological questions were identified for research. Research was performed at both the state and national levels as well as by private industry. The Federal Highway Administration's (FHWA) WMA Technical Working Group (TWG) was responsible for developing key research needs statements. WMA later became a focus area for the FHWA in its Every Day Counts (EDC) initiative, which encouraged state agencies to allow WMA in their specifications and track its usage.

A number of WMA technologies were developed and marketed during the mid to late 2000s. These technologies included the use of foam (water), waxes, and other specialty chemicals. A large number of demonstration sections were placed in the late 2000s by multiple states and contractor groups and performed favorably. This resulted in the continued and more rapid acceptance of WMA as the benefits were recognized. These benefits included lower production temperatures, reduced emissions and energy consumption, extended construction day and season, and additional opportunities for more uniform and higher density construction. In the 2014 construction season, over 32 percent of the asphalt mixture tonnage placed in the United States was produced with WMA technology.

A review of contemporary information indicated that gaps continue to exist concerning knowledge of WMA technology and performance. As additive technologies have continued to change and evolve, agencies and industry are scrutinizing production and performance to freshly assess whether WMA—as well as other technologies such as polymers, reclaimed asphalt pavement (RAP), recycled asphalt shingles (RAS), and recycling agents—provides the benefits originally envisioned. Lead States have widely adopted WMA and now well over 75% of all states have a standard WMA specification rather than a special provision. However, details on how those WMA specifications affect the characteristics of the WMA that is placed on roadways is difficult to capture. WMA represents less than half of total state department of transportation (DOT) tonnage with anecdotal evidence of WMA tonnage dropping in some areas. Research is needed to identify impediments to the wider use of WMA and develop strategies to foster its expanded implementation by the state DOTs.

Objectives

The National Cooperative Highway Research Program (NCHRP) Project 20-44(01) was initiated with the aim of identifying the state-of-the-knowledge regarding WMA performance and documenting the barriers encountered by agencies and industry, particularly in those state DOTs where WMA specifications remain to be implemented and/or proportional WMA tonnage has lagged. In addition, the research sought to establish the state-of-the-practice regarding WMA usage and to identify implementation performance indicators that better measure WMA implementation as its usage is increased nationwide. The results of this study will help federal, state, and local transportation agencies and their industry partners to revisit current WMA practices and to identify joint activities which could leverage the advantages of its implementation.

Various research efforts have been made in recent years by both states and industry to study the short- and long-term performance of WMA. There is a need to quantify these efforts and garner examples of practices that are reported to be effective, in order to facilitate the exchange of information and to help other states. This study will provide transportation agencies and their industry partners with useful information and ideas for cooperative options that they can use to more effectively address the impacts of WMA use on their pavements.

Study Approach

A multifaceted approach was taken to document the various efforts that have been made in recent years by federal, state, and local public agencies and the paving industry to address the impacts of WMA usage within those states. The approach to this study included: a critical review of published literature that was focused on WMA usage and implementation; surveys of both transportation agencies and members of the asphalt industry; interviews with transportation agencies, researchers, and paving contractors that were identified as having existing practices that are effective for the use of WMA. The following sections provide more detail on each step in the study approach.

Critical Review of Published Literature

In order to summarize the state-of-the-knowledge regarding WMA, a critical assessment of existing literature was conducted to identify gaps, best practices, and information from states in which WMA implementation has lagged. The review included both domestic and international sources of information, including the Transport Research International Documentation (TRID), the Internet and Web searches, FHWA and DOT internal reports, journal publications, conference proceedings, other published media including newspaper and magazine articles, and resources of professional associations. In addition, the key takeaways from several completed NCHRP projects that included WMA research were included in the review.

Additionally, the review of information online such as state DOT asphalt specifications and pavement policies. Interviews with key federal agencies (namely, the United States Army Corps of Engineers (USACE), FHWA Office of Federal Lands Highway (FLH), and FHWA Long-Term Pavement Performance Program) and national organizations (i.e., the American Public Works Association (APWA), the National Asphalt Pavement Association (NAPA), and the National Association of County Engineers (NACE)) were conducted to determine their experience and implementation activities associated with WMA. Particular attention was paid to references suggested in the RFP and other related resources.

From this critical review, the research team has compiled a topical bibliography, included in Appendix A of this report, which focuses on products and the implementation efforts. Topics include WMA mix design, WMA technology, laboratory performance, and field performance.

Survey of Transportation Agencies and Asphalt Industry

The study sought to determine the current state-of-the-practice regarding WMA usage and performance through the distribution of a survey to agencies and to asphalt industry representatives.

The agency survey consisted of 34 questions and was sent to members of the AASHTO Research Advisory Committee, with a suggestion for distribution through the chief engineer's office to the DOT Bituminous Materials Engineers to complete the survey. The survey was sent to contacts in each of the state DOTs, Washington DC, and Puerto Rico as well as to a number of local agencies, relevant federal agencies, Canadian provincial transportation ministries, and turnpike/tollway authorities. Ninety (90%) percent of all DOTs, plus 11 other agencies, responded to the survey and the survey questions and results are included in Appendix B of this report.

The industry survey consisted of 21 questions and was sent to asphalt paving contractors and producers of WMA to capture the views of the industry on the current usage and impacts of WMA technologies. There were 41 members of the asphalt industry from around the United States that responded to the survey and the survey questions and results are included in Appendix C of this report.

Delivery of National Stakeholder Workshop on WMA

The agenda for a two-day national workshop was established based on the results of the surveys. The survey respondents, along with representatives from all 50 states, were invited to attend a two-day stakeholder workshop on WMA implementation in Irvine, California, in May 2017. The purpose of the workshop was to create an opportunity for dialogue between agencies, industry, and researchers on the topic of WMA.

An online webinar series for agency and industry professionals was developed; 23 webinars were recorded by TRB through the Straight-to-Recording program and include PDF documents of each Warm Mix Brief webinar presentation to be used as Participant Notes for those attending the workshop. In addition, a Webinar Index (or "lesson plan") was created to introduce the content, speakers, and sequence of various recordings. These webinars can be found online at: https://vimeo.com/album/4436483.

Following the two-day workshop, two additional regional workshops were held in Rhode Island and Pennsylvania to capture feedback from agencies and contractors that could not attend the national workshop. A TRB Straight-to-Recording webinar was produced and released in November 2017 (http://www.trb.org/ElectronicSessions/Blurbs/176886.aspx) to elicit additional feedback. The results of the two-day national workshop, regional workshops, and feedback from the November 2017 TRB Straight-to-Recording webinar were compiled into a Workshop Proceedings that is included in Appendix D of this report.

Organization of Report

This report is organized into five chapters. The balance of chapter one presents the report's structure and defines key terms. The report structure is summarized with brief explanations of each chapter's content.

Chapter two summarizes the results of a critical review on the state-of-the-knowledge related to WMA testing, performance, tracking, and implementation activities in the U.S. and abroad, as documented in published literature and online state and local resources.

Chapter three presents an overview of the results of the state-of-the-practice of WMA usage and implementation, as reported by both transportation agencies and their asphalt industry partners. An overview of the survey results related to the performance of WMA, design of WMA mixtures, construction of WMA mixtures, WMA usage, and WMA implementation is presented.

Chapter four summarizes the results of a two-day national stakeholder workshop focused on future implementation of WMA. The chapter is organized to describe how to defining WMA (past versus future definitions), barriers to and disincentives against expanding the use of WMA, cooperative actions by agencies and industry to expand the future use of WMA, and ways and means to quantify the impacts of WMA over the long term. Sample implementation plans developed as a result of the feedback provided at workshops and subsequent participant surveys are also presented in this chapter.

Chapter five concludes the report with a summary of findings and suggestions for further study or consideration. A number of suggestions for future research are also presented in this chapter.

These chapters are followed by references, glossary, and four appendices. Appendix A presents the topical bibliography compiled from a review of the body-of-knowledge related to WMA field studies and implementation, etc., and specifically focused on the major findings, challenges, best practices, and gaps in knowledge. Appendix B includes a copy of the agency survey questions and detailed results. Appendix C includes a copy of the industry survey questions and detailed results. Appendix D presents the workshop proceedings from a few meetings and the online recorded webinar.

LITERATURE REVIEW ON STATE-OF-THE KNOWLEDGE OF WARM MIX ASPHALT

The information included in this chapter derives from the literature review and online research.

Introduction

Task 1a of NCHRP 20-44(01) focused on a review of available literature and the compilation of a topical bibliography concentrated on the performance and implementation of Warm Mix Asphalt (WMA). The literature review included available research reports that have been conducted at the national and state levels, journal publications focusing on case studies, specification documents, and available information from various websites regarding WMA. The Transportation Research Information Database (TRID) was the primary search engine used to identify NCHRP reports, state DOT reports, and other transportation research publications. In addition, literature documents were compiled as a result of interviews (with U.S. Army Corps of Engineers research arm), review of state DOT and asphalt industry websites (including the National Center for Asphalt Technology among others), searches of gray literature (e.g., web articles on the use of WMA by cities or other local agencies), and information included on the FHWA website.

The emphasis of this task and the literature review was to summarize documented gaps in the state of the knowledge regarding WMA and identify successful implementation and practices regarding WMA. This topical bibliography was used as background information to guide the discussion items for the two-day workshop held in Irvine, California, in May 2017.

The full topical bibliography is provided in Appendix A. It is divided into sections: NCHRP reports, Case Studies and State DOT reports, U.S. Army Corps of Engineers (USACE) reports, documents detailing the Long Term Pavement Performance Specific Pavement Studies (LTPP SPS) WMA experiments, and miscellaneous documents. Each section presents individual summaries of the various items in chronological order. A general overview of the information gleaned from each section is presented is the subsections below.

NCHRP Project Reports

In general, the results of the NCHRP projects conducted to date indicate that immediately after construction WMAs have lower stiffness and are more susceptible to rutting than HMA but become more similar or equal to HMA with field aging. Field densities were similar with slightly better compactability observed with the WMA materials. WMAs tend to have lower asphalt absorption levels during production, but volumetric properties of WMA and HMA are similar if a low absorption aggregate is used. Use of recycled materials increases the stiffness of

WMA generally, but the effect depends on the specific material and WMA combinations. Properties of foamed asphalts were different between laboratory and plant production.

Lower stack emissions were measured with WMA and were attributed to the lower production temperatures. Lower levels of fumes were observed behind the paver as compared with emissions measured during the production of HMA.

Gaps that have been identified through the NCHRP projects include identification of appropriate short- and long-term aging protocols for WMA to simulate field conditions, and evaluation of long term field performance of WMA. They also include the identification of performance tests, particularly for fatigue and low temperature cracking, which can be used in the laboratory at the mixture design stage.

Challenges to implementation of WMA that have been identified include: unknown long-term field performance, initial product approval, and the structure of specifications in terms of the allowance of various WMA technologies.

Case Studies and Reports from the State Departments of Transportation

Generally, the laboratory evaluations of WMA materials have showed better compactability, lower air voids, lower asphalt absorption, and lower optimum binder contents than HMA. WMA materials were generally more susceptible to rutting and moisture damage although results depended upon the particular materials and test methods used. Stiffness values measured for WMA were lower than those measured for HMA.

Field trials showed that WMA materials had similar or higher densities and improved workability over HMA mixtures. WMA sections were observed to have higher rutting and less cracking in the early life of the pavement, but performance was similar to HMA after several years of field aging. During production, decreases in emissions and fuel usage were measured.

The gaps identified in these projects include long term monitoring of WMA field sections, the need for standard specifications, and establishment of appropriate curing time and temperatures during mix design. Also, several studies pointed out the unknown interactions with WMA and higher percentages of recycled materials.

United States Army Corps of Engineers Reports

In the laboratory, WMA was observed to have better workability but increased susceptibility to moisture and higher rutting than HMA. Production for airfield pavements showed better workability in the field with WMA, similar moisture contents during production and no differences in volumetric properties between WMA and HMA. Initially, more rutting was observed with the WMA materials, but the performance was rated as good as or better than HMA after some field curing time.

These studies identify gaps in documented long-term performance of WMA mixtures and evaluation of cracking properties of WMA mixtures.

FHWA Research and Technology: Long-Term Pavement Performance, Specific Pavement Studies

The experimental design plans, selection of candidate projects, construction documentation, sampling and testing, and performance monitoring requirements for the LTPP SPS-10 Warm

Mix Asphalt Overlay of Asphalt Pavement Study are summarized and provide insight on the parameters that are important for the evaluation of WMA. It should be noted that at the time of this report's publication, the LTPP WMA study is relatively new and is awaiting performance results.

Miscellaneous Documents

Information available in brochures and on various websites is summarized and generally covers basic information about WMA including definitions and descriptions of the various types of WMA technologies. The general findings from the NAPA Information Series 138 are summarized and the usage trends of warm mix asphalt are reported. In the 2016 construction season, WMA made up 31.2% of the estimated asphalt mixture market, with production plant foaming being the most commonly used warm-mix technology representing over 75% of the market.

Summary

In summary, the literature review identified the following gaps in the state of the knowledge regarding WMA:

- Need for appropriate short- and long-term aging protocols for WMA;
- Evaluation of long term field performance;
- Identification of performance tests for rutting, fatigue cracking and low temperature cracking;
- Need for standard specifications; and,
- Unknown interactions with WMA and higher percentages of recycled materials.

SURVEYS ON THE STATE-OF-THE-PRACTICE OF WARM MIX ASPHALT USAGE

Introduction

This chapter provides the state-of-the-practice reported by the DOTs and other agencies on the extent to which warm mix asphalt (WMA) is being used and/or implemented. An overview of the various practices, testing strategies, and economic implications that are reported by the survey respondents is presented.

Results of Agency Survey on Warm Mix Asphalt Usage and Implementation

The purpose of the survey was to gather information on approaches that agencies use to make an informed decision about the use of WMA technologies for the construction of asphalt pavements. Nearly all state DOTs have some experience with WMA, from hosting WMA demonstrations to developing performance related specifications that apply to WMA for state funded paving projects. In addition, the survey solicited valuable input regarding how each agency is handling the use of WMA and to report each agency's experience with the success and challenges of implementing WMA.

The detailed results of the Agency Survey are included in Appendix B of this report. A list of state DOT contacts was generated from the AASHTO Subcommittee on Materials roster. The 50 state DOTs, District of Columbia DOT, and Puerto Rico DOT were all included in the distribution of surveys, along with all of the Canadian provincial transportation agencies, local agencies. The survey response rate from state DOTs was 45 out of 50 states (90%) plus a response from the District of Columbia DOT and the British Columbia (Canada) transportation agency. Both Alaska and Wisconsin DOTs offered two survey responses, from the perspectives of the central materials office and a district construction/materials office.

The survey was also distributed to a small group of other agencies that have had or considered experience with WMA; specifically, the Port Authority of New York New Jersey, Pennsylvania Turnpike Authority, USACE, and the FHWA Office of Federal Lands Highway (FLH). In addition, past discussion with state DOT and industry contacts has alluded to the number of local agencies who have constructed WMA pavements; in some cases, many years before WMA was implemented by the state DOT. This outreach resulted in five additional survey responses from local agencies.

Overall, a total of 55 agencies responded to the survey, as shown in Figure 1. Appendix B presents the blank copy of the agency survey questionnaire, specific survey respondents, and which agencies were able to attend the two-day workshop.

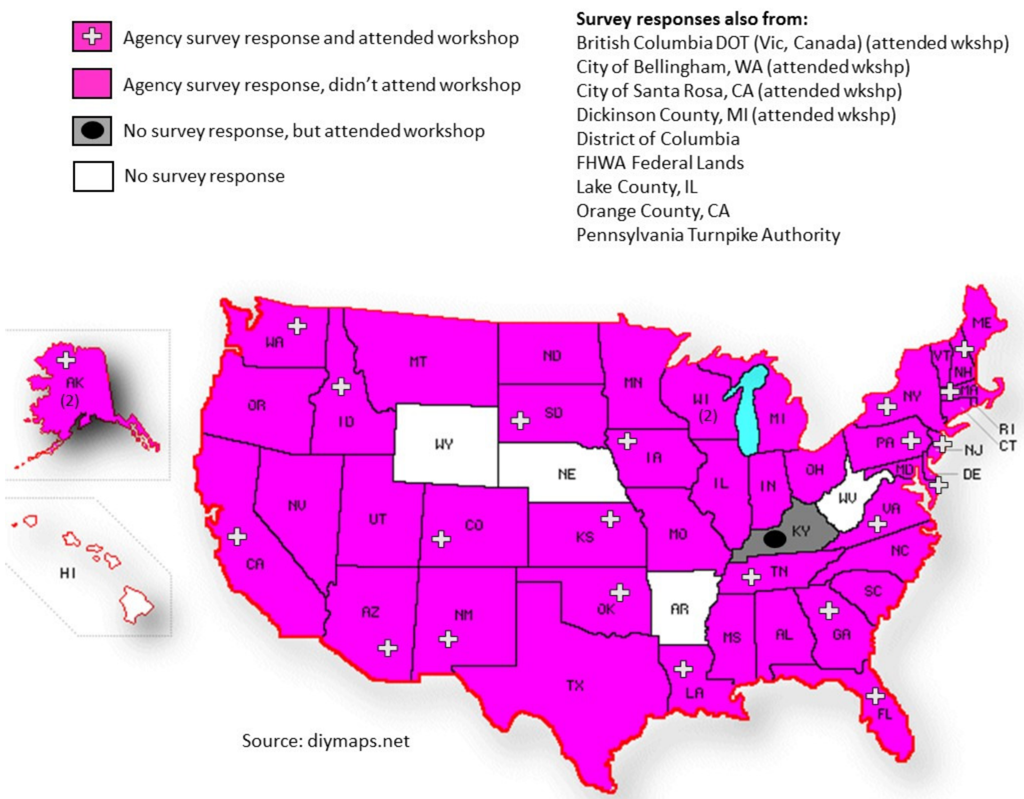

FIGURE 1: Summary of Respondents to Agency Survey on WMA Implementation

All of the agencies who responded to the survey indicated that they have implemented a WMA technology on at least one paving project. The majority have been foaming (49 responses) or chemical additive (42 responses) WMA technologies, but 27 agencies also reported use of organic additive WMA technologies. Alaska, District of Columbia, Minnesota, and Ohio DOTs all reported the use of Evotherm on a number of projects. Figure 2 shows the various goals for encouraging WMA use that were reported. The most frequently-reported reasons were to improve workability and quality, to extend the paving season, to increase haul distances (or allow for longer haul times), and to reduce fuel consumption at the plant.

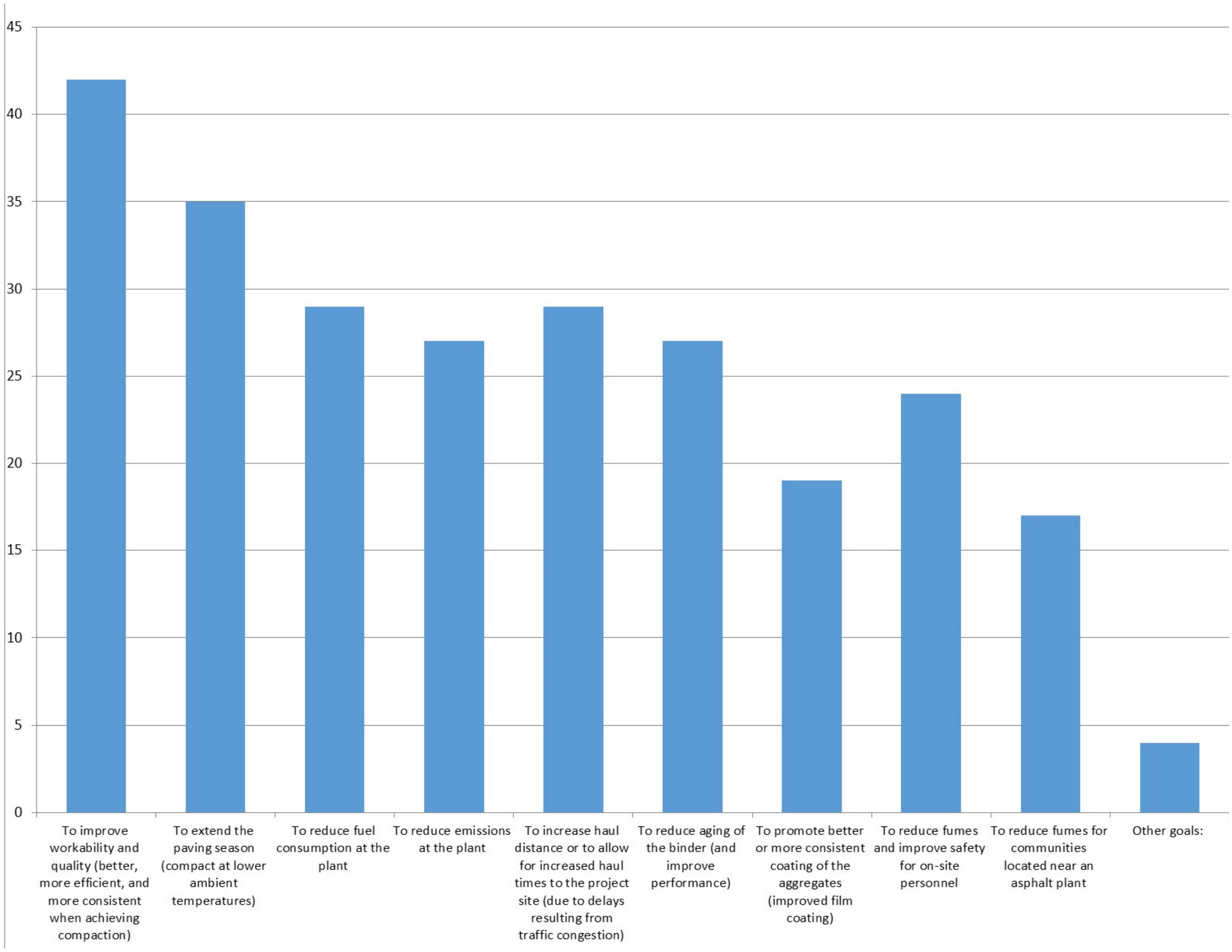

FIGURE 2: Primary Agency Goals for Encouraging Use of WMA

Other goals for using WMA include to increase competition among contractors (with the effect of lower bid prices), to reduce segregation in asphalt mixtures, and to achieve compliance with state environmental goals or regulations (such as the Commonwealth of Massachusetts' "Global Warming Solutions Act of 2008").

Agencies were asked to provide a definition for WMA and a variety of responses were received and are detailed in Appendix B. However, some general categories were evident, as shown in Figure 3, and the vast majority of agencies defined either per technology type or as a function of temperature (e.g., production temperature, range of temperatures, compaction temperature).

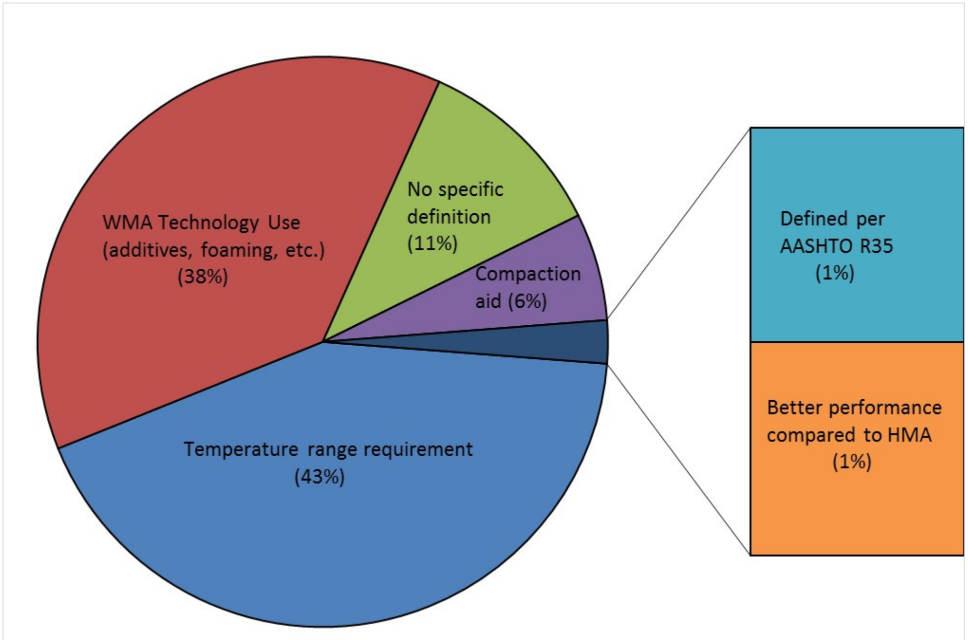

FIGURE 3: General Categories of Agency Definitions for WMA

Information Related to Performance of WMA

Agencies reported that the most critical properties for WMA performance are mixture compactability (36 agencies), in situ air voids (36 agencies), and binder content (32 agencies). Other properties listed include film thickness, moisture susceptibility, and voids in the mineral aggregate (VMA). In terms of field performance properties, 41 agencies listed moisture damage (stripping, raveling, potholes) as the most critical to WMA, followed by rutting (32 agencies) and fatigue (bottom up or top down) cracking (22 agencies). Other critical distresses reported include longitudinal joint cracking, segregation, and loss of temperature or lack of enough heat to properly compact the mixture.

The agencies indicated that for the types of known mix variations (i.e., RAP, RAS, antistrip additives, polymer-modified binders, polyphosphuric acid (PPA) binders, stone matrix aggregate (SMA), and recycled ceramics or glass), the vast majority observed no difference in performance when combined with WMA as compared to HMA. For some of the additives, agencies reported seeing better performance when combined with WMA (7 responses for polymer-modified, 3 responses for RAP, 2 responses for rubber, 2 responses for SMA, 1 response for RAS, and 3 responses for antistrip additives). Dickinson County (Michigan) Road Commission also tried using a WMA ultra-thin overlay and reported no difference in performance from a HMA ultra-thin overlay. There were a few instances when worse performance was reported for certain variations combined with WMA (1 response for polymer-modified, 2 responses for RAP, 3 responses for PPA, 3 responses for RAS) as compared to with HMA.

Just over half (54%) of the agencies who responded to the survey are tracking the usage of WMA, construction properties, or post-installation performance. Of those agencies, the types of approaches that are used for tracking are indicated in Figure 4. Some other approaches reported for tracking WMA are listed in Table 1, but only 13% (7 out of 51) of agencies reported that their pavement management system includes any data elements that allow for tracking the performance of pavements constructed with WMA.

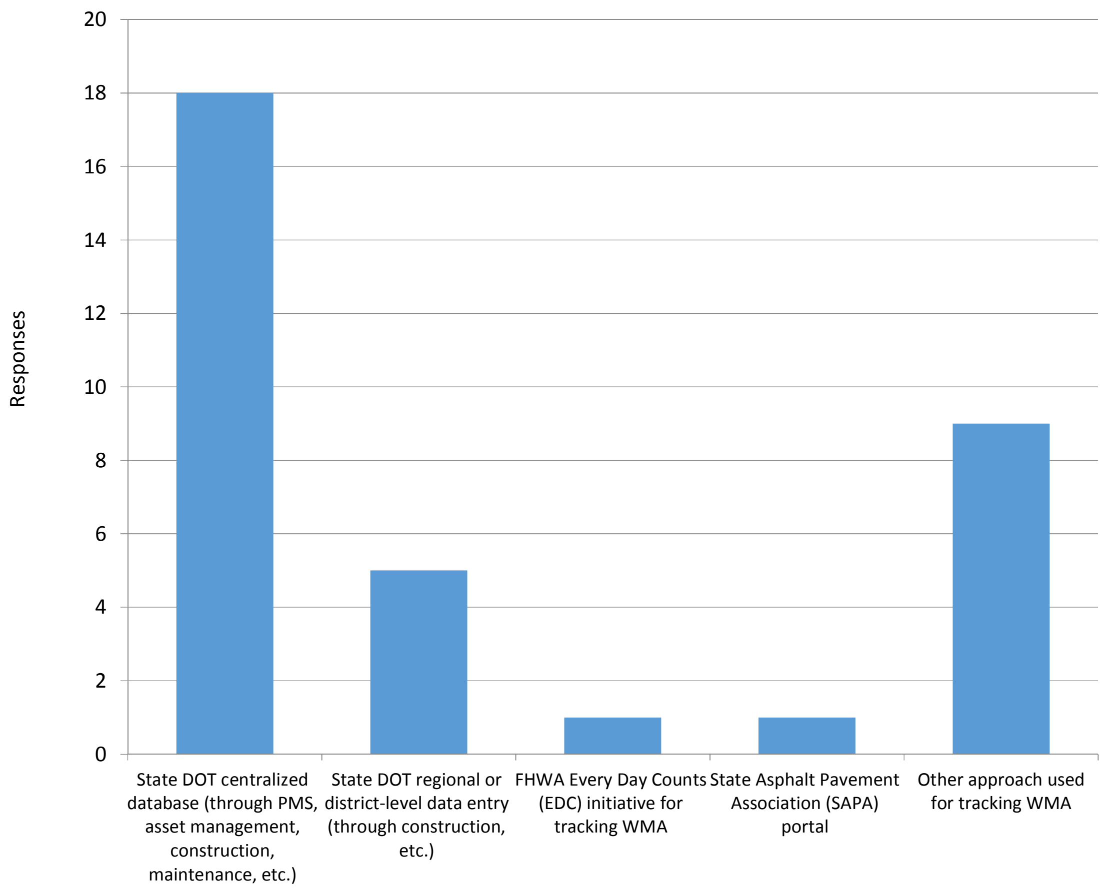

FIGURE 4: Approaches Reported for Tracking WMA Usage and Performance

TABLE 1: Other Approaches Reported for Tracking WMA

Agency	Other Approach Reported for Tracking WMA
North Carolina DOT	Track usage of individual approved mix designs. This is done by giving WMA mix design numbers a unique identifier and then tracking tonnage placed based on the mix design number/identifier
South Dakota DOT	State Research Project
Texas DOT	Use of TxDOT Site Manager
New Mexico DOT	Research Project with local university to do some tracking of WMA projects
City of Santa Rosa, California	ACCESS-based lab system tracking of HMA and WMA
Lake County Division of Transportation (Illinois)	Job tickets and plant reports used to track usage
DC DOT	Records of WMA tonnage used versus HMA tonnage
Alaska DOT&PF	Plans to populate the new PMS with WMA projects
Dickinson County Road Commission (Michigan)	Local agency pavement database

Many agencies (57%) reported having built a control section when they built a WMA project. Figure 5 summarizes the general categories of how differences in performance between the WMA and HMA control sections were captured by the agencies. The details of each response to Question 8 are included in Appendix B. In 10 of the 20 responses (50%) offered, there was no difference in performance between the HMA and WMA pavements and a number of studies are underway but the results have not yet been collected. For example, South Carolina DOT noted that it constructed a 12.5-mm open graded friction course (OGFC) with WMA (using Evotherm and no fibers), adjacent to the same mix with ground tire rubber (GTR) with no fibers, and a third mix with SBS polymer combined with fibers on Interstate I-20. The three sections have been performing for five years with no reported distresses with any of the mixes.

There were some agencies that did notice a difference in performance between WMA and HMA and these are presented in Table 2. Out of 50 agencies, 94% reported that they observed no differences in distress levels between WMA and HMA pavements. Only one agency had observed more rutting in WMA pavements and one agency had noted fatigue cracking in WMA. In addition, District of Columbia DOT observed that WMA allows contractors to place asphalt mixes at colder and windier conditions which may lead to a shortened pavement life. Dickinson County (Michigan) observed transverse cracking in the WMA section but after taking cores, it is possible that the cracking is reflecting up from the layer below.

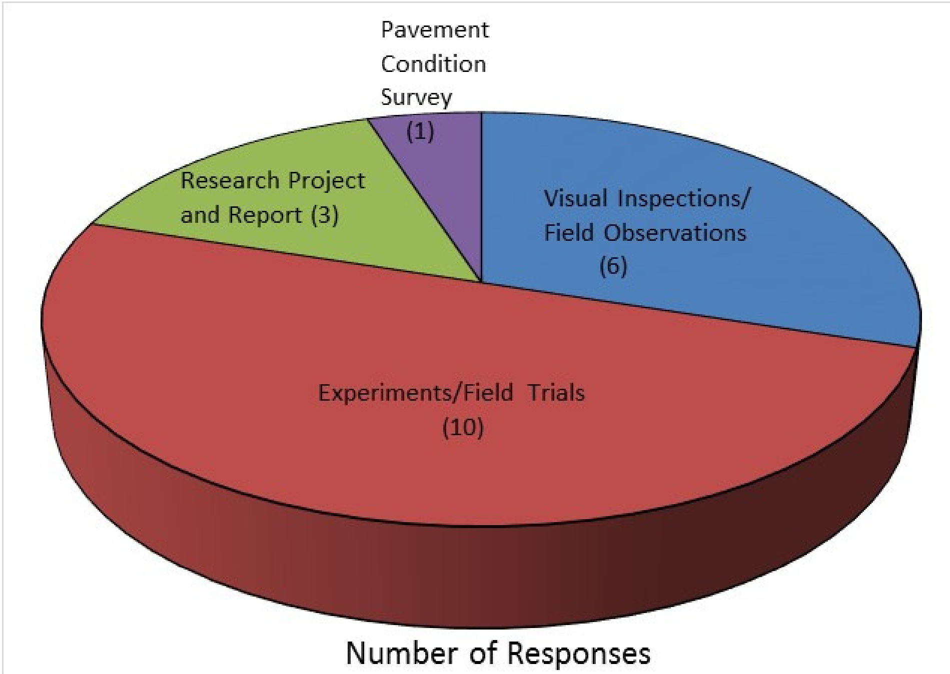

FIGURE 5: Methods Reported for Documenting Differences in Performance Between Control HMA and WMA Sections

TABLE 2: Performance Differences Between Control HMA and WMA Sections

Agency	Response
Lake County, Illinois	Via informal field inspection, not noticeable difference in WMA and HMA in first 3 years. After 5 years, WMA had less longitudinal cracking. Via laser road surface testing, rutting and smoothness are slightly better for WMA, but cracking and overall condition are same for WMA and HMA.
Louisiana	Wax additives showed cracking earlier than other technologies used.
New Jersey	Differences were documented during construction that resulted in WMA yielding better workability, reduced emissions on asphalt-rubber mixtures, and increased compaction. Cool weather paving allowed increased time for compaction with WMA.
New Mexico	We built the first SPS-10 Test Project on I-40 in October of 2014. We built 5 test sections. One HMA Control Section with 4 WMA Test sections using Evotherm, Foaming & Ceca base with PG 70-28 and Ceca base with PG 70-28+). Fugro BRE is monitoring and keeping records of testing. University of New Mexico did some testing using the mix placed on those sections and Ceca base sections seems to be performing better than other sections.
South Dakota	Cores taken every year for 4 years and the test results show some differences as compared to the HMA control section

Information Related to Design of WMA Mixtures

The agencies were asked to indicate which design methodology they follow in determining the optimum asphalt content when using WMA mixtures. The majority (65%) of agencies follow the HMA mix design and then terminally-blend (or "drop in") the WMA additive. There were seven agencies who determine the optimum asphalt content with the WMA included and 11 agencies who follow another approach (shown in Table 3) that is dependent on the technology type and/or is more of a hybrid approach.

TABLE 3: Other Approaches to Determine Optimum Asphalt Content of WMA Mixes

Agency	Details on Other Approaches for Determining Optimum Asphalt Content of WMA
British Columbia MOT	Contractor follows Agency HMA specification and optimizes the asphalt content through an end-product performance specification.
California DOT	For water injection technology, use "drop in". For additive technology, include additives at mix design
DC DOT	DDOT tests the WMA mix design at the producer's predetermined optimum binder content
Florida DOT	FDOT uses a hybrid approach of these two methods. Additives are included during the WMA mix design process. Foaming technologies are not used during the mix design process.
Georgia DOT	GDOT allows the use of a GDOT-approved mix design if using a mechanical foaming device at the asphalt plant, but requires new mix designs for WMA additives.
Montana DOT	The WMA additive is "dropped in" when foaming is used. Other methods of modification require the WMA to be included when the design is developed.
Ohio DOT	Follow agency's HMA mix design and then reduce mixing and compaction temperature by 30^0F. Specify no grade bump, if the WMA contains between 26% and 40% RAP.
Oregon DOT	Depends, if foaming without additive standard HMA mix design process and require HMA production before WMA production; if chemical additive design in the lab with WMA included
South Carolina DOT	Drop in method for foaming designs. Additives used in the WMA are blended in the design to set the optimum binder content.

Figure 6 shows the various types of laboratory tests that agencies perform on WMA binders or mixtures (and not on HMA mixes). The tensile strength ratio (TSR) test is run on WMA by 43% of the agencies and the theoretical maximum specific gravity (33%) and volumetric properties (33%) are also frequently-required. There were 13 agencies who indicated that they require other laboratory tests. For example, Arizona DOT requires that the Arizona Test Method 802 Immersion Compression Testing be run on WMA mixes. New Mexico DOT is in the process of developing the Hamburg Test for WMA, as well as for HMA. Georgia DOT requires the tensile strength test for HMA, but it requires it to be done more frequently on WMA; whereas, South Carolina DOT tests the first day's production for WMA and every 30 days afterwards for TSR. The New York DOT requires that the RTFO DSR be done at both 275^0F and 325^0F to assure the binder characteristic does not change under lower temperature production.

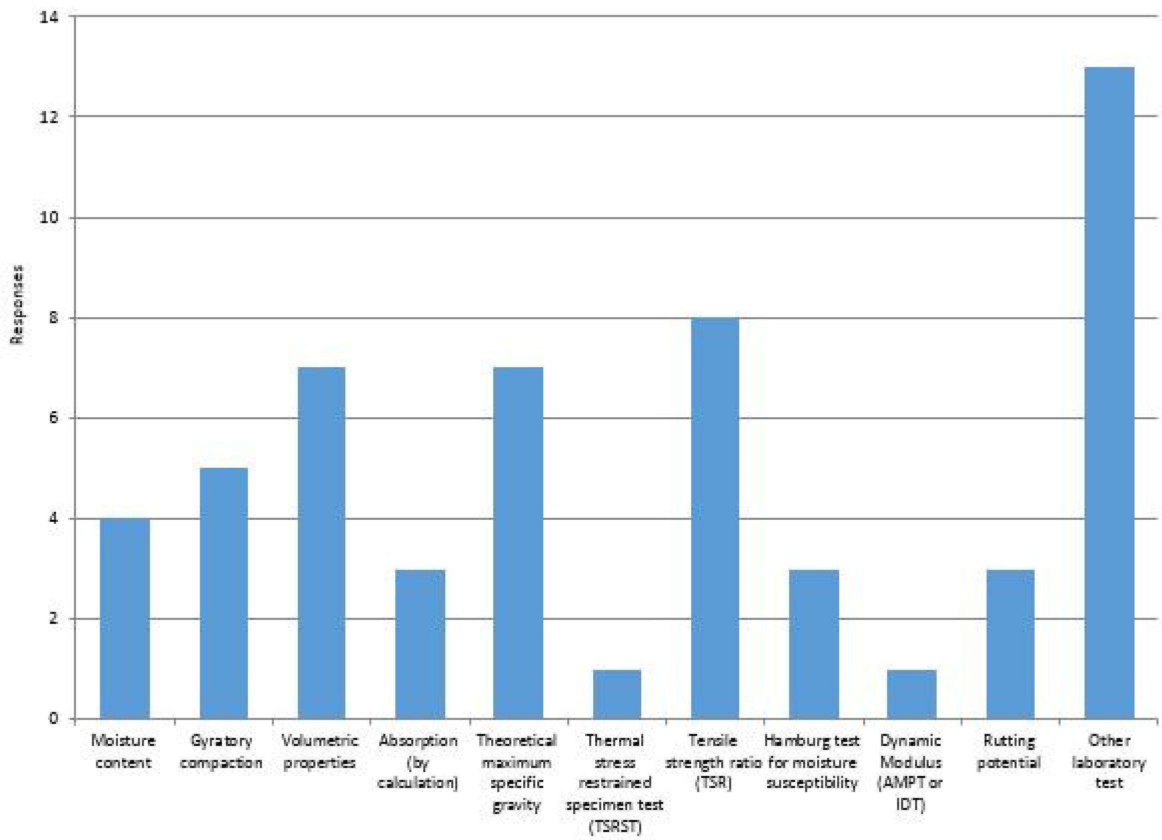

FIGURE 6: Laboratory Tests Required by Agencies for WMA Mixtures

Only five out of 52 (10%) agencies require different conditioning methods than for HMA for short-term aging or long-term aging of WMA. Georgia DOT doesn't allow additional aging for WMA; whereas, Texas DOT requires a 4-hour cure instead of a 2-hour cure for Hamburg wheel track testing. Ohio DOT requires contractor during quality control (QC) to compact at 30^{0}F lower than HMA per the ODOT Construction and Materials Specification 441.09.C (conditioning for short term is one hour for QC at compaction temperature for both HMA and WMA). California DOT and the City of Santa Rosa require that for HMA with WMA additive technology, the HMA mix samples for the mix design must be produced using a methodology for inclusion of WMA admixture in laboratory-produced HMA and that samples be cured in a forced-air draft oven at 275^{0}F for 4 hours ± 10 minutes.

The survey data indicated that there are very few agencies that require field performance tests that are different than what are run on the HMA pavements. The same field performance tests are run on both types of pavements. Only six (California, City of Santa Rosa, Massachusetts, New Hampshire, Pennsylvania, and Wisconsin) out of 50 agencies reported that their specification requires the use of WMA. The majority (59%) of agencies do have a certification process or qualification program for WMA: 27 agencies follow a state process and three agencies follow the AASHTO NTPEP for WMA. Twenty-four agencies provided links to or a copy of their WMA specification or supplemental provision and these were reviewed prior to the two-day workshop. For example, Nevada DOT requires that a test section be placed and monitored for two months before the specific WMA technology is allowed for further use. The Ohio DOT stated that for

WMA technologies other than by water injection, each technology must be approved on an individual basis. Pennsylvania DOT reported that there is no formal written process but WMA products are tested to determine any detrimental effects on binders before being approved for use in its product listing.

Information Related to Construction of WMA Mixtures

The survey revealed that 87% of agencies do not require contractors to do anything beyond what is normally done to pave with HMA in order to become pre-qualified for paving WMA. Only seven agencies indicated that a separate process exists. Discussion on a few of these states follows:

- Colorado: Approval is required for each WMA technology and/or each contractor intending to use WMA in Colorado. If the WMA technology is already approved for use by Colorado DOT, each Contractor must receive approval to supply WMA based on their submittal prior to placement on a Colorado DOT project. Additionally, Colorado DOT specifies that changes in WMA properties or formulations that result in changes to mixture properties will require a new WMA technology submittal and approval.
- Florida: The requirements to have WMA included on the Florida DOT approved products/process list include: 1) product must be acknowledged by another state agency as an acceptable warm mix technology or be listed on the following website: http://warmmixasphalt.com with a successful project(s) constructed nationally or internationally; 2) producer can partner with a contractor and Florida DOT District Office and construct a demonstration section on a FDOT project; and, 3) meet all Florida DOT construction specifications during construction of the demonstration section.
- Georgia: Georgia DOT requires three acceptable test sections using WMA.
- South Carolina: South Carolina requires submission of a QC plan that outlines which process is being used with the objective of setting the compaction temperature for volumetric testing (and reheat if necessary), etc.

The agencies were queried as to how cold weather paving (at temperatures less than 40^{0}F) is specified in their state and Figure 7 indicates that there are multiple methods being used and provides some of the categories captured. The details for each of the 15 other responses are presented in Appendix B.

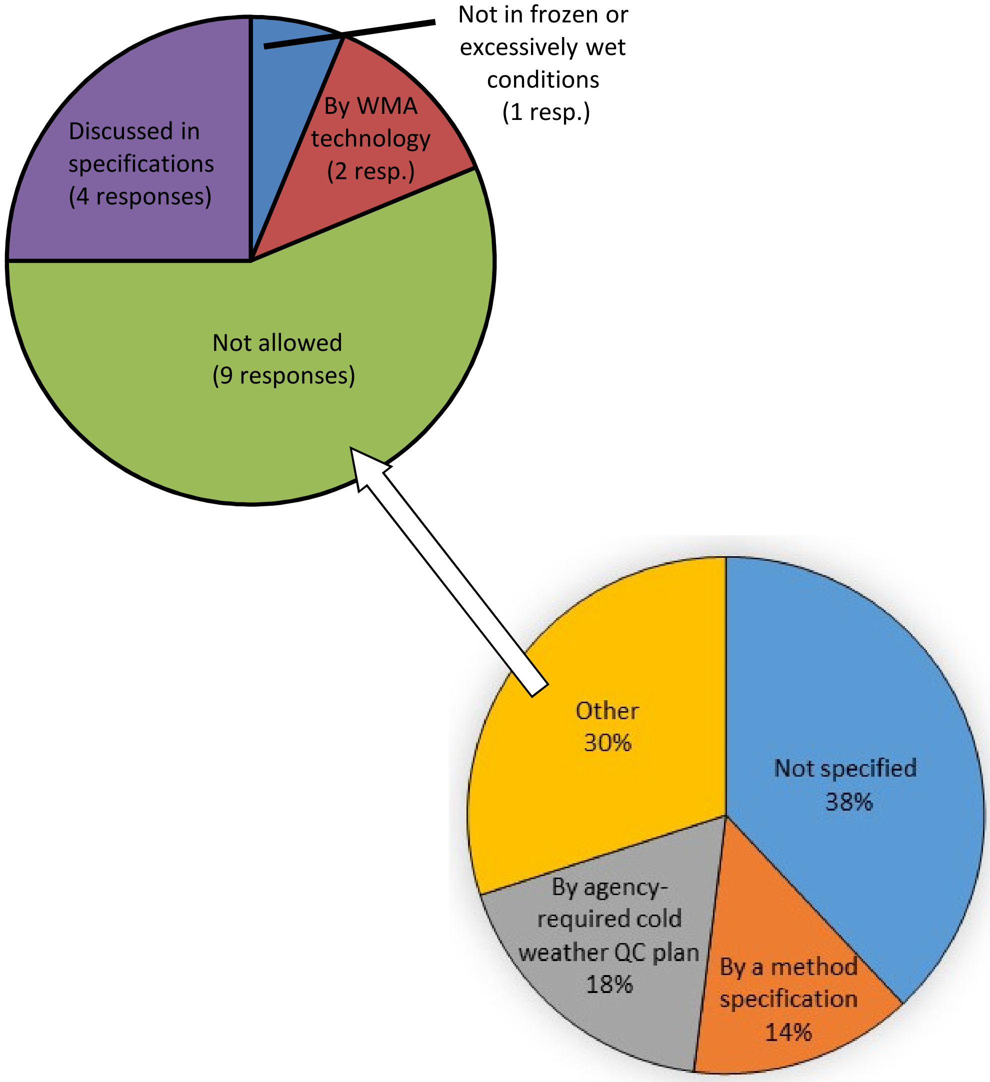

FIGURE 7: Specifications for Cold Weather Paving of WMA

Information Related to WMA Usage

Figure 8 illustrates the range of asphalt tonnages produced for all of the 49 agencies that responded to this question. The largest tonnage agencies were California, Kansas, and North Carolina. The agencies paving less than 50,000 tons were the four local agencies along with Arizona, Florida, Idaho, Nevada, New Jersey, Tennessee, and Washington. The proportion of tonnage estimated to be WMA is also shown.

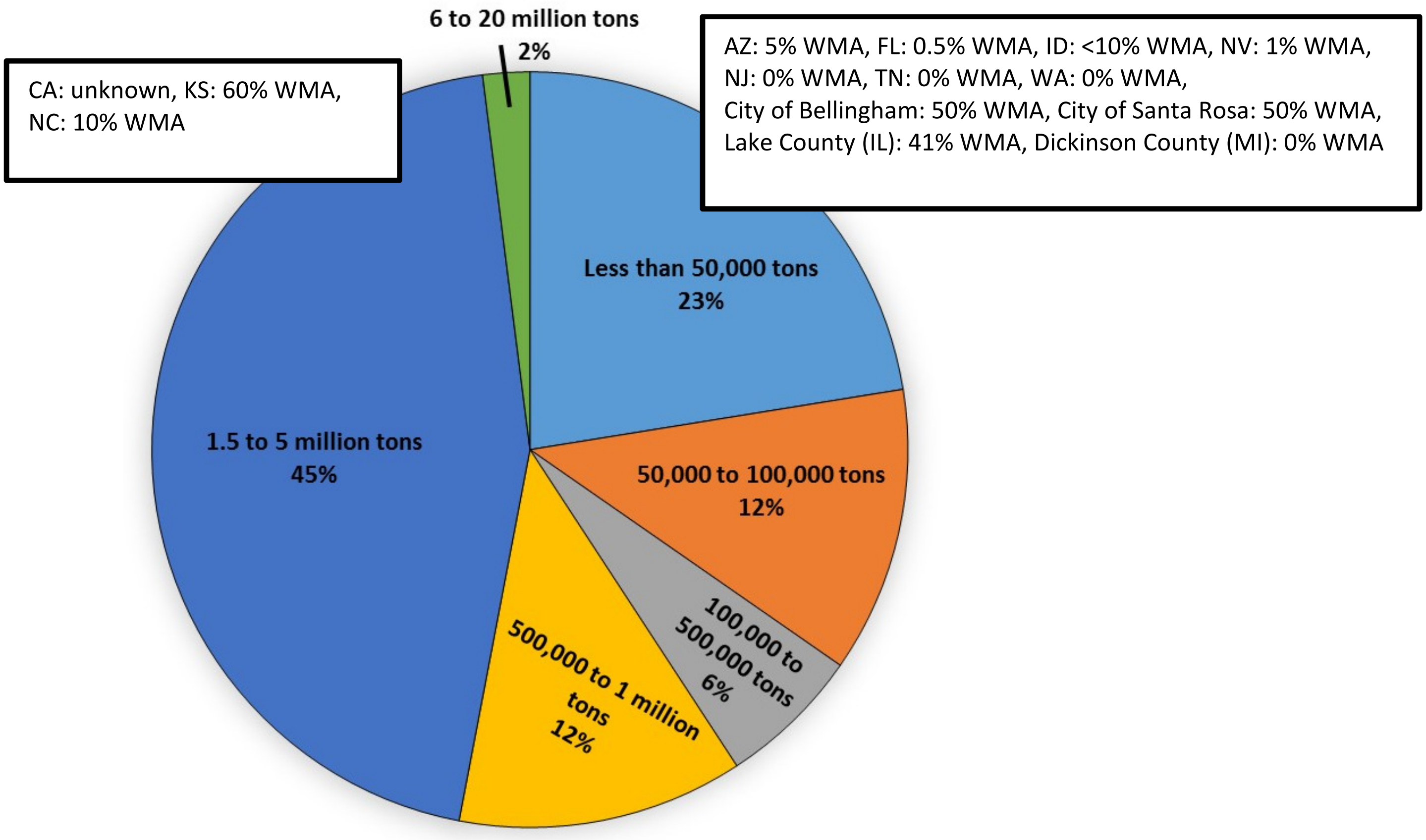

FIGURE 8: Range of Total Asphalt Tonnages Reported by Agencies

Based on the estimated WMA proportion to all asphalt produced, the agencies using the most WMA are included in Figure 9. For some agencies, such as California and Indiana, it was not possible to estimate the proportion of asphalt that was WMA because the decision to use WMA rests with the contractor and is not tracked specifically by the DOT. Another item to note is that what is considered WMA varies, as discussed previously. For example, Minnesota DOT estimated about 95% of production of HMA uses foaming (a warm mix technology), but the temperature is not lowered by the producer.

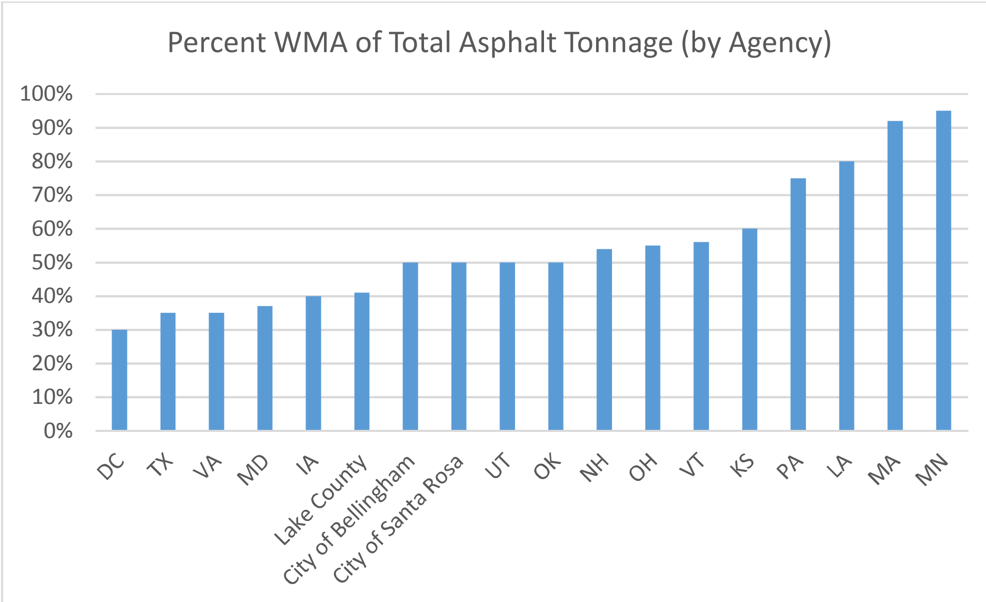

FIGURE 9: Agency Estimates of 30% or More WMA of Total Tonnage

Additionally, 38% of the agencies have observed that the amount of WMA usage has decreased over time. In terms of the noted decline in WMA use, Figure 10 shows that the primary reasons appear to be a function of a lack of a standard specification for WMA, lack of contractual incentives for contractors to use WMA, and no impact on bid pricing. Some of the other reasons included:

- Cost: Contractors are moving away from using the foaming technology, and additives cost more, so they will only use WMA when absolutely necessary. No cost savings for the contractor. Maintenance of water foaming process at plant could also be an additional cost. WMA had higher interest when fuel prices (heating) were high and it resulted in more significant savings;
- Logistics: Some local agencies do not allow WMA and producers don't want to switch between HMA and WMA;
- Temperature Definition: if a contractor's temperature drop is 10^0F or less, the product is still called HMA; and,
- Resistance to Change: Contractors have not indicated interest, even when given the choice, and do not see the benefit of WMA.

In Indiana, WMA entails dropping the temperature to around 285^0F from 300^0 F or 315^0F with conventional HMA. The decision to use WMA was less about the environmental concerns and heating costs and more about the improvement in mix workability and density achievement.

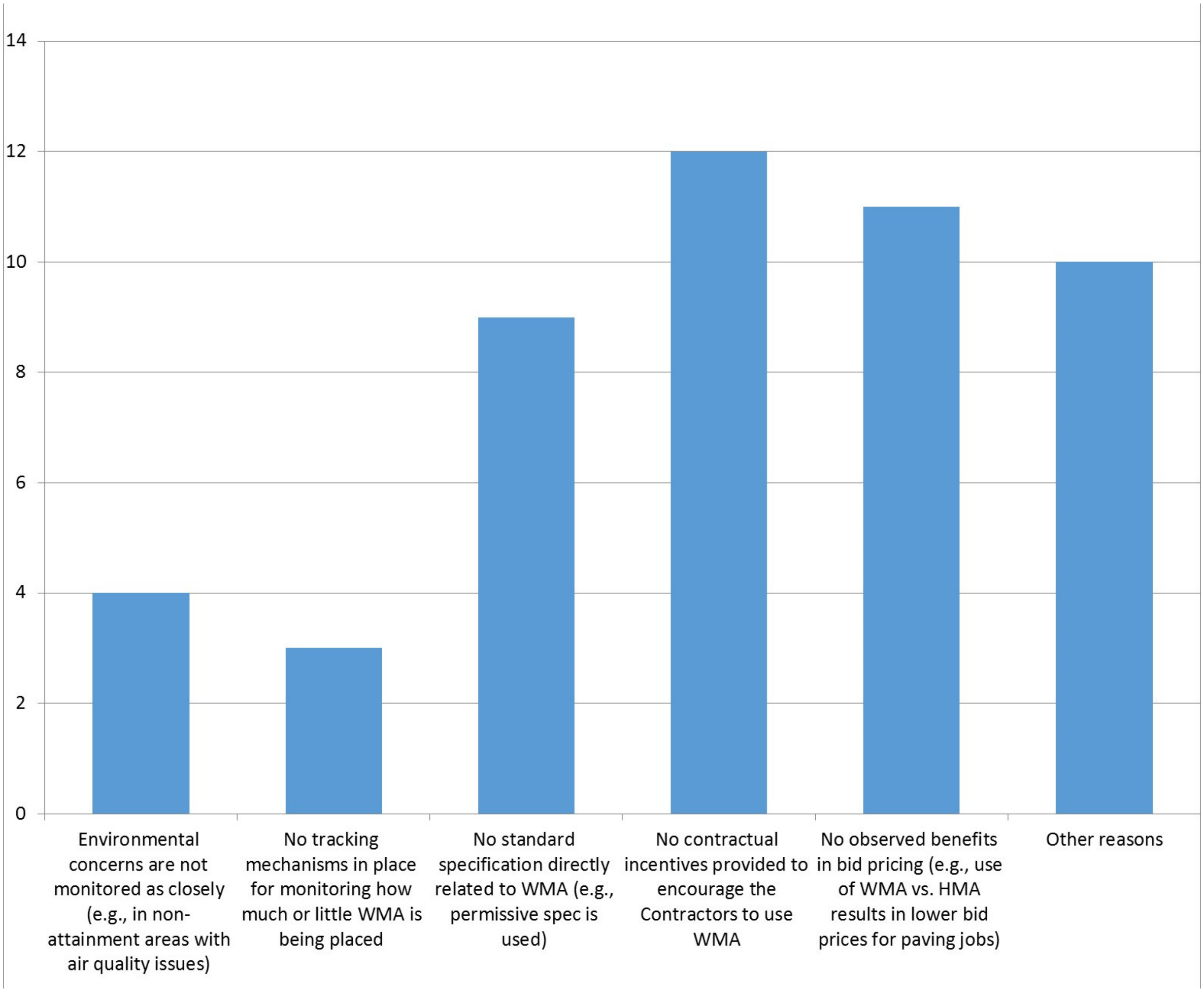

FIGURE 10: Reasons Reported for Decline in WMA Usage

Agencies were also asked to share how they had made progress in furthering the use of WMA technologies and the results are included in Figure 11. Other approaches include in Florida, allowing the minimum ambient temperature to be reduced by 5^0F when using a warm mix technology. Dickinson County inserts a specification in every paving job that states WMA is a contractor option.

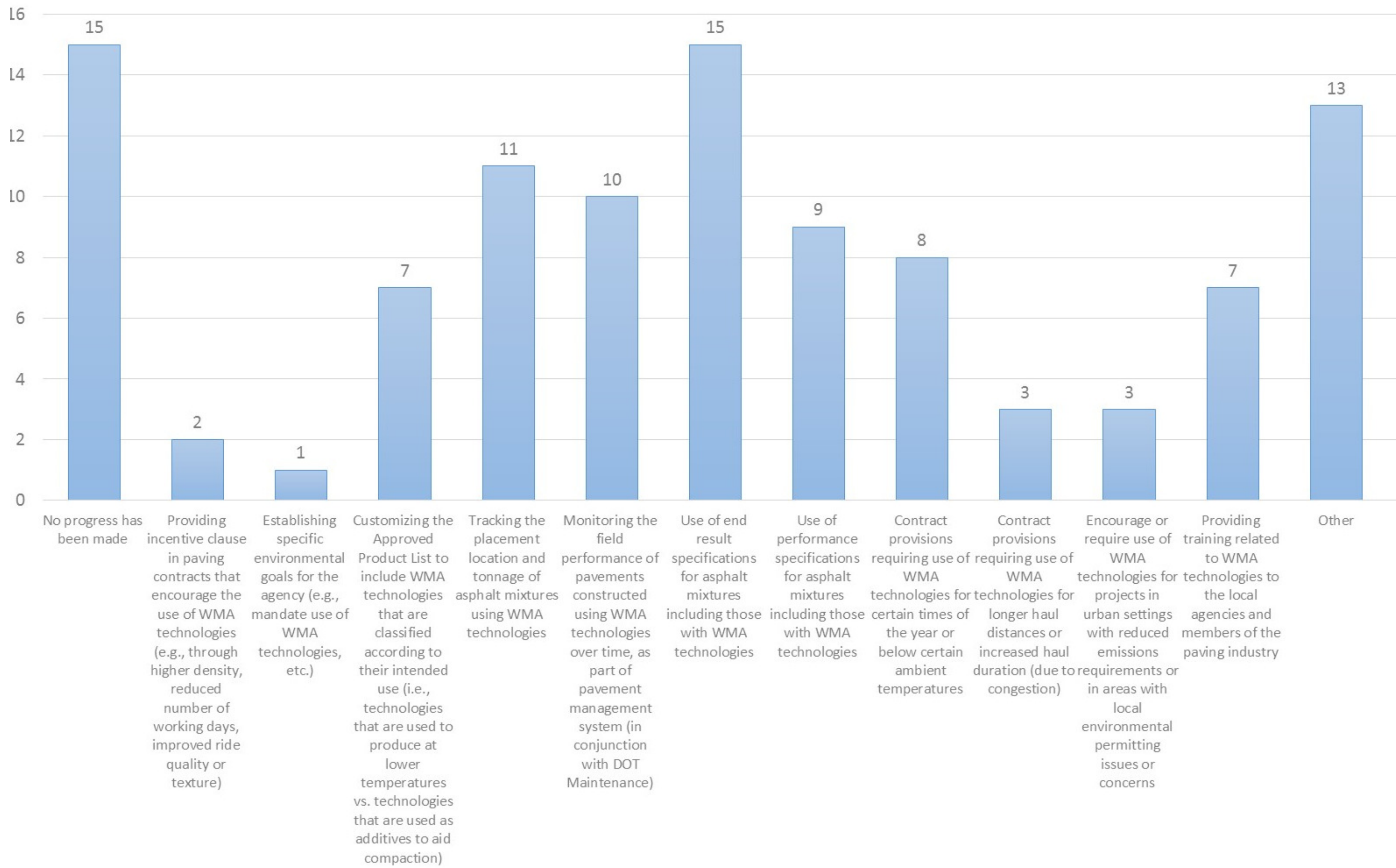

FIGURE 11: Methods Reported for Furthering WMA Usage

Alaska, California, New Jersey, Oklahoma, and Utah DOTs all use permissive specifications and allow the contractor option for WMA. Connecticut DOT's approach is that WMA is required when a PG 76-22 (64E-22) binder is specified. New Hampshire DOT requires WMA for asphalt rubber gap graded (ARGG) mixes as well as for paving between October 1 and May 1 dates. Finally, Pennsylvania DOT requires the use of WMA in order to capture the higher compaction potential of WMA mixes.

Information Related to Implementation of WMA

More than half of the agencies have sponsored research on WMA, primarily through university research or in-house research. A listing of information provided on the research projects can be viewed in Appendix B. Figure 12 illustrates some of the best management practices (BMPs) that agencies reported to effectively use WMA. The long list of responses is included in Appendix B.

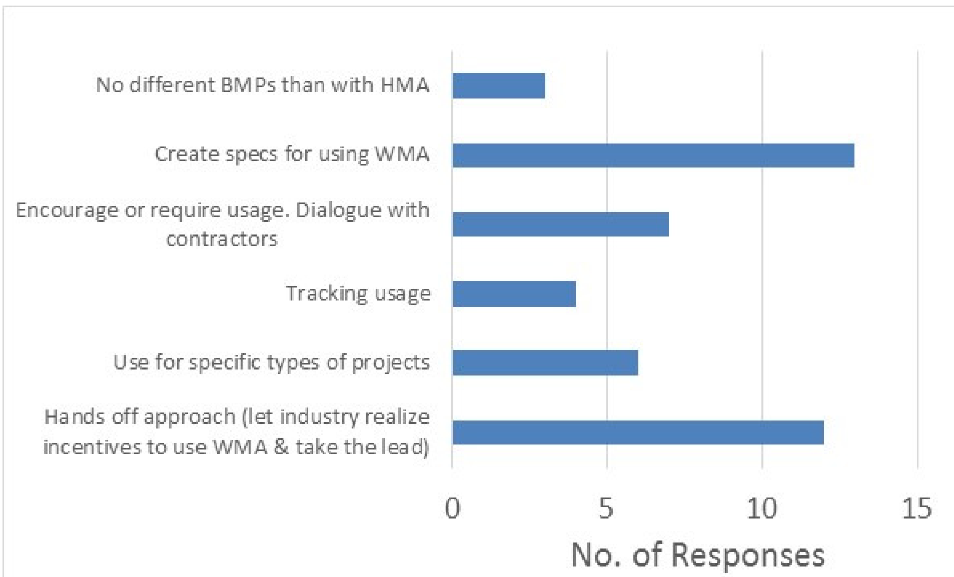

FIGURE 12: Categories of BMPs Reported for Effective WMA Usage

There were a few difficulties reported to be overcome for the implementation of WMA. For example, Kansas DOT does not require a temperature drop if WMA additives are used, so the additives are being used to aid with compaction and as anti-stripping agents. California DOT approved the WMA technology but using the same end result/performance specifications as for HMA. It cited that the presence of a WMA product representative at the project sites can serve as a way to overcome difficulties with WMA implementation.

Agencies were also asked to list some ideas on how to overcome barriers that agencies may face in increasing the implementation of WMA. These responses are generalized in Figure 13 and the full list is found in Appendix B.

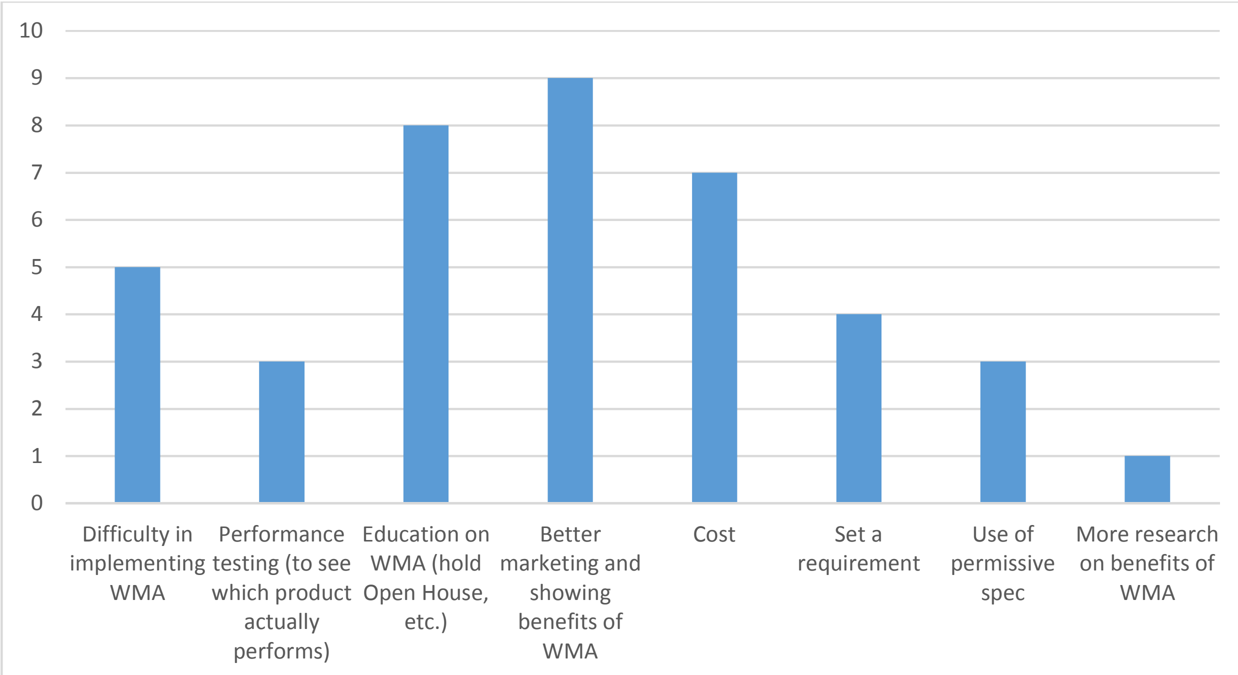

FIGURE 13: Categories of Ideas to Overcome Barriers to WMA Usage

Below is a sampling of the specific thoughts on how to overcome barriers:

- Alaska DOT: Educate the contracting community about the economic (compactibility, density pay bonus, less plant fuel usage) and environmental (reduced emissions, fumes) benefits of WMA usage. Offer cost incentives and provide mix design assistance;
- City of Bellingham: Work with the batch plants to become comfortable with the technologies available. Agencies need to just go for it and test a few small installations;
- DC DOT: Discuss benefits of the increased use of recycled materials with WMA as well as the environmental benefits and improved worker safety;
- Iowa DOT: 1) Conduct trials and open houses using some of the more common WMA technologies (with known successes), 2) Conduct workshops, speak at agency/industry meetings, etc., to promote the "green" aspects of WMA, as well as the potential cost savings due to reduced burner fuel requirements, 3) emphasize improvements in working environment due to reductions in heat and fumes produced vs. HMA;
- Louisiana DOTD: With the emergence of performance testing, it seems a lot of avenues will open regarding the freedom to try (or increase the use of) new technologies associated with WMA;
- Maryland DOT: Consider incentivizing the WMA usage by showing some merit to contractor, or mandate the use of it under certain circumstances in order to get real benefits of it;
- North Carolina DOT: Better define specifically what needs to be done by (or required of) contractors when using WMA. WMA has been "sold" to agencies and industry as the fix-all for asphalt: better coating, better mixing, lower fuel costs, less emissions, higher recycle content, better compaction, etc. However, no one has forced the contractors to change how they operate their plants when they switch to WMA and mixing cycle times

are the same, recycle materials are introduced into the mixer at the same point (but with lower mixing temperatures, but the same mixing times), etc. No one has forced contractors to slow production or change how their plants are set up to produce same-level quality of mix, but at lower temperatures. At the same time, all of the above are difficult to enforce for an agency when it is trying to use much less prescriptive specifications than ever before. The industry should lead the way in implementing best practices for the use of WMA; and,

- Pennsylvania: Start addressing the moisture susceptibility issue and gather large amounts of compaction data on a both HMA and WMA mixtures to show that WMA has a benefit (even just slightly) for the compaction of asphalt mixtures. This makes WMA better than HMA and then agencies will be more likely to embrace WMA.

Results of Industry Survey on Warm Mix Asphalt Usage and Implementation

A survey was also distributed to members of the asphalt paving industry through the state Asphalt Pavement Association (SAPA) executives and other industry members who are active in directing research related to warm mix asphalt. The survey was focused on: WMA usage and technologies; the construction and testing of WMA; the performance of WMA; practices and challenges related to WMA; and, ideas for overcoming barriers to increase the implementation of WMA. A total of 41 members of the asphalt paving industry (14 SAPA executives and 27 contractors or producers) responded to the survey and Figure 14 shows the states in which the industry respondents were located. The organizations that responded to the survey are listed in Appendix C of this report, along with the detailed results of the Industry Survey.

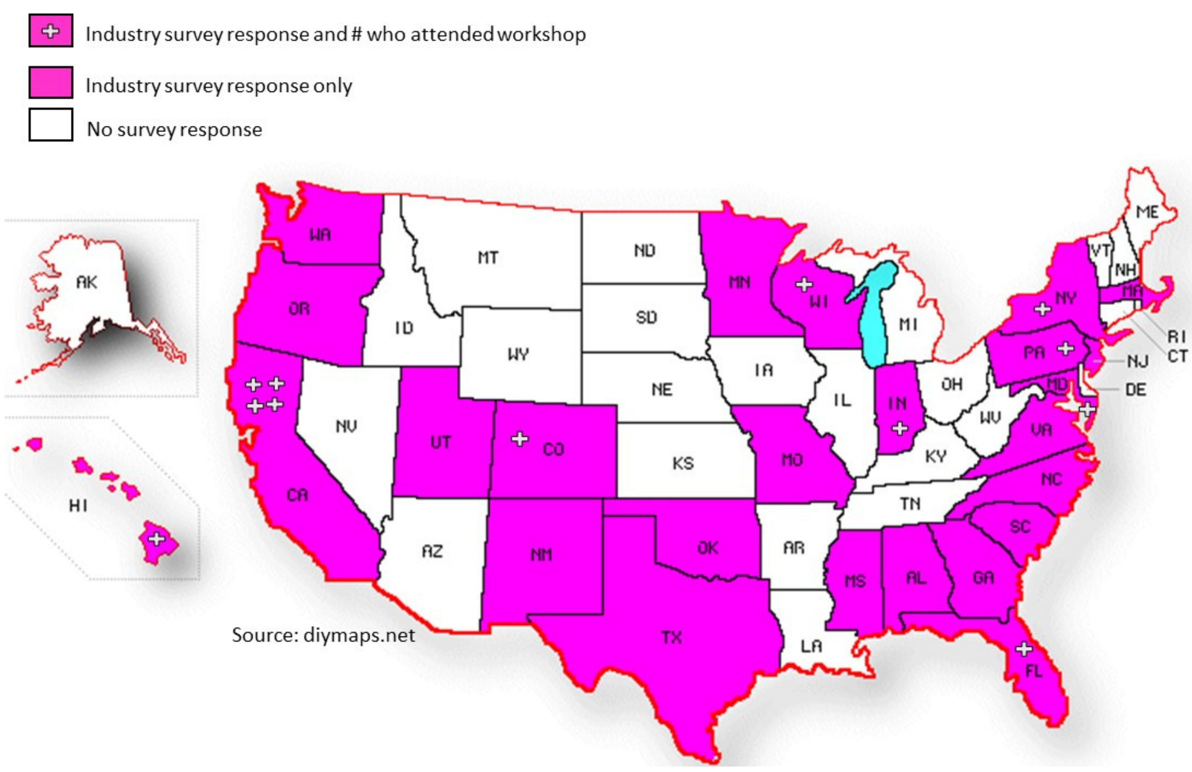

FIGURE 14: Summary of Respondents to Industry Survey on WMA Implementation

The survey consisted of 23 questions. The first question was similar to that of the Agency survey in asking respondents to identify how they would define WMA. There were 38% of respondents who defined WMA as mixture production at a specific reduced temperature. Nineteen percent of respondents defined it as the use of WMA technology and 17% of respondents defined WMA as a mix produced with the use of additives. Only five respondents defined WMA as a compaction aid. The list of definitions is shown in Appendix C.

Figure 15 shows the number of asphalt plants currently operated by each respondent. The responses returned as not applicable belonged to the SAPA executives. Approximately one-quarter of respondents are smaller contractors and one-quarter are larger contractors with more than 30 plants.

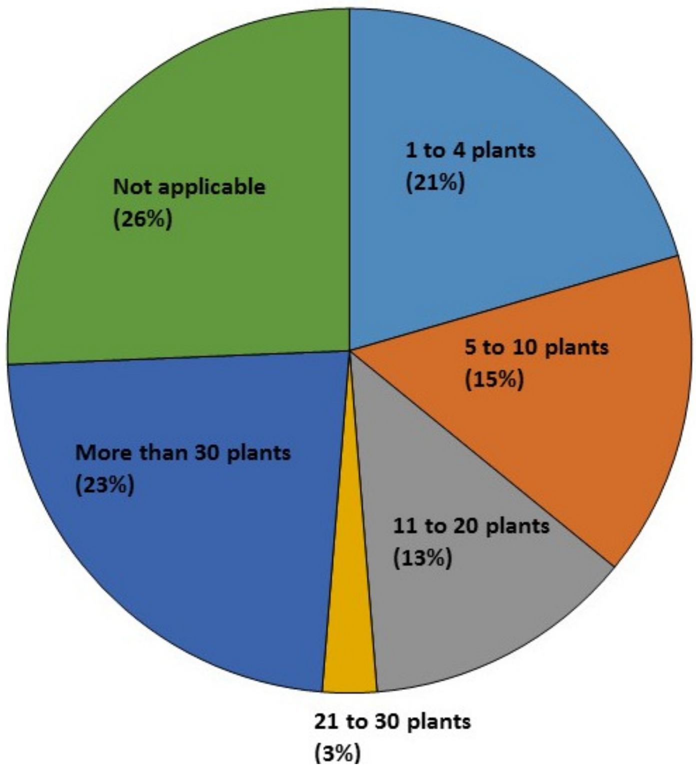

FIGURE 15: Number of Asphalt Plants by Paving Company

Information Related to WMA Usage

The amount of asphalt tonnage, and the estimated relative proportion that is WMA, produced for state DOT clients versus other customers (e.g., cities, counties, municipalities, port authorities, airports, turnpike or expressway authorities, or private/commercial customers) is captured in Table 4 by the most frequently-reported ranges of asphalt tonnage. It appears that for an equivalent total asphalt tonnage, the estimated portion that is WMA is similar for both types of customers at lower tonnage levels. However, at the higher tonnage range (1.5 to 5.0 million tons), the state DOT projects comprised more than 50% WMA twice as often as the projects for other customer types. The contractors paving more than 50% of their tonnage as WMA are located in Alabama, California, Maryland, Massachusetts, Minnesota, Oklahoma, Pennsylvania, Utah, and Washington.

TABLE 4: Total Asphalt Tonnage and Relative WMA Proportion by Customer Type

Customer Type	Total Asphalt Tonnage (percent of responses)	Estimated WMA Portion (percent of responses)
State DOTs	100,000 to 500,000 tons (30.0%)	1 to 10% (22.5%)
Other Customers	100,000 to 500,000 tons (23.1%)	1 to 10% (22.5%)
State DOTs	1.5 to 5 million tons (33.3%)	More than 50% (30.0%)
Other Customers	1.5 to 5 million tons (25.0%)	More than 50% (15.0%)

Approximately 30% of respondents have observed a reduced demand for WMA in the past few years. This observation came from companies operating in Alabama, Colorado, Florida, Georgia, Indiana, Maryland, Minnesota, New York, North Carolina, South Carolina, Utah, and Washington. Over 50% of the respondents expressed that the reason for the reduction was related to cost – either in the form of benefits in bid pricing or contractual incentives (Figure 16). Other reasons offered for the reduced demand for WMA included one state DOT's mandate of chemical warm mix additives being terminally blended, as well as the use of a permissive specification in another state in which contractors did not observe the benefits from WMA as originally thought.

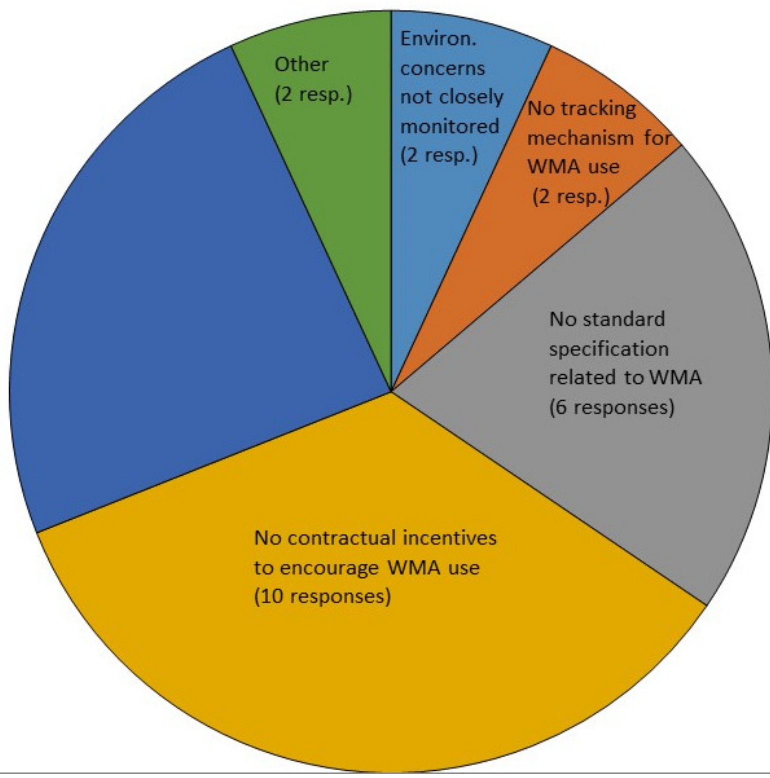

FIGURE 16: Reasons for Reduced Demand for WMA in Recent Years

Information Related to WMA Technologies

Industry respondents were queried regarding the WMA technologies and types of mixtures they have experience with. Figure 17 shows the various categories of WMA technologies along with the reasons why contractors choose to use them in paving construction. Overall, the majority of contractors reported using either chemical additives or foaming process for achieving better compaction, maintaining mix temperature over longer haul distances or duration times, extending the paving season or pave at night, and for lowering the target production or placement temperature for reduced emissions or for energy savings.

	Material Processing (e.g., LEA, hot-coated coarse aggreg. + moist fine aggreg.+ additives)	**Organic Additives (e.g., waxes, Zeolite)**	**Chemical Additives (e.g., surfactants)**	**Foaming Processing (e.g., water injection, Zeolite)**	**Hybrid Systems (e.g., water injection and surfactant)**	**Hybrid Systems (e.g., water injection and organic additive)**
Reasons for Various WMA Technologies	**Count**	**Count**	**Count**	**Count**	**Count**	**Count**
Not used to date	22	12	9	7	15	16
Used to achieve better compaction	1	8	30	28	10	3
Used to maintain temperature for longer haul distances or haul durations (due to congestion delays)	0	3	22	20	6	1
Used to target lower production or placement temperature for emissions or energy savings	1	5	25	21	7	2
Used to extend paving season or to allow paving at night (at ambient temperatures less than 40^0F)	0	7	26	19	5	2
State Demonstration Project	2	2	1	2	0	0
Can place mixture in thicker lifts in reconstruction projects	0	0	1	0	0	0
Handwork or workability	0	0	1	1	0	0
Increase use of recycled materials	0	0	1	1	1	0

FIGURE 17: WMA Technologies and Reasons Reported for Their Use

About 40% of contractors reported using either polymer-modified binders or antistrip additives with WMA regularly. Seventy-five percent (75%) of contractors regularly use WMA with RAP and 25% of contractors regularly use WMA with RAS or with a SMA design. Contractors in South Carolina are reported to be regularly using WMA for OGFC pavements.

Information Related to Construction and Testing of WMA

There were 85% of contractors who reported that it is easier to reach field compaction targets when constructing with WMA. Approximately 97% of the contractors felt this was achieved by using WMA as a compaction aid. Other reasons included use of foaming technology (1 respondent in Oregon), dropping the temperature by 30^0F or more (3 respondents in California, Florida, and New Mexico), and the mixture design approach used (5 respondents).

Figure 18 presents the data on the observed impacts of using WMA on constructability and shows that the impacts most-frequently observed on constructability include improved workability for a longer period of time, a longer time period in which to get compaction, and it is easier to reach compaction targets.

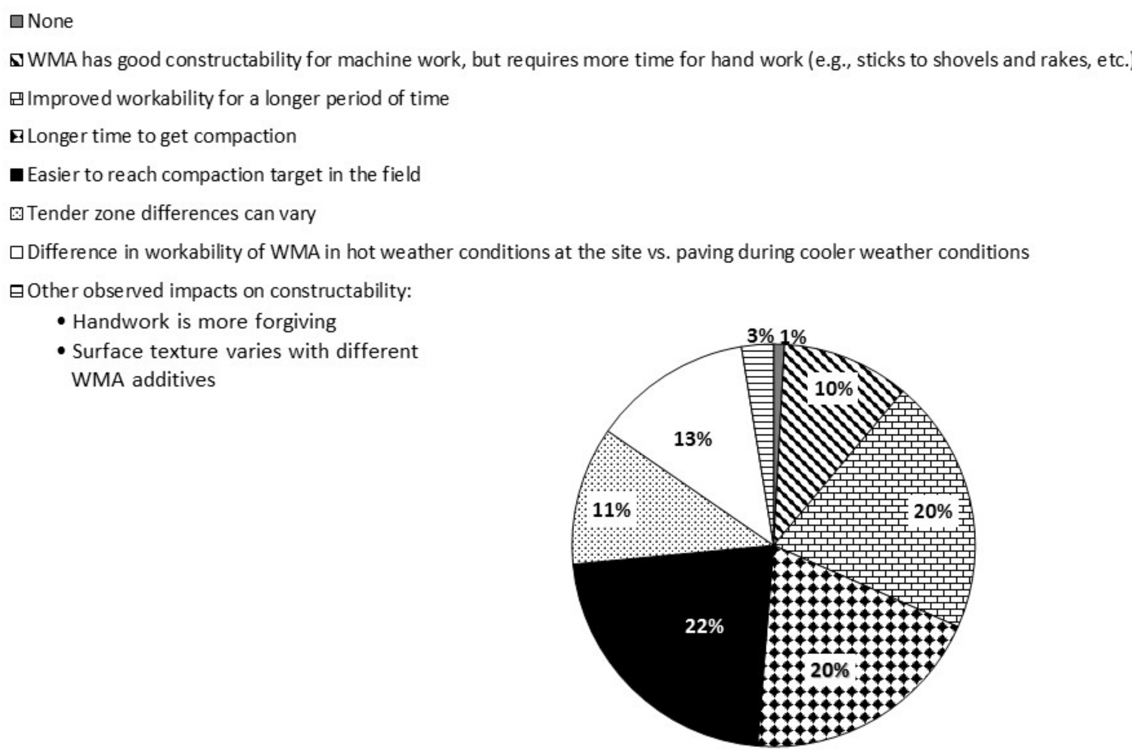

FIGURE 18: Observed Impacts of Using WMA Technologies on Constructability

Only two out of 37 contractors responded that they run any different laboratory or field tests on WMA, as compared to HMA mixtures. In Oklahoma, conditioning of the WMA is done for two hours before molding for lab-measured properties. In South Carolina, WMA mixes must meet the Indirect Tensile Strength specification requirement when they are used for the first time, and it is then tested once every 30 days.

Information Related to Performance of WMA

Respondents were asked to report any of the conditions that have been observed to significantly affect the short term or long term field performance of WMA, as compared to HMA sections. Figure 19 indicate that 65% of respondents found that no conditions affected WMA field performance any differently than they affect HMA field performance. There were seven respondents who noted that using higher percentages (more than 30%) of RAP affected WMA performance differently than with HMA and six respondents indicated that longer distances or haul times made for different field performance with WMA than for HMA. In addition, a respondent reported that some tenderness in the WMA has been observed during summer months in Florida. Contractors from Pennsylvania noted that liquid de-icing agents, such as potassium chloride, have also been reported to impact WMA differently than HMA pavements and that placing traffic on a WMA pavement at or slightly above 140^0 F sometimes results in a sheen developing on the pavement which may or may not be slippery. Another Pennsylvania contractor relayed that they waited for the next day to fill in core holes and noticed that the edges of the core holes had curled into the hole for a WMA mix using SonneWarmix at 0.75% of asphalt content. It was further noted that the higher dosage caused this to occur (in July 2015), but field observations have not shown any pavement problems to date.

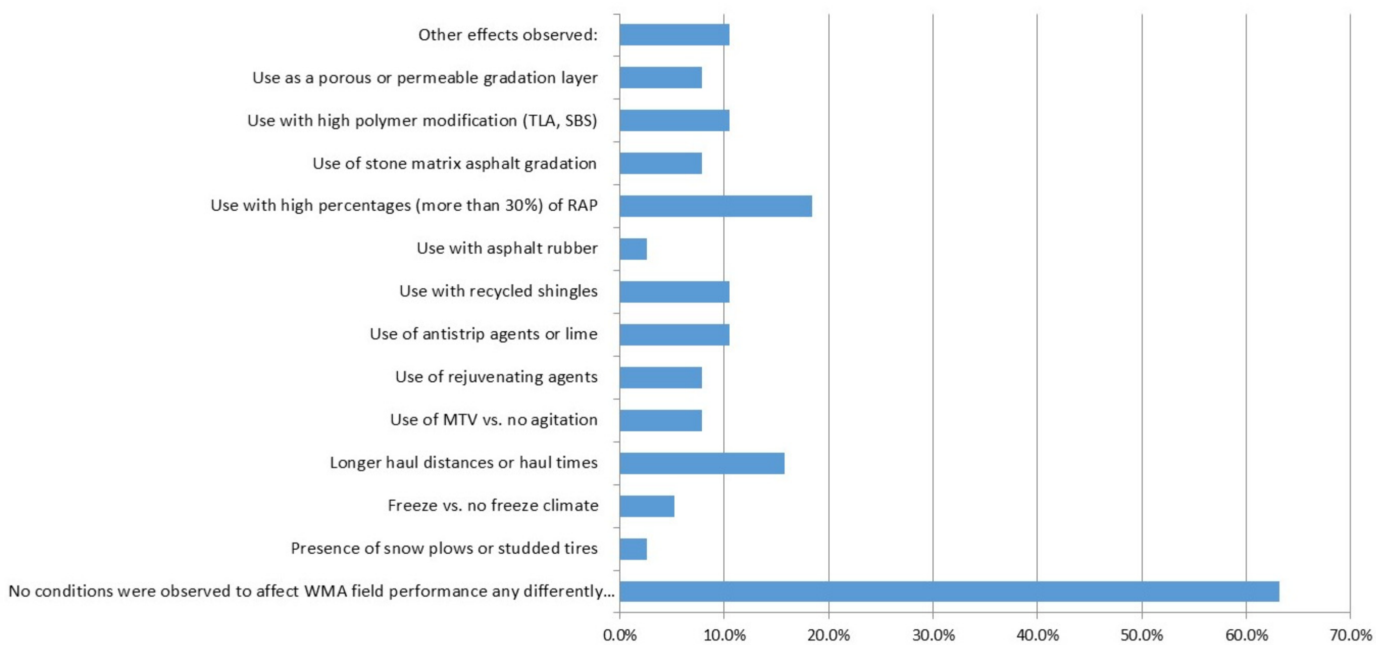

FIGURE 19: Observed Impacts of Using WMA Technologies on Field Performance

The survey also asked whether any benefits have been observed with the use of WMA. Figure 20 presents the results and shows that the most-frequently reported benefits were reduced emissions, energy conservation at the plant, improved workability in the field over a longer period of time, and improved worker conditions. One respondent in Pennsylvania noted that the paving crews like the decrease in higher temperature fumes. Other reasons included the asphalt temperatures held more constantly for longer haul distances or durations and extension of the paving season.

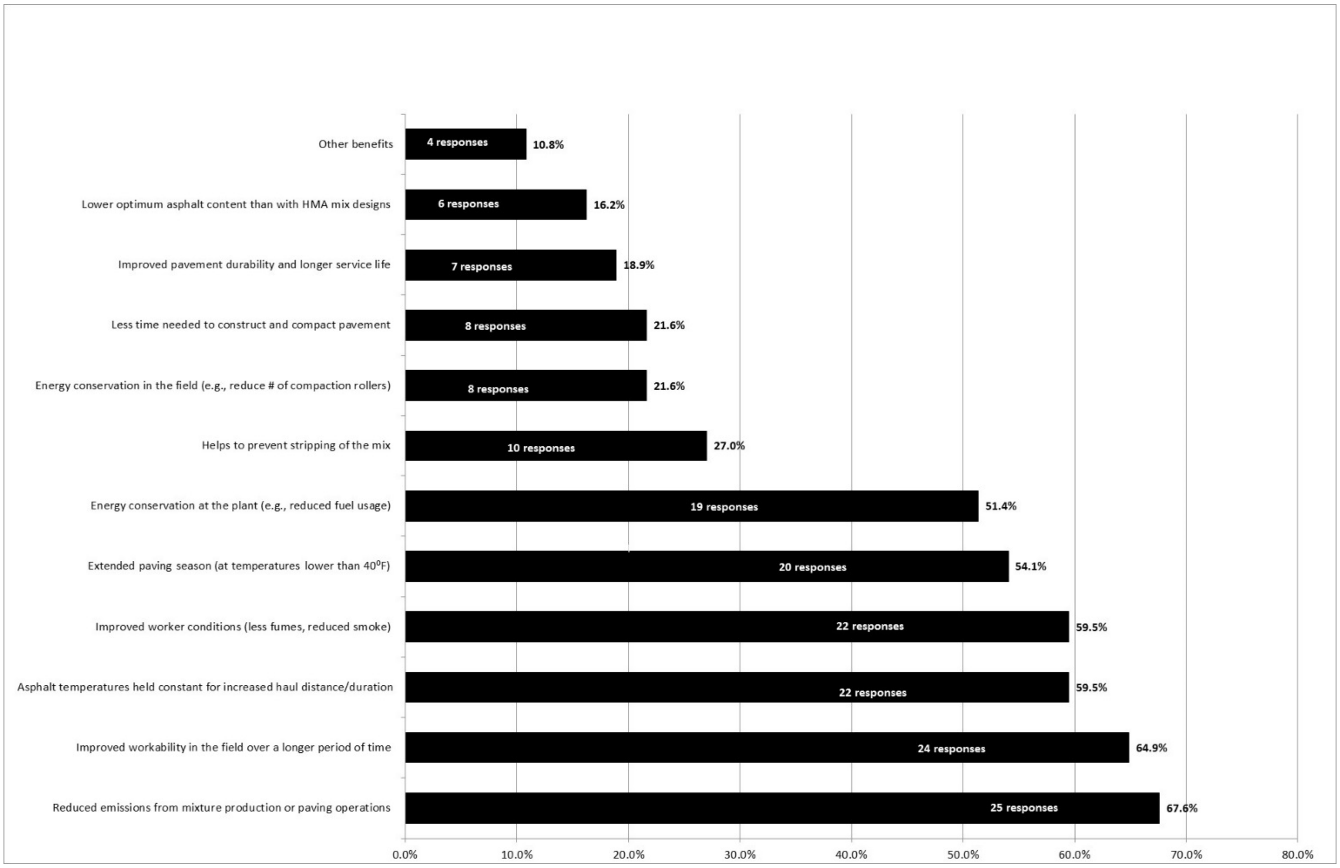

FIGURE 20: Observed Benefits of Using WMA Reported in Industry Survey

Other benefits included an increased film thickness and less differential in the effective binder content as compared to the effective binder content with HMA mixtures reported by a contractor in Pennsylvania. A contractor in Minnesota notes a benefit as the ability to maintain mixing temperatures over 300^{0}F while a contractor in Georgia noted the benefit of WMA was to replace lime as an antistrip additive. Finally, a contractor in Washington indicated that use of WMA in porous mixtures exhibits slightly lower rates of permeability loss (i.e., long-term draindown of binder).

Practices and Challenges Related to WMA

The industry survey asked for examples of best management practices (BMPs) for using WMA effectively on paving jobs. Figure 21 generalizes the various categories of BMPs reported and indicates that the education of stakeholders involved with WMA is essential as well as the use of temperature adjustments. There were five respondents who reported that the same BMPs used for conventional HMA would apply. A contractor in Pennsylvania noted that it is routine to achieve 1.8% better compaction with WMA without any changes to the paving process. In South Carolina, WMA is used primarily on OGFC mixtures and has been found to help with the workability of those mixes. A contractor in California reported a BMP to be monitoring the production temperature of WMA as opposed to compaction on the grade as this is impacted by haul time, lift thickness, and ambient temperature. A major temperature reduction in porous mixtures was reported as a BMP by a contractor in Washington and a contractor in Wisconsin reported a BMP to be increasing the WMA temperature by 30^0F when doing handwork.

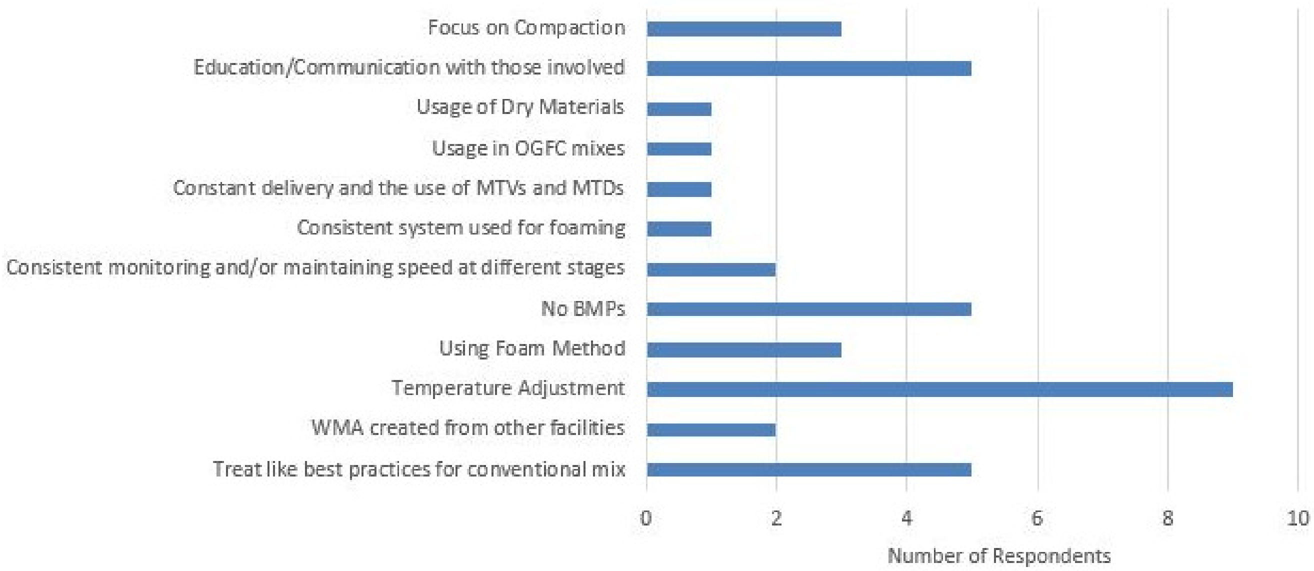

FIGURE 21: Types of Best Management Practices for WMA Reported by Industry

When asked about the types of difficulties that the paving industry had to overcome in implementing WMA, Table 5 shows that the cost of WMA technology additives, the inconsistent demand for and lack of familiarity with WMA by different customers, and the use of prescriptive specifications that require minimum production temperatures (or that restrict tonnage) are the most-frequently reported. A few contractors in Minnesota, Oklahoma, and Pennsylvania reported that they have had no difficulties with implementing WMA. Other difficulties reported included asphalt cement storage at the plant, the incorporation of 0.5% antistrip additive into WMA, and employee complaints about fumes when using amine-based chemical WMA additives.

TABLE 5: Types of Difficulties in Implementing WMA

Types of Difficulties Reported in Implementing WMA	Response Count
Cost of WMA technology additives	25
Inconsistent demand for WMA technologies among different customers (DOT vs. local agencies vs. airports vs. commercial)	21
Lack of familiarity with WMA among different customers (local agencies, airports, commercial vs. DOT)	21
Prescriptive specifications that require minimum production temperatures or that restrict tonnage	17
Meeting agency specifications or approved product list (e.g., restrictions on approved WMA products by agency)	15
Contractual issues with customers (e.g., no incentive clauses, last-minute switches from WMA to HMA, etc.)	14
Maintenance and upkeep of equipment at the plant (e.g., foaming tips get clogged and need constant cleaning; bags clog more often and require more frequent cleaning, etc.)	12
Lack of quantification of the cost benefits of using WMA technologies	9
Cost of equipment to produce the WMA technology	9
Lack of information on the impacts of combining WMA technologies with other mix elements like PPA, lime, fibers, SMA, etc.	8
Batch vs. drum plant gives different (or insignificant) fuel cost savings	7
Initial installation, set-up, and logistics to continue use of WMA	5
Convincing upper management to run WMA jobs on a more frequent basis (for better operation of equipment over time, greater cost savings, more competitive bid pricing, etc.)	3
Hard temperature restrictions by agencies. For example, defining WMA as maximum of 270^0F without regard to the conventional mix being modified	1
DOT needs to limit the number of ESAL ranges, so more consistent mix can be produced. The vast range of available mixes has handicapped operations, due to not being able to set-up plants for a more fixed temperature range; e.g., adjusting flighting to keep baghouse temperatures above dew point	1

The respondents were asked to name one barrier that prevents the more widespread use of WMA by paving contractors. The barriers reported all fell into the four general categories shown in Figure 22 and the ideas proposed by respondents to overcome the barriers are shown in the categories in Figure 23. Most ideas centered on improvements to education related to WMA and refining its definition and criteria; however, one idea provided was to allow contractors to meter chemicals at the plant, similar to the process used with hydrated lime.

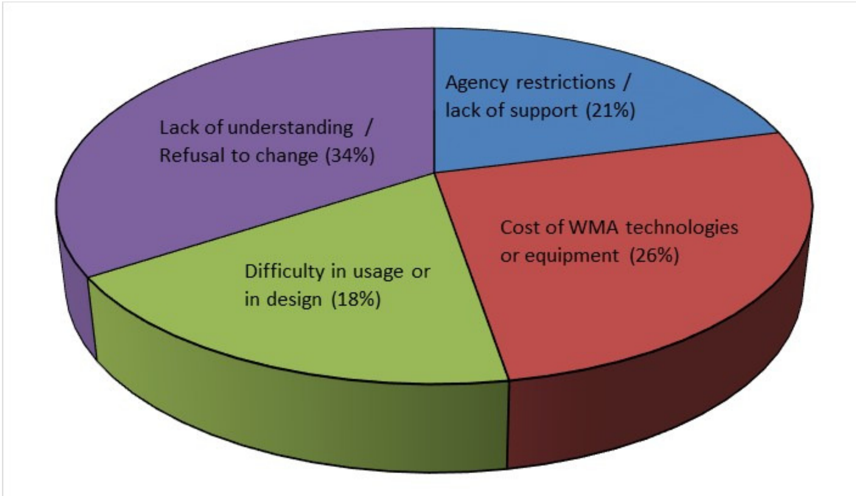

FIGURE 22: Types of Barriers to More Widespread Use of WMA

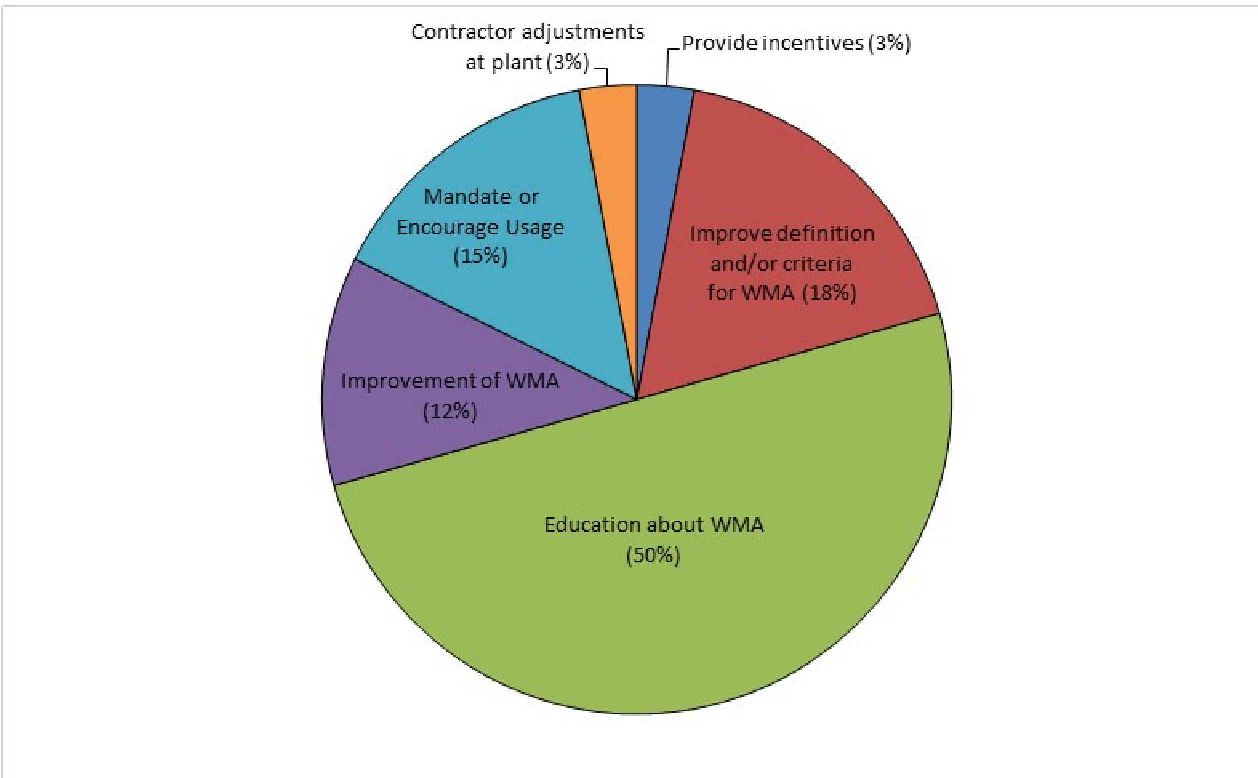

FIGURE 23: Ideas for Overcoming Barriers and Increase Implementation of WMA

Contractors in Pennsylvania reported the following ideas for increasing implementation: 1) hold township or municipal meetings regarding WMA versus HMA performance and promote WMA through LTAP, State Association of Township Supervisors, Boroughs Association, etc.; 2) marketing WMA to the public as a "green" technology; providing LEED-type credits and/or engineering credits on commercial projects that encourage the use of WMA; and, 4) eliminate

HMA from the state's Department of General Services bituminous Invitation to Qualify (ITQ) contracts because the local agencies procure asphalt mix from this contract.
A respondent from Colorado reported its company requires the use of WMA for all night paving, early season paving, and late season paving jobs. Another idea provided by an industry respondent was to encourage agencies to see the value in 1) any temperature reduction from the conventional asphalt mixtures and 2) the improved and more consistent mat compaction achieved with the use of WMA, but also use less prescriptive specifications. An idea was offered for conducting more research on how WMA improves pavement performance over the long term (and calculation of life cycle costs) and how it works with the new performance tests, as well as how to deal with the cost of WMA at bid time. The full list of ideas is provided in Appendix C.

Results from Agency and Industry Interviews on Warm Mix Asphalt

A number of informal interviews were conducted with both agencies and paving contractors as part of additional information gathering. The results of these interviews are summarized in the following sections.

American Public Works Association (APWA) and National Association of County Engineers (NACE)

Informal interviews were conducted with members of the American Public Works Association (APWA) Transportation Committee and the National Association of County Engineers (NACE) Pavement Preservation Committee. The goal was to establish an understanding of the status on the use of WMA by the majority of local agencies. This is intended to supplement information on the state-of-the-practice by other users of WMA. Some of the key elements discussed were: how locals have been using WMA; how it is defined by local agencies; and, general description of local agency experience with WMA, any implementation efforts, usage levels, specifications used, etc.

According to the APWA's Greenroads Board of Directors, the cities are generally quicker to respond to changing trends, such as by using WMA. For the most part, the impetus for cities to award paving projects using WMA is motivated by cost savings. Most owners were reported to operate with permissive specifications (e.g., contractors can use WMA if they want for a local project, as long as they exhibit some level of minimal performance). The cities observed that WMA use is driven by contractor economics. The APWA members also noted that WMA is becoming widely available and has been used on approximately 30 to 50% of local agency asphalt paving jobs. Cities embraced the use of WMA first, due to their more progressive policies. Counties eventually followed suit, but more due to actual fuel savings and cost benefits, as compared to concerns with emissions and compliance with air quality goals.

To date, the NACE Pavement Preservation Committee has focused primarily on pavement issues related to milling, rehabilitation, rejuvenating, various forms of in-place recycling, etc. WMA has not been discussed because, for the most part, the local agencies follow the State DOT procedures and practices. As part of the interview preparation, an informal questionnaire on the status of WMA usage and performance was distributed by the head of the NACE Pavement Preservation Committee to the Iowa County Engineers Association. Three counties in Iowa

(Plymouth, Dickinson, and Cedar counties) responded to the questionnaire stating they had used WMA on local paving projects. Two of the WMA projects were produced using Evotherm and one project had used a foaming technology. All of these WMA pavements were reported to be performing successfully. The Iowa counties follow the Iowa DOT's 2011 supplemental specification for WMA (as part of the Iowa DOT Standard Specification), which allows counties to easily let bid documents through the State DOT with the WMA specification number assigned. However, it was observed that the cost of paving with WMA isn't always competitive with HMA. In addition, it was reported that there is a general lack of education and discussion on WMA at the county level, except presentations occasionally given at the state asphalt conference.

Asphalt Paving Contractors in North Carolina and Pennsylvania

Phone interviews and informal data gathering were conducted with asphalt paving contractors in North Carolina and Pennsylvania. These were done to collect data at more of a grass-roots level to supplement the information gathered by the surveys. The findings of these efforts are reported in the sections below.

North Carolina Asphalt Paving Contractor

The QC manager from a paving contractor in North Carolina was interviewed regarding his company's experience with WMA technologies. In one of their early projects constructed more than 10 years ago, both a WMA and a HMA control section were constructed. The WMA used included the foaming technology, Aspha-min®. The emissions were measured at the plant when producing the HMA and the WMA. A significant reduction in emissions was recorded. In addition, an improvement in density was realized with the WMA, based on cores taken at the time of construction and also extracted after two years in service. The energy savings at the plant was also quantified and amounted to about 6% on energy costs (e.g., 440 BTU for 1 ton of aggregate to 1^0F). Plant data indicated that there was a lower VMA and lower asphalt content as a result of using the WMA technology. A TSR value of 55 was measured on the WMA; however, it has been exhibiting good performance for 10 years.

A number of city paving contracts requested WMA over a period of time, specifically to be produced at reduced emissions in order to meet local air quality requirements (in non-attainment areas). These projects appear to be performing well in the field; however, the cities haven't specified the use of WMA in recent years. Similarly, the state DOTs (North Carolina and South Carolina) do not specify the use of WMA technologies and the local agencies mainly look to the state for guidance on the use of WMA. Recently, one city specified a high RAP (35%) mix with Evotherm added for workability; however, it was noted that use of Evotherm was more expensive than using the conventional antistrip additive. Another challenge to using more WMA was reported to be that if foaming equipment (like the Double Barrel Green system) is not used daily, then the equipment becomes more difficult to maintain over time.

Southeastern Pennsylvania Asphalt Paving Contractors

Informal interviews were conducted with members of nine asphalt plants in the southeastern Pennsylvania, northern Maryland and northern Delaware regions. Those interviewed included two laboratory technicians, four mid-level quality assurance (QA) managers, two regional QA managers, and one senior manager. Four out of nine contractors have drum plants and the other five contractors operated batch plants.

Of the nine contractors that were interviewed, five indicated that they prefer to pave with WMA (all but one operated drum plants). Of the remaining four, two had chosen HMA (both operated batch plants) and the other two specified that plant operators prefer HMA while construction crews would rather work with WMA. A few main reasons reported for a preference of using HMA included cost (HMA is cheaper to produce), easier to deal with, and it puts more heat in baghouse. Those who favored WMA noted that it enables a longer workability, achieves better compaction, can be used at lower ambient temperatures (less than 40^0F), and generates less fumes than HMA.

When asked about the advantages of WMA production and placement, eight out of nine discussed the workability of the pavement. Additionally, most of the contractors interviewed stated that WMA allows for an extended paving season. Other advantages mentioned by multiple contractors included longer haul distances or durations (due to congestion delays), extended laydown time, and a period in which to reach compaction in the field. It was also noted that it provides better working conditions for construction crewmembers.

Challenges reported regarding the production and placement of WMA included the initial setup and installation of foaming equipment and the need for extra equipment add-ons and frequent maintenance. The extra equipment could be problematic because more equipment increases the likelihood of a part breaking. The fumes associated with chemical additives and issues with stickiness when handwork is required were also reported as issues related to using WMA. A few of the interviewees mentioned that WMA has a higher cost per ton (as compared to HMA) and that there are high replacement costs for broken parts related to equipment used for producing WMA.

In order to produce WMA, every contractor listed Evotherm as the primary additive. Most of the contractors interviewed concluded that Evotherm is easier to work with and more useful in cold weather. One contractor also stated that WMA produced with Evotherm resulted in better compaction results in the laboratory. Foaming was also mentioned as a method to produce WMA; however, it was mentioned that it is harder to use when ambient temperatures are less than 40^0F and the foaming tips tend to clog repeatedly at the colder temperatures.

FHWA LTPP Program

An interview was conducted with a member of the FHWA LTPP team in order to find out more about the states that are participating in the SPS-10 experiments, in an attempt to better ascertain which states are leading or lagging in terms of implementation of WMA. It was reported in the interview that the use of permissive specifications (i.e., the contractor's option to use WMA) was cited by practitioners as a possible hindrance to the implementation of WMA. Anecdotal evidence indicates that nationwide, paving contractors are using WMA technologies more as an antistrip additive with HMA (at hot temperatures) rather than as a classically-defined WMA. For example, states such as North Carolina and Pennsylvania were reported to terminally-blend in additives such as Evotherm into all HMA mixtures as a method for preventing or postponing the occurrence of stripping.

The LTPP SPS-10 experiments will collect data on the field sites for ten years and Weigh-in-Motion (WIM) data will be gathered at every site. The states (and Canadian provinces) who are participating in the SPS-10 experiments are:

• Arizona (*two sites*) • Florida • Manitoba • Missouri • Nevada • New Mexico
• Oklahoma • Oregon • Ontario • Texas • Washington

United States Army Corps of Engineers (USACE)

An interview was conducted with a Research Civil Engineer in the Airfields and Pavements Branch of the Research and Development arm of the USACE. The USACE Airfields and Pavements Branch researches and develops specifications for the Navy, Army, and Air Force; however, any specifications are implemented through another arm of the military – specifically the Transportation Systems Center of the USACE.

Research on WMA for airfield pavements has been ongoing for more than five years and included a series of laboratory tests along with a full-scale WMA airfield and control HMA section constructed in the field. The field sections included conventional HMA (control), chemical-additive WMA, foamed WMA, and organic (Sasobit) WMA. Thickness measurements were taken along with the use of grinding (to ensure each pavement section was built to the exact same thickness) prior to the start of the field experiments. A temperature-controlled heavy vehicle simulator (HVS) setup was used to simulate the most severe aircraft loading (an F-15 aircraft load with a 325 psi tire pressure) at a very high temperature. The asphalt for the field experiment sections was produced and compacted using same process. All of the sections were found to have similar (low) moisture in both the HMA and WMA. One finding was that the temperatures of the WMA were more consistent throughout the mat. In addition, the foamed WMA section was observed to perform better than all of the other sections. Performance was evaluated by observing rutting, moisture susceptibility, binder properties, low-temperature cracking, durability, and workability. Other results of the subsequent reports were included in the topical bibliography in Appendix A.

As a result of the successful WMA performance exhibited from the laboratory and field experiments, the USACE developed a Guide Specification for WMA for airfields (note: the focus on airfields because the research was funded by the US Air Force), but there has not yet been a WMA specification developed for paved roads for military installations (typically the DOT specification for that state is used). The UFGS 32 12 15.16 *Warm-Mix Asphalt for Airfields* (2015) was developed as a tailored option with the HMA specification and the only differences between the HMA and WMA mix design include: production temperature of 270°F (minimum plant temperature for binder and aggregate heating); laboratory compaction temperature of 250°F; and, grade the asphalt binder with the additive included (except for in the case of foamed asphalt). It should be noted that RAP is not permitted in the surface course on airfields except on shoulders and for shoulders there is a maximum limit of 30% RAP when combined with WMA.

It is currently unknown how many (if any) projects have used the WMA specification on Department of Defense (DoD) airfield installations. One airbase in Seattle was paved using both WMA and HMA and premature damage was reported. Upon further investigation, it was found that the Contractor had used a highway mixtures design for the WMA on the runway instead of the UFGS specification. The issues with damage occurred mainly when aircraft turned to go onto runway but the problems were observed only in the HMA sections and not in the WMA sections, as previously thought. The pavements were investigated by the USACE Airfields and Pavements

Branch and it was reported that no significant difference in groove closing existed between HMA and WMA pavements.

There are a few commercial airports known to have WMA and HMA sections. The taxiways at Boston's Logan Airport were paved in 2007 with WMA (using Sasobit) adjacent to HMA sections. The performance was monitored for eight years and the same damage accumulation in WMA was found to occur at the same rate and to the same extent as in the HMA sections. Although the performance of both sections was good, in 2015 the WMA section was milled and replaced due to the airport's maintenance and funding cycle. Unfortunately that action relinquished the opportunity for the collection of long-term performance data for those sites. It is possible that the Massachusetts Port Authority could be contacted to see whether it has information on those WMA sections and whether there were grooved taxiways that experienced premature closing of the grooves (as compared to the HMA taxiway sections). The airports in Anchorage, Alaska, and Chicago (O'Hare), Illinois are thought to have WMA sections, but it is not clear whether or how the performance of those sections are being tracked.

Identification of Gaps, Needs, and Ideas from Warm Mix Asphalt Peer User Exchange

The FHWA WMA Peer Exchange meeting was held on February 14 and 15, 2017, in Denver, Colorado, at the Colorado DOT Materials Office and was facilitated by the FHWA Resource Center. Six states were represented at the meeting, along with their FHWA Division Office counterparts: Colorado, Florida, Maryland, Nevada, Pennsylvania, and Ohio. The exchange was intended to address many similar goals of the NCHRP 20-44(01) project such as experience and usage of WMA; lessons learned with WMA; and, the current and future WMA implementation processes. Specific topics included items related to the specification process (e.g., how WMA is defined, how new products are approved, the mix design and construction criteria, usage data), construction process (e.g., mix design practices for WMA, plant and construction equipment practices, and mix production and control requirements), and the acceptance program process (e.g., testing and acceptance of WMA, materials QA, long term performance data, and use with reclaimed materials). Members of the Colorado asphalt contractors, suppliers, and testing consultants were also among the meeting participants and were invited to provide an industry perspective on what is and what is not working with WMA.

A detailed discussion was conducted as the result of a breakout session on "what is working, what is not" with WMA. These notes are summarized into the general categories of Gaps, Needs, and Ideas, as they relate to this NCHRP 20-44(1) project. The FHWA Resource Center has published the proceedings of the peer exchange and can be found at: http://co-asphalt.com/wp-content/uploads/2017/05/WMA-Peer-Exchange-Final-Proceedings.pdf.

Gaps

1. There is not a formal outreach plan in place for local agencies on the topic of WMA. Local agencies remain uneducated on the requirements, benefits, and processes associated with WMA. These agencies own more than 70% of the roadway mileage in the United States.
2. A shift from permissive specifications that allow WMA to a type of specifications that proactively encourage the use of WMA.
3. To date, the implementation of WMA has been based on economic decisions. However, there has been a lack of consideration of engineering decisions in the overall process.

4. In some states, the state DOT product approval process is relatively intensive which makes it more difficult for contractors to justify trying new products.
5. WMA should be marketed with incentives to show that it results in decreased life cycle costs over time. As part of that, pavement management systems currently don't track pavements in terms of their mixture types (e.g., project level data). Gap exists in terms of identifying the key indicators that should be tracked for WMA technologies in order to include those as part of a life cycle cost.
6. Measuring tonnage doesn't really track the benefits of WMA (only the units paved) and there is very little (if any) information on the potential benefits of WMA to user delay costs, work zone safety, and long-term performance benefits (i.e., maintenance activities scheduled at less frequent intervals). A gap exists for describing the more holistic metrics that define the use of WMA technologies.

Needs

1. Education on WMA needs to be provided to other customers who are served by the asphalt paving industry such as the local agencies, airports, and commercial owners. However, it needs to be clearly defined who the messenger should be (the DOT Central Office, the state DOT and/or the state asphalt paving association executives?) and who the audience should be (the DOT Districts, local agencies, smaller paving contractors?).
2. There is a need to develop performance specifications that include incentives for contractors to bid and build WMA pavements. However, a need exists to establish what the performance criteria should be and which criteria are appropriate considering different applications (e.g., parts of the state (climate and topography), roadway functional classification, truck volumes, local material source quality, pavement performance history (distress types and amounts), etc.). The performance specification would still have to account for volumetric controls. At the same time, the specifications should tie into the common goal of "get in, get out, stay out" and contribute to the goals of improved safety and operations (e.g., better compaction with WMA begets better performance over time and less frequent maintenance which lowers work zone exposure and user delay costs).
3. There is a need to document the long-term performance of pavements built using WMA. Doing so would allow for better estimates of the life cycle costs of WMA pavements in order to obtain a better view of the cost benefits. This could help move the tools and use of WMA forward. The outcome of addressing this need would be to establish appropriate performance indicators that can formally document what quantifies WMA as equal or better performance as compared to HMA.
4. There needs to be consensus on the definition of WMA (or does there?...). For example, warm mix can be placed at warm temperatures when used to reduce emissions or extend haul distances (or durations) and it could be placed at hot temperatures when used as a compaction aid.
5. There is a need to conduct back-end tracking of maintenance activities (e.g., chip seals, crack sealing, etc.) for WMA in order to establish a true life cycle analysis.
6. Leadership at the national and state level is required to show how by electing to use WMA over HMA, there is a positive impact on safety and operations efficiency. The improvement in production can lower bid item unit costs. In addition, electing to pave with WMA could lead to improved work zone safety (e.g., because the MOT setup is only active for 18 days rather than 20 days).

7. In order for performance specifications to be implemented and to be successful, incentive clauses of some sort are needed either during the bidding stage and/or final acceptance stage. However, for this to happen, support of upper management at the state DOTs and at the FHWA Division Offices would be helpful.

Ideas

1. Leadership should be taken to include other asphalt paving stakeholders in the overall WMA implementation initiative. It is possible that FHWA and NAPA could start a dialogue with the APWA and NACE to develop a strategy for outreach and education. Either way, the state DOTs must take part in leading the locals because of the nature of the Federal-aid project delivery process.
2. In the effort to estimate the cost benefits (over the life of a pavement built with WMA), it would be helpful to identify effective and efficient data collection techniques that facilitate long-term monitoring. The current FHWA LTPP SPS-10 experiments may provide some insight into the appropriate and cost-effective (both in terms of actual cost and staff effort) ways that long-term performance monitoring could be accomplished by DOTs.
3. The low-bid environment makes contractors risk-averse to bidding WMA. Can the contract review process include a clause that encourages the use of WMA (perhaps through a technical score in addition to the cost element)? For example, a contract might say that the paving project must be "built in 18 days, at 94% density, meeting both texture and ride quality numbers" such that these factors are built into the bid documents as an incentive clause. It should be noted that this idea would require the support of upper management at the state DOT and FHWA Division Office.
4. Expand the Approved Product List at state DOTs to show a differentiation between the two primary uses. For example, the list might show one WMA option as a "green technology" where the temperatures drop more than "x^0F" and could even show those products in a green font in the online list. For the other WMA option, it would show as being produced at near HMA temperatures but is used as an additive for a compaction aid. These technologies could be shown in a different color font. A byproduct of this idea is to make it simpler for the contractors to know what they're bidding on and for the local agencies to have more choice in terms of using the DOT's list to set up their bid documents for contractors.
5. Ideas for the types of appropriate (more holistic) metrics for WMA were generated to think beyond just the economic and environmental benefits. These ideas included: (1) increased production tonnage; (2) reduced duration of construction or "take up the MOT faster", indicating that both DOT Maintenance and contractor laborers are exposed to traffic in an active work zone for less time; (3) safety improvements; (4) less maintenance if WMA performs better over time; (5) lane closure strategies (night vs. day hours; paving at lower ambient temperatures and extending the paving season); and, (6) the ability to calculate user costs in order to justify incentives built into the paving contracts.

RESULTS FROM WORKSHOPS ON WARM MIX ASPHALT IMPLEMENTATION

This chapter summarizes the results of the various workshops and other outreach efforts designed to gather feedback for the specific topics shown in the subsections below. The details for each of these sections are addressed in the workshop proceedings in Appendix D.

Introduction

There were multiple outreach activities conducted in this project for gathering feedback and encouraging interactive discussions on WMA. These included a two-day workshop (by invitation only), a half-day workshop, multiple presentations at regional asphalt annual meetings, and through the TRB Straight-to-Recording program entitled "Dialogue on Implementation of Warm Mix Asphalt: Present and Future" (http://www.trb.org/ElectronicSessions/Blurbs/176886.aspx), all of which were accompanied by feedback questionnaires. These approaches were used to gather feedback from a wide audience of stakeholders.

The two-day workshop was conducted on May 8-9, 2017, at the Beckman Center of the National Academies of Science, Engineering, and Medicine in Irvine, California. There were two follow-up surveys with the participants: one conducted within one month after the workshop and the other conducted six months after the workshop survey. The feedback from all of the various outreach activities formed the basis of the workshop proceedings included in Appendix D.

Redefining Warm Mix Asphalt

One of the primary goals of the outreach activities in the project was to explore the idea whether WMA should be redefined. There were some participants who sent their thoughts on the definition of WMA to the research team after the workshop. The feedback received on WMA definitions is summarized below:

1. Asphalt mixes modified with a various technologies (including water foaming, chemical additives, and organic waxes) to achieve improve compactability, in-place density, and sustainability. These mixes have an expanded range of working temperatures and haul distances without a diminution of short- or long-term performance.
2. WMA defined as a mix produced with significant emission reductions, defined as 25% or 50% less than those currently produced at temperatures less than 300^0F. [This definition is independent of process or additive. Products or processes not achieving this reduction in temperature would be defined as compaction aids (rather than warm mix asphalt)].
3. WMA is an asphalt mix made by a foaming process or with an additive that:

a. Reduces production, plant, placement temperature of less than 300°F for an asphalt mix application;
b. Improves workability and compaction of the asphalt;
c. Provides potential reduction of plant and site emissions;
d. Provides possible cost savings for the Contractor and/or Owner; and,
e. May provide a longer pavement life cycle.

Based on the feedback majority, it appears that the definition to be considered in moving forward is suggested to be:

> "Modified asphalt mixes produced with various technologies – including water foaming, chemical additives, and organic waxes – that have the capacity to be used with lower production temperatures (at a maximum of 300 degrees F), but can also be used at normal production temperatures to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance."

Barriers to and Disincentives Limiting the Use of WMA

There was much discussion during the outreach events related to the perceived barriers to implementation of WMA. Challenges reported to implementing WMA generally included the cost of WMA technology additives, the inconsistent demand for and lack of familiarity with WMA by different customers, and the use of prescriptive specifications that require minimum production temperatures (or that restrict tonnage).

Cooperative Actions by Agency and Industry

There were a number of ideas related to how agencies and industry can work together to better utilize WMA and more fully benefit from its use. Some of the ideas for overcoming barriers and to help increase the implementation of WMA include to:

- educate the public and contracting community about WMA compared to HMA performance, economic benefits (compactibility, density pay bonus, less plant fuel usage) and environmental benefits (reduced emissions, improved worker safety, increased use of recycled materials) of WMA usage;
- market WMA to the public as a "green" technology;
- provide LEED-type credits and/or engineering credits on commercial projects that encourage the use of WMA;
- incentivize the WMA usage by showing some merit to contractor, or mandate the use of it under certain circumstances in order to get real benefits of it (e.g., require WMA for all night paving, early season, and late season paving jobs);
- encourage agencies to see the value in 1) any temperature reduction from the conventional asphalt mixtures and, 2) the improved and more consistent mat compaction achieved with the use of WMA, but also use less prescriptive specifications;
- conduct more research on how WMA improves pavement performance over the long term (and calculation of life cycle costs), how it works with the new performance tests, and how to deal with the cost of WMA at bid time; and,
- use performance testing to encourage the use of new technologies associated with WMA.

Quantifying the Impacts of WMA over the Long Term

Attendees were asked to provide an update on the actions that their agency, organization, or company are taking, or are planning to take, based on their takeaways from the workshop. The results showed that the majority of participants planned to review the WMA definition with their state/jurisdiction/agency partners, to review the details of current asphalt specifications, and to review current contracting practices (or work with their agency partners to do so).

Participants were also asked as part of the outreach activities whether the collection of pavement management system (PMS) data would include definitions of which warm mix additives or processes were used and/or how projects are being classified as WMA, in order to more effectively track the performance of WMA in the future. There were seven participants (86%) that replied they would start identifying WMA specifically in their PMS systems and one participant (14%) responded that "this is something we will need to discuss with our Pavement Management team and then implement, if possible."

Some other ideas for quantifying the impacts of WMA over the long term included creating a question-and-answer Q&A blog for WMA applications for the DOTs, and the development of useful tool such as an AASHTO Standard (similar to the ASTM C494 for concrete admixtures) that could organize and categorize technologies into a simple-to-use chart format that would help people select WMA products or technologies and instruct how best to implement them.

Future Implementation Efforts and Ideas

Based on the review of the notes from the various workshops held and feedback provided by the participants in these workshops, there were eight implementation plans generated by the research team. The format of each of these plans was to include: the need or basis for the plan; key actions suggested to further the implementation plan; and, the proposed implementation leads. The ideas are based on workshop participants' ideas and are not recommendations to the FHWA or any other part of the federal government. These ideas for implementation plans are presented on the following pages, in the following order:

1. WMA Community of Practice
2. Annual NAPA-FHWA Survey
3. Outreach
4. Tracking WMA Usage and Performance
5. Modifications to Existing Research Needs Statements
6. Developing Research Needs Statements
7. WMA Website
8. Informational Briefs

Additionally, a one-page briefing on WMA was drafted which could be used for distribution to agency executives or division chiefs. This WMA project brief can be found in Appendix E.

1. Implementation Plan for WMA Community of Practice

Need/Basis:
Feedback was provided at the two-day workshop that indicated strong interest in forming a FHWA and/or AASHTO Lead States group to participate in and guide outreach activities and form the Community of Practice membership to serve in Peer State Assistance. Some of the items continuously raised in the survey data and at the two-day meeting were:

- a forum in which information could be shared between agencies (e.g., create an online repository for Agency approved product lists (APL) related to WMA technologies);
- a way to share the results of case studies (e.g., use of performance-based specifications on projects, use of new technologies, benefits of contract incentives, etc.); and,
- a process for agencies to learn from each other (e.g., efforts to disseminate information about WMA to stakeholders, especially through peer-to-peer contact).

Key Actions:
A community of practice would allow for NAPA, AASHTO, FHWA, and APWA to get coordinated communication out to their networks. This would primarily be a mechanism for online interaction and access to information.

There are examples of successful models of community of practice websites that exist. For example, the FHWA's Manual on Uniform Control Devices (MUTCD) Community of Practice (https://mutcd.fhwa.dot.gov/mutcdcop.htm) is free to access online by registering and creating a user account. It functions by allowing users to add new discussion questions or to respond to existing questions, and the discussion questions are sorted by topic area. There is a "Subscribe to Discussion" option which allows registered users to be kept up-to-date on all topic areas on the discussion board, along with an "alert" option which sends users a message when something new is posted on the site. The website is a part of the Transportation Research Collaborative Site (TRCS) and there are rules of conduct that each user agrees to by confirming he/she understands that the site is intended to foster collaboration and provides tools allowing discussion (ideas and opinions) feedback and interaction among users (no selling products or services or attacking public policy).

There is also the American Public Works Association's infoNOW (http://infonow.apwa.net/). The APWA infoNow site states: "*This resource connects you with public works professionals who have experience in the areas you have questions about. These topic-based groups provide members with a platform for sharing questions, answers and real-life experiences. Subscribe to one or all, it's up to you.*"

Proposed Implementation Leads:
This effort could be led by the FHWA and/or NAPA, perhaps through a maintenance contract through the Asphalt Institute or other consultants. The success of the Community of Practice will certainly be tied to the level of interaction and responsiveness. It is suggested that this website be monitored (perhaps by an employee of FHWA and one from NAPA) to ensure its impact, relevance, and that it's being used in the way that it is intended. The APWA infoNOW site requires membership – this may be an appropriate mechanism for the WMA community of practice as well, whether it is free membership or restricted (i.e., membership comes through NAPA (for industry), AASHTO (for state and provincial agencies), and APWA (for local agencies and other transportation agencies like turnpike authorities, etc.). Access would best be restricted through NAPA, AASHTO, and APWA.

2. Implementation Plan for Annual NAPA-FHWA Survey

Need/Basis:

Feedback was provided at the two-day workshop that indicated the current format of how warm mix asphalt is defined in the *Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage* annual survey produced by NAPA and FHWA (as part of Info Series 138) would benefit if it were revisited.

The current definition in the survey is: "Warm-mix asphalt is the generic term for a variety of technologies that allow the producers of asphalt pavement material to lower the temperatures at which the material is mixed and placed on the road by 10 to 100 degrees F."

The basis of concern is that in the way the data is currently collected, there is no distinction made between warm mix asphalt produced with or without an actual temperature reduction.

A question was posed in the TRB Straight-to-Recording webinar feedback survey, and in the 6-month follow-up survey for the two-day workshop participants, to solicit options for the redefinition of warm mix technologies.

Key Actions:

Revisions to the NAPA survey as related to the redefinition of warm mix would be helpful. By making the definition of WMA more distinct, there may also be more benefit in better clarification for the environmental product declaration (EPDs).

Based on the NCHRP 20-44(01) survey feedback, it is proposed that WMA be defined for the 2017 Info Series 138 report as:

"*Modified asphalt mixes produced with various technologies – including water foaming, chemical additives, and organic waxes – that have the capacity to be used with lower production temperatures (at a maximum of 300 degrees F), but can also be used at normal production temperatures to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance.*"

It may also be useful to provide information in the future in terms of how the survey data can be specifically applied for more targeted implementation of warm mix, and for dissemination to a broader audience to leverage information from the survey. For example, one idea was for cooperative efforts at the regional (or national) level to establish a benchmark for when tracking of WMA no longer needs to be done. It is plausible that this survey could capture the information that establishes this benchmark.

Related to the subject of quantifying the impacts of WMA usage, it is suggested that the questions in the survey been revised or added to collect information on some key items suggested by stakeholders during the course of the NCHRP 20-44(01) project.

Proposed Implementation Leads:

This effort could be led by a combination of the FHWA headquarters and NAPA.

3. Implementation Plan for Outreach

Need/Basis:
A great deal of discussion at the two-day workshop and subsequent stakeholder events centered on better increasing the amount and quality of outreach related to implementation of warm mix technologies. It would be beneficial to provide education opportunities to LTAP centers, DOT Managers, other agencies (local agencies, FAA, USACE, EPA, tribal nations, turnpike or tollway authorities, etc.), and state DOTs.

Key Actions:
It is proposed that informational videos related to warm mix technologies be developed that are easily accessible for on-demand viewing on the internet, similar in format to the FHWA Federal-Aid Essentials (http://www.fhwa.dot.gov/federal-aidessentials/).

These videos should be kept to 15 minutes or less (*educational research has shown that the ideal viewing time is 7 minutes*), per the post-workshop survey feedback received for this project. At a minimum, the following topics would be helpful (in no particular order):

- The advent of warm mix technologies (a brief history)
- AASHTO NTPEP for warm mix technologies,
- State DOT QPLs and listing of approved warm mix technologies,
- Warm mix technologies combined with recycled or reclaimed materials,
- Environmental benefits of using warm mix technologies
    - Public health (project scale (workers) and regional level (community health)
    - Energy savings (haul distance, equipment, and during production)
    - Emissions reduction (GHG and global warming potential (GWP))
- Defining features of various warm mix technologies in the lab,
    - Foaming equipment and procedures
    - Additives
- Defining features of various warm mix technologies in the field,
    - Increased compactibility
    - Equipment impacts (reduction in number of rollers and/or roller passes)
- Constructing asphalt mixtures with warm mix technologies
    - With temperature reduction
    - Without temperature reduction
- Operational benefits of using warm mix technologies
    - Extension of paving season and cool weather paving (local economy benefits)
    - Haul duration and distance (transportation costs)
    - Work zone (MOT) duration (worker safety, impacts on user costs)

Proposed Implementation Leads:
This effort could be led by a combination of the FHWA Resource Center, TRB, AASHTO Transportation Curriculum Coordination Council (TC3), and the NAPA (perhaps through the Asphalt Institute). Engagement of the LTAP centers, the FHWA Division Office pavement and materials engineers, state DOT Local Program Office staff, state DOT Specifications and Estimates office, and the ACEC is critical to expanding outreach related to the emphasis of technical aspects of WMA through the education of these partners.
A subset of these videos would be helpful if targeted to the environmental and economic aspects (related to sustainability) of WMA, intended for agency and industry executives: FHWA Division Administrators, DOT Executives (Directors of the Office of Planning, Design, Construction, Materials, Maintenance, and the Chief Engineers), state Asphalt Paving executives, the APWA Transportation Committee, League of Cities, and the NACE Pavement Preservation Committee.

4. Implementation Plan for Tracking WMA Usage and Performance

Need/Basis:
Many of the questions that were posed as part of the various workshops, webinar, and survey data all pointed to the need to track the use and performance of warm mix technologies to get at these very strategic answers. Dedicated and effective tracking of WMA across regions or by another means will help to build the evidence and clarify environmental aspects. At this time, there are no data reporting processes that tie WMA directly into asset management.

As an example, many members of industry mentioned that contracts which include incentives will encourage contractors to bid with WMA and thus, help to increase its use to gain the associated benefits. Establishing an approach for recording and comparing mat density and longitudinal joint densities (between WMA and HMA pavement sections) is an example of how to support the agencies in making the case for creating contract incentives and establishing the criteria for these incentives.

Feedback from the workshop in New England indicated that it would be beneficial for a tool to be developed for contractors that shows the savings and profit that result from the use of WMA, and that this information be distributed to Industry members.

Key Actions:
Develop a template of key information for Industry members (or Contractors) to collect for tracking usage of warm mix technologies, such as:

- emissions (measured directly, or estimated based on plant temperature readings);
- energy savings (estimated from plant fuel usage monthly/annually/period of time);
- range of dates for the paving season (e.g., ran pavement jobs in March through December);
- paving job duration (MOT setup for "x" number of days);
- number of compactive rollers used on paving projects (assesses whether less equipment was required); and,
- contract incentives achieved (Yes/No?).

Develop a template of key information for agencies to collect for tracking performance of warm mix technologies, either by state or by region, e.g.:

- update to pavement management system and tie in to capital projects lists with WMA identifier added (i.e., create data platform for integration for effective monitoring);
- maintenance schedule (i.e., does the use of WMA on a project allow for longer periods between required maintenance on pavement?);
- contract bid award prices;
- number of public complaints filed (and compare for projects with HMA vs. projects with WMA);
- common PMS database with WMA identifier which would be accessible to all agencies in the state (with assistance from state APA in populating and maintaining this database);
- explore the use of tools such as StreetSaver or other types of annual updates to PMS and collect data on "before and after" rutting, cracking and texture impacts at the network level.

Some key metrics that could be established by the Implementation Leads that will be revisited annually in order to help in setting the standard of practice for when tracking of WMA is no longer needed and it is considered "fully implemented".

As data is compiled and analyzed, the long term impacts of WMA could be advertised on fact sheets to be disseminated through LTAP, State APAs, and AASHTO.

Proposed Implementation Leads:
This effort could be led by the NAPA along with FHWA, AASHTO, and possibly the Asphalt Institute.

5. Implementation Plan for Modifications to Existing Research Needs Statements

Need/Basis:
It would be helpful to examine existing research needs statements and suggest modifications for including evaluation of WMA in the proposed projects. Particularly, it may be worth considering whether research needs statements (RNS) regarding pavement management systems that are collecting performance information should be modified.

Key Actions:

- Search for existing RNS in the TRB database
- Make proposeded modifications to the RNS
- Modify the RNS in the database

Proposed Implementation Leads:
The research team has completed the first two key actions. Suggested modifications for existing RNS and are included in Appendix E with changes tracked.

These changes would have to be approved by the appropriate sponsor(s) and then the RNS would have to be updated in the database. This could be led by the Panel or FHWA.

6. Implementation Plan for Developing Research Needs Statements

Need/Basis:
Based on the discussion during and following the workshop, several items were identified that could require the development of RNS for future projects:

- WMA Synthesis project
- A project funded through the NCHRP 20-07 series to write a Standard Practice to go with AASHTO M320 and a Recommended Practice for using warm mix technologies.
- A project to determine the temperature thresholds for WMA

Key Actions:

- Write the RNS or Scope of work for the different projects
- Submit the RNS to AASHTO/database

Proposed Implementation Leads:
The research team has developed draft versions of the RNS and Scopes of Work that are presented. These draft versions (included in Appendix F) would best be reviewed by the various TRB asphalt committees for subsequent submission for consideration to AASHTO.

7. *Implementation Plan for WMA Website*

Need/Basis:
The existing WMA website that was developed by the FHWA WMA TWG and NAPA (http://www.warmmixasphalt.org/) is out of date. The website was originally developed "to promote the understanding of warm-mix asphalt during its research and development phase in the United States" (*quote from website disclaimer*). Based on discussion at the workshops and other feedback received during this project, there was strong interest in redesigning and relaunching the website to reflect the current state of implementation and use of WMA in the US and provide resources for agencies and contractors looking to expand use of WMA. The feedback from the workshop and following discussions is that the site would best be structured as a Community of Practice, similar to the FHWA Safety MUTCD COP and to the APWA list-serve that allows people to post questions and answers.

Key Actions:

1. Website Development
    - Evaluate existing content and design
    - Work with end users to develop new content and organization
    - Possible content:
        - Definition and general description of technology types and applications
        - Lead states group
        - NCHRP research that is upcoming or is ongoing
        - Example projects
        - NAPA survey results
2. Website Maintenance

Proposed Implementation Leads:
The website could be redesigned under a separate contract. It is possible that this could fall under the general work tasks included in the FHWA cooperative agreement "Development and Deployment of Innovative Asphalt Pavement Technologies".
FHWA and NAPA jointly could host and maintain the site.

8. *Implementation Plan for Informational Briefs*

Need/Basis:
Much of the available information on WMA is in the form of technical reports and journal papers that are not effective for dissemination to transportation agency managers (e.g., Chief Engineers, mayors) and industry executives. Short (1-2 page) informational briefs on various WMA topics written for this audience would be helpful.

Key Actions:

1. Identify topics (preliminary suggestions listed below)
    - Outcomes from NCHRP projects related to asphalt mixtures with warm mix technologies,
    - Topics covered in the video series (presented in point 3 above),
    - Peer state assistance opportunities,
    - Combining warm mix technologies with recycled materials (RAP, RAS, rubber, etc.).
2. Write briefs
3. Disseminate briefs

Proposed Implementation Leads:
Briefs could be written by FHWA or under a separate contract. It is possible that this could fall under the general work tasks included in the FHWA cooperative agreement "Development and Deployment of Innovative Asphalt Pavement Technologies". Dissemination could be done via FHWA, NAPA, and the redesigned WMA website.

CONCLUSIONS

Introduction

In this chapter, the key findings and conclusions from the NCHRP 20-44(01) project are summarized. Knowledge gaps and barriers to implementation and expanded use of WMA identified through the literature review, workshops, and surveys are outlined with suggested future efforts to address those issues.

Conclusions

One of the key findings from the project is that WMA technologies continue to be attractive to agencies and contractors for a range of reasons that include environmental and economic benefits related to lower production temperatures and construction benefits related to increased workability and ability to achieve compaction at lower temperatures, allowing for late season paving and longer haul times. Results of the literature review and surveys indicate that, in general, the overall performance of WMA is similar to HMA in the field. WMA was reported to have higher susceptibility to rutting and lower susceptibility to cracking initially, with similar performance reported after one to two years of time in-service. Moisture sensitivity of mixtures varied, with no overall trend with respect to WMA showing better or worse performance than HMA.

Surveys of agency and industry representatives conducted at the beginning of the project clearly showed that WMA has a range of definitions across the country and that there is no clear consensus on what is meant by WMA. Therefore, a primary objective of this project was to develop a consensus definition that incorporates the different types of technologies and the different applications of those technologies. Based on discussions during various workshops and feedback from follow-up surveys, the consensus definition proposed is as follows:

> *WMA (warm mix asphalt) = Modified asphalt mixes produced with various technologies— including water foaming, chemical additives, and organic waxes— that have the capacity to be used with lower production temperatures (below 300 degrees F), but can also be used at normal production temperatures, to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance.*

Barriers or disincentives to implementation and/or increased usage of WMA were identified through the two-day workshop and feedback obtained from various meetings and surveys.

Cooperative actions and future implementation efforts to address these issues were also identified through the workshops and surveys. These are detailed in the workshop proceedings in Appendix D and the detailed implementation plans in Chapter 4. A summary of the barriers and possible actions needed to remove or minimize those are summarized in Table 6.

TABLE 6: Summary of Barriers Identified and Possible Cooperative Actions for WMA Implementation

Identified Barrier/Disincentive	Cooperative Actions	Associated Implementation Plan (Number)[a]
Specifications that are restrictive, conflicting, or otherwise create disincentives to use of WMA; lack of specific bid or line items	Change to end-result or performance-based specifications Incentivize the use of WMA through innovative project award techniques/funding Standard of practice in AASHTO format	RNS through NCHRP 20-07 for Standard Practice to go with AASHTO M320 and Recommended Practice for WMA (6)
Restrictive, unclear, or time-consuming certification and approval process	Change to end-result or performance-based specifications More effective use of NTPEP	Encourage use of NTPEP through training/outreach (3)
Lack of experience and knowledge of agency staff and upper management; no champions in positions to make decisions	More effective training documents and resources for targeted audiences Case study sharing and mechanism for agencies and contractors to learn from each other	Development of Informational Briefs and Videos (8) WMA community of practice and website update (1, 7)
No clear quantification of savings in low bid environment; full impacts of WMA use from production through long term performance are not considered holistically	Incentivize the use of WMA Clear communication of benefits for agencies and contractors	Addition of WMA to existing RNS in PMS topic areas (5) WMA community of practice and website update (1, 7) Template for tracking WMA information (4)
Lack of effective and efficient technology transfer and communication	More effective training documents and resources for targeted audiences	Development of Informational Briefs and Videos (8) WMA community of practice and website update (1, 7)

Identified Barrier/Disincentive	Cooperative Actions	Associated Implementation Plan (Number)[a]
Discomfort with change and lack of experience with WMA, especially with some production concerns and new products – from both agencies and contractors	Case study sharing and mechanism for agencies and contractors to learn from each other Incentivize the use of WMA through innovative project award techniques/funding	Development of Informational Briefs and Videos (8) WMA community of practice and website update (1, 7)
Lack of documentation and dissemination of long-term WMA field performance, accurate tracking of WMA use	Ties to asset management, database platform and integration for effective monitoring Case study sharing and mechanism for agencies and contractors to learn from each other	Addition of WMA to existing RNS in PMS topic areas (5) Development of Informational Briefs and Videos (8) WMA community of practice and website update (1, 7) Revisions to annual NAPA-FHWA survey (2) Template for tracking WMA information (4)
Remaining technical questions on how to design and evaluate performance, lack of evaluation/analysis tools (LCCA)	Continued research on laboratory conditioning, performance testing, and tool development	Addition of WMA to existing RNS (5)
Management of risk and liability	Clear communication Incentivize the use of WMA through innovative project award techniques/funding Performance metrics	WMA community of practice and website update (1, 7)

[a]as designated in Future Implementation Efforts and Ideas section

Suggested Future Research

There are some broader ideas for future research which were generated as part of the discussion feedback with many of the participants who contributed to this project's results. These are presented in Table 7 along with the basis for the suggestion.

TABLE 7: Ideas for Suggested Future Research That Supports WMA Implementation

Proposed Future Research	Rationale
The development of a clear methodology to quantify the environmental benefits would provide many benefits. For example, the determination of the highest asphalt mix production temperature at which asphalt mixes can be produced without a significant increase in emissions is of benefit to the asphalt industry. The research outcomes would help to identify the critical temperature to produce most asphalt mixes without significant emissions. One possible initiative could be including this research as part of the next round of FHWA's EDC innovations.	By conducting this research, measurable benefits could be identified to encourage asphalt producers to continue advancement of WMA. At this time, many producers elect to use HMA instead because of the high maintenance associated with producing WMA at the asphalt plants and, as a result, contractors do not see any clear advantages.
Establish a clear method to quantify the cost savings and performance advantages over HMA. This could include an interactive spreadsheet type tool that is programmed with various key criteria supporting the automatic calculation of a cost and cost savings with use of WMA. It is possible that the research scope include expertise in the Business Economics and Marketing sector to get to a better understanding of market analysis and how contractors can remain competitive when consistently bidding with WMA. This research may also provide a better sense of the appropriate pricing for WMA use and the establishment of its life cycle cost.	Engineering advancements made over the past several years have demonstrated the technology exists which can support agencies moving from prescriptive or permissive specifications to performance-related or performance-based specifications. There is a need to show a direct comparison of the cost per ton (with a predicted pavement life of "x" years) for WMA vs. HMA to owners.
Develop a concise guidance tool that clearly shows the criteria for when WMA will be the most economical and beneficial choice for paving. This research could take the format of a chart that is based on information such as the level of traffic (ADT), anticipated ESALs, the pavement thickness, local environmental concerns, the time of year paving, haul distances, land use features (urban vs. rural), compaction level, joint density requirements, etc.	Typically asphalt plants must add additional equipment or processes to produce WMA, and as such, there has to be a long term reason for producers to make the investment. It is important to consider that many of the roads are owned by counties, cities, and municipalities who typically desire pavements that last but at the least possible cost, due to competing interests for their capital funds.
It would be beneficial to research more innovative project award techniques that can encourage and place value on the use of WMA (perhaps through a new Federal-aid grant program for projects that use sustainable materials and can demonstrate the benefits of their use).	Feedback through this project has indicated that for WMA to be used on a more widespread basis, dedicated funding or contractual changes to encourage its use are necessary.
It is advisable to support research efforts on appropriate laboratory conditioning protocols to simulate short and long-term aging in the field, performance tests, and appropriate thresholds that can be used at the mix design and quality control/quality assurance levels.	There are a number of lingering questions related to the standard practice for quality assurance testing of WMA prior to production and placement.

ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials
ADT – Average Daily Traffic
AMPT – Asphalt Mixture Performance Tester
APT – Accelerated Pavement Testing
APWA – American Public Works Association
ASTM – ASTM International
BMP – Best Management Practice
DoD – United States Department of Defense
DOT – State Department of Transportation (state highway agency)
DSR – Dynamic Shear Rheometer
ESAL – Equivalent Single Axle Load
FHWA – Federal Highway Administration
HMA – Hot Mix Asphalt
HVS – Heavy Vehicle Simulator
IDT – Indirect Tension Test
ITQ – Invitation To Qualify
LCCA – Life Cycle Cost Analysis
LEA – Low Energy Asphalt
LTAP – Local Technical Assistance Program
LTPP – Long Term Pavement Performance
MOT – Maintenance of Traffic
MTD – Material Transfer Device
MTV – Material Transfer Vehicle
NAPA – National Asphalt Pavement Association
NCHRP – National Cooperative Highway Research Program
NTPEP – National Test Product Evaluation Program
OGFC – Open Graded Friction Course
PMA – Pavement Management System
PPA – Polyphosphuric Acid
QA – Quality Assurance
QC – Quality Control
RAP – Reclaimed Asphalt Pavement
RAS – Recycled Asphalt Shingles
RNS – Research Needs Statement
RTFO – Rolling Thin Film Oven
SAPA – State Asphalt Pavement Association
SBS- Styrene Butadiene Styrene
SMA- Stone Matrix Asphalt
SPS – Special Project Section (of the LTPP Program)
TLA- Trinidad Lake Asphalt
TSR – Tensile Strength Ratio
USACE – United States Army Corps of Engineers
WMA – Warm Mix Asphalt