Evaluation of Thin Hot Mix Asphalt Overlay

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FINAL REPORT

June 20, 2016

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Pennsylvania Transportation Institute

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

CONTRACT # 355I01
PROJECT # 110807

Technical Report Documentation Page

1. Report No. FHWA-PA-2016-005-110807	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Evaluation of Thin Hot Mix Asphalt Overlay		**5. Report Date** June 20, 2016 **6. Performing Organization Code**
7. Author(s) Mansour Solaimanian, Shelley Stoffels, Scott Milander, and Dennis Morian		**8. Performing Organization Report No.** LTI 2016-25
9. Performing Organization Name and Address The Thomas D. Larson Pennsylvania Transportation Institute The Pennsylvania State University 201 Transportation Research Building University Park, PA 16802-4710		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 355I01 - 110807
12. Sponsoring Agency Name and Address The Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064		**13. Type of Report and Period Covered** Final Report: 6/21/12 – 6/20/16 **14. Sponsoring Agency Code**
15. Supplementary Notes COTR: Neal Fannin, nfannin@pa.gov, 717-775-8099		

16. Abstract

Preserving the road surface and maintaining it at a proper functional level is essential to safe transportation. Among alternatives for pavement surface treatment, thin asphalt overlays have been utilized and promoted by several states to serve this need. To evaluate the performance of such overlays and develop relevant specifications, PennDOT initiated a four-year research program with Penn State. The project carried several major objectives. One was to assess best practices for design and construction of such mixes through field application of three pilot projects and conducting necessary laboratory testing. Second was to evaluate the performance of such mixes placed in these pilot projects through visual survey and pavement condition measurements. Third was the use of existing advanced technology such as thermal imaging and ground-penetrating radar to determine the uniformity of such mixes during placement in regard to temperature and density. Finally, it was the intention of the project to develop relevant specifications and guidelines for thin asphalt overlays. Field evaluations, in general, indicated satisfactory performance of these roads. Considerable improvement has been achieved in terms of ride quality and skid resistance after placement of thin asphalt. The exception is SR 0220, for which the skid numbers were already high and skid resistance improvements were not as significant as for the other two projects. Field measurements have indicated minimal rutting, fatigue cracking, and raveling at all three sites. Reflective cracking has been the dominant distress at all three projects. Overall, it can be assessed that both construction and performance of the three pilot projects has been successful based on observations within this limited period of time. The results of the study were reflected in newly developed construction specifications for 6.3-mm mixes as well as construction guidelines and a manual of best practices.

17. Key Words Thin asphalt, pavement, distress, rutting, cracking, GPR, thermal imaging		**18. Distribution Statement** No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 24	**22. Price** N/A

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

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EXECUTIVE SUMMARY

There is widespread recognition that highways are among the most valuable assets of the nation. Preserving this asset in a quality way and maintaining it at a proper functional level is essential to the overall health of the communities served. Deterioration of our highway system will endanger public safety and will adversely impact the economy and people's daily commutes. At the same time, the need to stretch transportation-allocated budgets puts a burden on state highway agencies to seek the best economical ways of addressing the need of pavement preservation. Among alternatives for pavement surface treatment, thin asphalt overlays have been utilized and promoted by several states to serve this need.

The Pennsylvania Department of Transportation (PennDOT) has been using various pavement treatment and preservation techniques for decades. Recently, PennDOT in collaboration with industry has been looking into thin asphalt overlays and their best applications on Pennsylvania roads. To evaluate the performance of such mixes and develop relevant specifications, PennDOT initiated a four-year research program with Penn State, titled "Evaluation of Thin Hot Mix Asphalt Overlay." The project began in June 2011 and was completed in June 2016. The project carried several major objectives. One was to assess best practices for design and construction of such mixes through field application of three pilot projects and conducting necessary laboratory testing. Second was to evaluate the performance of such mixes placed in these pilot projects through visual survey and pavement condition measurements. Third was the use of existing advanced technology such as thermal imaging and ground-penetrating radar (GPR) to determine the uniformity of such mixes during placement in regard to temperature and density. Finally, it was the intention of the project to develop relevant specifications and guidelines for thin asphalt overlays.

The first pilot project included application of thin hot mix asphalt overlay at SR 0022 (Cameron Road) in Dauphin County. The mix was placed on repaired jointed concrete in July 2012. It was during June 2013 when the second hot mix asphalt was placed on SR 0230 in Lancaster County, again on repaired jointed concrete. The last project included placement of thin asphalt on SR 0220 in Lycoming County in September 2013. For this project, warm mix asphalt, processed through foaming, was placed on the milled road, and on the top of an old asphalt concrete, laying over jointed concrete.

Laboratory testing included evaluation of rutting and fatigue cracking of the mixes through wheel tracking and overlay tester, respectively. Resistance to rutting from lab testing proved to be excellent for the SR 0022 and SR 0230 projects. For SR 0220, there were two sections of the road, with one of the two including fiber in the mix. The fiber section had lower rutting compared to that of the no-fiber section. However, neither one has demonstrated any rutting problems in the field. The overlay test for all three projects showed that the mixes passed cracking criteria.

Field evaluations, in general, indicated satisfactory performance of these roads. Considerable improvement has been achieved in terms of ride quality and skid resistance after placement of thin asphalt. Roughness numbers, indicating ride quality, remain low and well below the values obtained prior to placement of thin asphalt overlay. Considerable increase in skid resistance level was noted after placement of thin overlay. The exception is SR 0220, for which the skid numbers were already high and skid resistance improvements were not as significant as for the other two projects. Within these first few years after placement of thin mixes, there has not been significant change in skid resistance and the values remain high. One area of concern is with the skid resistance at SR 0220, which shows a gradual decrease of friction with time, dropping to the prepaving levels. It is our assessment that skid resistance could have been further improved for this site through a coarser aggregate gradation and better control of aggregate skid resistance level.

Field measurements have indicated minimal rutting, fatigue cracking, and raveling at all three sites. Reflective cracking has been the dominant distress at all three projects. All three projects have suffered reflective cracks from underlying concrete joints or cracks. The reflective cracks at SR 0022 and SR 0230 have widened with time, triggering crack sealing operation.

The pilot projects are three and four years old at the time of this writing. Overall, it can be assessed that both construction and performance of the three pilot projects has been successful based on observations within this limited period of time. Various performance measures have been used through the course of the research to demonstrate the success of these projects. The results of the study were reflected in newly developed construction specifications for 6.3-mm mixes as well as construction guidelines and a manual of best practices.

INTRODUCTION

A number of state highway agencies have embarked on using thin asphalt overlays, mainly as a useful tool for pavement preservation and extending pavement life. Research has demonstrated the benefits of such overlays, such as those outlined by many references (Johnson, 2000; Hicks et al., 2000; Labi et al., 2005; Corley and Lay, 2007; Chou et al., 2008; Jahren et al., 2008). A four-year research project was sponsored by the Pennsylvania Department of Transportation (PennDOT) to evaluate performance of asphalt concrete thin overlays, using three pilot projects, and to develop design/construction guidelines and specifications for the use of these thin overlays. The project, conducted by Penn State, began in June 2012 and was completed in June 2016. The results of this study exhibited significant improvements achieved in ride quality and skid resistance, with minimal amount of rutting/fatigue cracking observed to date. The outcome of this research resulted in the development of a construction specification for a dense-graded, 6.3-mm Superpave asphalt mix for thin overlays, to be included in PennDOT Specification 408. The research also produced design and construction guidelines affecting several chapters of Publication 242 (Pavement Policy Manual). At the time of this writing, 33 reports for various deliverables of the project have been submitted to PennDOT. By the end of project, the total number of deliverable reports will be 40, which includes the final report and an end-of-project summary report.

OBJECTIVES OF THE STUDY

This research project was focused on polymer modified thin hot-mix asphalt overlay (THMAO) constructed with 6.3-mm nominal maximum aggregate size. The objective of the research was to determine the feasibility of constructing this type of THMAO and to evaluate the performance of this mix in both the laboratory and the field. It was also the research goal to modify existing specifications or develop new specifications and guidelines for the use of this material, in cooperation with PennDOT and industry. In addition to such modifications to existing specifications, a best practices document covering design and construction of such mixes was to be developed based on findings from construction of demonstration projects.

SCOPE OF WORK

The research project was extensive in terms of various tasks and the goal of each task. The results of each task or subtask were delivered in a report specific to that task. Comments were received from PennDOT on each deliverable. Necessary revisions were made to the report based on the comments, and a final report was submitted.

The following tasks were accomplished during the course of this research.

- Literature Review (1 report)
    - Specifications of other state highway agencies on thin asphalt overlays
    - Design and performance of thin asphalt overlays
- Life-cycle cost analysis (1 report)
- Evaluation of field pilot projects with thin overlay (3 projects)
    - Laboratory evaluation
        - mix design verification (3 reports)
        - verification of aggregate skid resistance level (3 reports)
        - laboratory performance testing of the mix (wheel tracking and overlay crack tester), tack coat bond strength test through direct shear (provided with the mix design reports)
    - Field activities
        - Documentation of construction and relevant findings (3 reports)
        - Thermal imaging of selected sections of the road to evaluate mat temperature variability (provided with construction reports)
        - Use of ground-penetrating radar to determine mat uniformity with respect to density, and mat thickness (included in the construction reports)
        - Coring to determine tack coat bond strength, layer thickness, and mat density
        - Pavement condition survey (18 reports)
        - Rut profiling (provided in the pavement condition survey reports)
        - Visual distress survey, crack measurement, and rut measurement (provided in pavement condition survey reports)
        - Friction evaluation using dynamic friction tester (twice during the project and provided in the pavement condition survey reports)
        - Texture evaluation using circular track meter (twice during the project and provided in the pavement condition survey reports)
        - Skid measurements (conducted by PennDOT's Bureau of Maintenance and Operations and provided in the pavement condition survey reports)
        - Pavement rutting, ride quality, cracking, and distress survey (conducted by BOMO and provided in the pavement condition survey reports)
- Development of specifications (1 report)
- Development of design and construction guidelines (2 reports)
- Development of best practices document (4 reports)

- Determination of project lifetime based on evaluation of the pilot projects (1 report)
- Draft final report, final report, and implementation road map (2 reports)
- End-of-project summary report (1 report)
- Delivery of a webinar to accomplish technology transfer

SUMMARY OF LITERATURE REVIEW

Review of existing literature on thin hot mix asphalt overlays indicated that the use of THMAO has emerged as one of the most important techniques for pavement preservation. From review of the literature, it seems that THMAO has extended the pavement service life up to 12 years, in some cases. However, it seems that, on average, the expected performance is in the range of 7 to 8 years. Many states have been using THMAO as part of their pavement preservation strategies, and some, such as Maryland and Ohio, have been using them for decades. The specifications used by these states vary, in some parts, on mix design approach, material requirements, and quality control measures. THMAO is referred to by multiple names in different specifications, but fundamentally they all refer to hot/warm mix asphalt concrete placed at thicknesses between 5/8 inch and 1.25 inches.

In many respects, thin asphalt overlays are preferred over other techniques for pavement preservation, as they provide increased smoothness and higher ride quality compared to the alternatives. While the initial cost of paving with thin asphalt overlay is higher than some other preservation techniques such as microsurfacing and chip sealing, extended durability and lower maintenance for these mixes could result in more cost savings.

EVALUATION OF PILOT PROJECTS WITH THIN OVERLAY – FIELD WORK

In relation to this research project, three pilot projects were constructed using a 1-inch-thick overlay with a Superpave 6.3-mm asphalt concrete mix. The research for this phase of study involved documentation of the paving and compaction operation, evaluation of performance after construction, and conducting necessary laboratory testing and evaluation. The field evaluation also included assessment of mat density and mat temperature uniformity using ground-penetrating radar (GPR) and thermal imaging. There were several findings from field evaluation, as noted in the following sections.

Project Locations and Pavement Information

The locations of the three projects and a brief description of the pavement structure are presented in Table 1.

Table 1 Location of Pilot Projects and Corresponding Pavement Structure

Highway County	Segment/Offset	Existing Pavement	Action before THMAO	Dates of THMAO Paving	
				From	**To**
SR 0022 Dauphin	341/450 to 331/000 (West) and 330/095 to 340/454 (East)	37-yr-old, 10-inch-thick jointed concrete	Patch/Repair	7/22/12	7/26/12
SR 0230 Lancaster	291/2244 to 281/1926 (West) and 280/1964 to 290/1605 (East)	64-yr-old, 9-inch-thick jointed concrete	Patch/Repair	6/11/13	6/18/13
SR 0220 Lycoming	10/0000 To 90/1226 (North)	45-year-old, 10-inch-thick jointed concrete overlaid with 4 inches of asphalt concrete (scratch, binder, wearing) and a single surface treatment with microsurfacing	1-inch milling followed by 1/2-inch-thick, 9.5-mm NMAS leveling course	9/5/13	9/10/13

Thermal Imaging

An infrared thermography (IRT) survey was conducted for all three projects at selected locations. Details of thermal imaging for all three projects are available in the three reports submitted under Task 3.3: Findings from THMAO Application and Paving.

The objectives of the IRT inspection were to determine the thermal profiles and temperature gradients of newly placed asphalt during the paving operation and post compaction. The tests included approximately 0.5 lane-miles of pavement for each project. The IRT system, developed by Penetrader Corp., produces plan-view mappings of temperature gradients at the surface of the pavement. Temperature surveying with IRT is inherently a nondestructive and non-contacting test method that operates at speeds of up to 10 mph.

The major emphasis of this program was the recording and quantification of temperature gradients produced during placement of thin asphalt and subsequent to compaction. An example is shown in Figure 1, which belongs to the travel lane of the northbound on SR 0220. There are two graphs presented, precompaction and post compaction. The precompaction chart is the temperature captured after placement and before compaction.

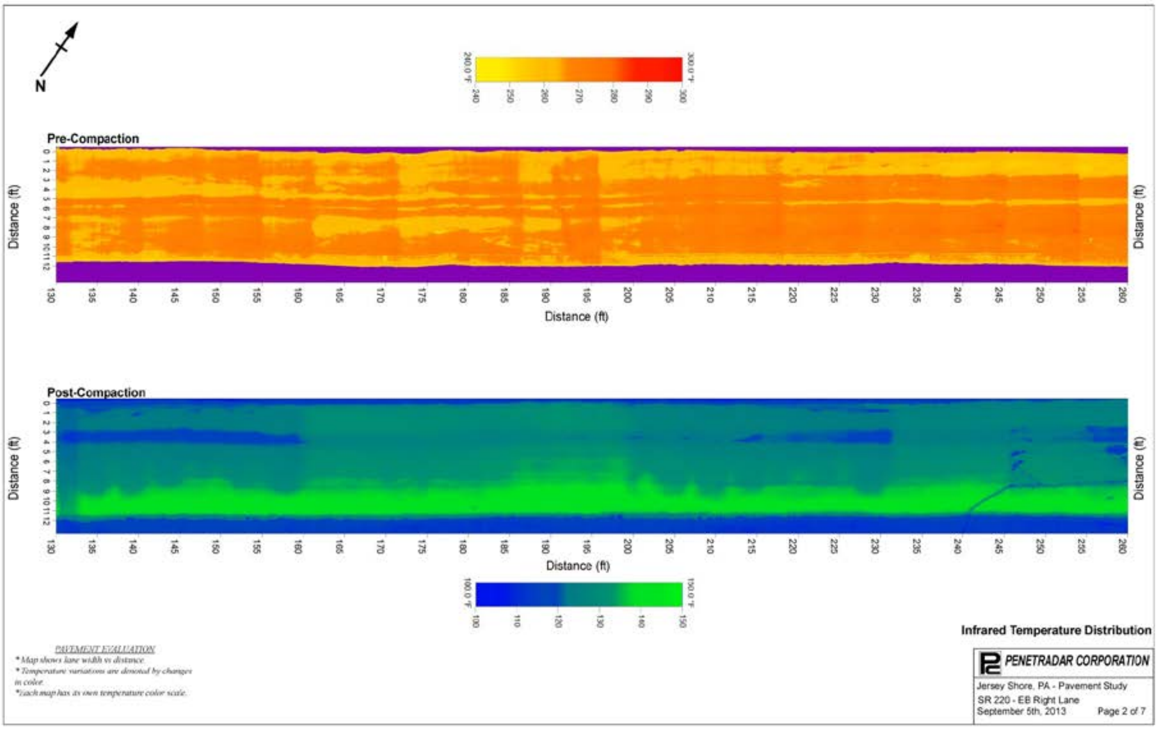

Figure 1 An example of mat temperature distribution captured after placement and after compaction

For SR 0022, thermal imaging indicated that the temperature of the mat immediately following placement varied in the range of 300-315ºF for one of the lanes and in the range of 290-300ºF for another lane. (See the report on Findings from THMAO Applications and Paving for graphs and details.) There were sporadic areas where the temperature dropped to about 280-290ºF. Overall, the temperature difference seems to be less than 25ºF immediately after placement for the majority of the mat, indicating that thermal segregation was not of concern. Mat temperature varied in the range of 100-110ºF after compaction, indicating significant temperature drop after compaction.

For SR 0230, the IRT pre-compaction maps showed temperature variations typically ranging from 260°F to 320°F across the lane. (See the report on Findings from THMAO Applications and Paving for graphs and details.) There were multiple isolated locations and "streaks" showing areas of the lower temperature immediately following paving operations. Many of these “cooler" areas were observed in locations where the paver started moving after having stopped for an extended period of time. Post-compaction temperature was collected after the rollers had completed their operation. Due to the nature of the roller compaction process, this varied significantly depending on several factors and led to large variations in post-compaction temperatures throughout the pavement.

For SR 0220, the IRT pre-compaction maps show temperature variations typically ranging from 240°F to 300°F across the lane. (See the report on Findings from THMAO Applications and Paving for graphs and details.) There were multiple isolated locations and "streaks" showing areas of lower temperature found throughout the lane. The thermal data appeared to be more uniform and areas of lower temperature were not as prevalent, compared to SR 0230. The majority of the cooler temperature areas occurred just outside the center of the lane and in certain areas on the outside of the lanes. This is most likely due to the method by which the asphalt mix was distributed during the paving operation. The post-compaction maps show temperature variations that typically range from 120°F to 150°F across the lane. As compared to SR 0230, the temperatures across the lane appeared to be more uniform and evenly distributed. There were fewer areas of cooler temperature observed within the lane.

Thermal imaging is a useful technique to check mat temperature uniformity in a continuous way, especially for thin asphalt overlays where temperature loss after placement takes place at a faster rate compared to thicker layers. Significant temperature differences could result in non-uniform pavement compaction. It is recommended that for thin asphalt layers, such a system be utilized to check mat temperature. Use of thermal imaging could potentially be included in the PennDOT specification for asphalt concrete placed in thin layers. Pave-IR is one of these systems, developed by the Texas Transportation Institute, and has been used on a number of projects in various states.

Ground-Penetrating Radar

The main goal of using ground-penetrating radar in this project was to evaluate the capability of GPR in providing a reliable estimate of the density of newly constructed thin asphalt overlays, and to provide a measure of the mat uniformity in regard to compaction. Advanced Infrastructure Design, Inc. (AID) conducted all measurements and analysis associated with GPR work for this project. AID conducted an air-launched GPR survey for the purpose of this project. The air-launched GPR survey was conducted using two high-frequency (2 GHz) antennae. Details of GPR measurements for all three projects are available in the three reports submitted under Task 3.3: Findings from THMAO Application and Paving.

After the entire section was evaluated and all GPR longitudinal lines were conducted, dielectric results were obtained. Color contour maps that show the variation of dielectric properties were generated, as illustrated in the example in Figure 2. Lower dielectric values are presented with red and orange colors, while green and blue colors correspond to higher dielectric values. Lower dielectric properties are associated with lower densities and thus higher air voids content and vice versa.

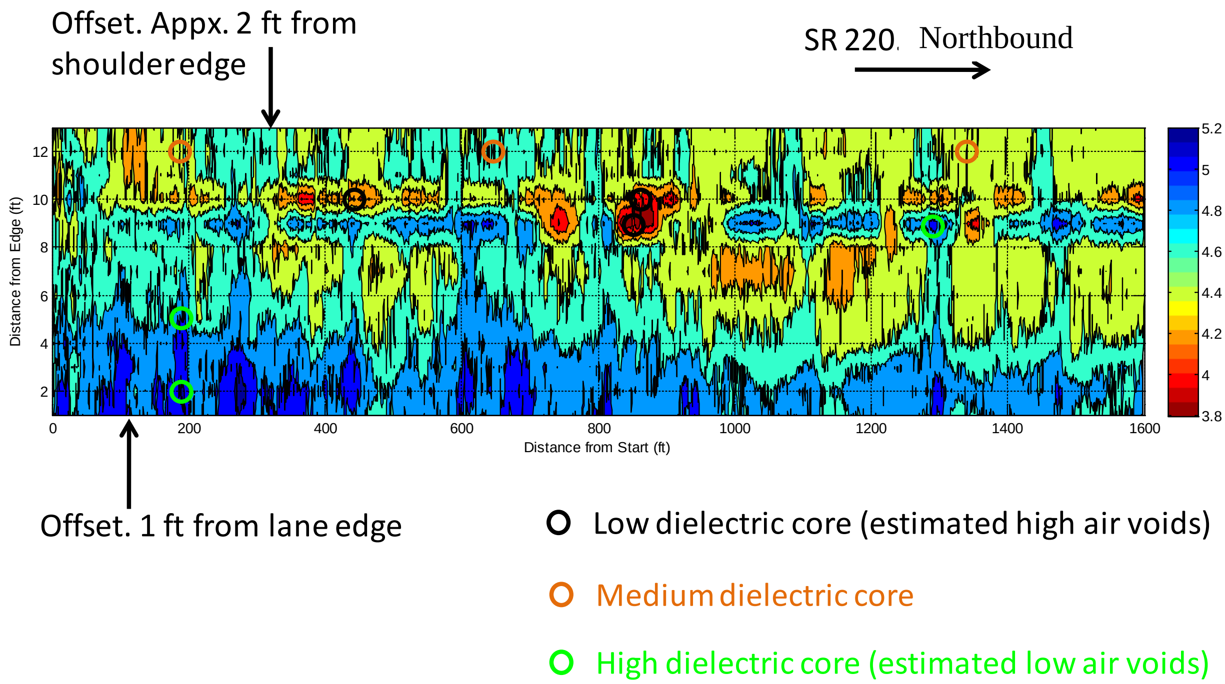

Figure 2 An example of dielectric distribution in the mat captured by GPR, indicative of mat density uniformity

Using GPR with these projects was a learning experience. Significant improvements in correlation between density from GPR and density from lab measurements were made as research moved from the first project (SR 0022) to the second (SR 0230) and to the third (SR 0220). Figure 3 presents the correlation found between density of cores and dielectric value of GPR.

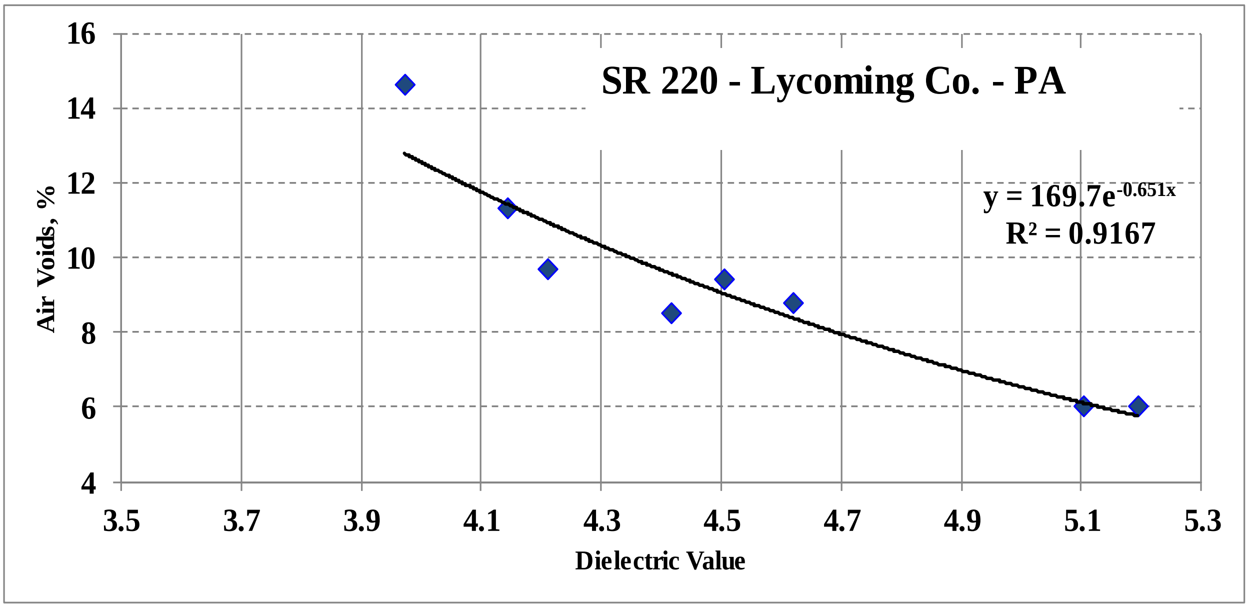

Figure 3 Correlation between density of cores and dielectric constant captured from GPR for one of the pilot projects

A larger range of air voids and a larger range of dielectric values are needed to investigate the strength of this correlation for thin lift applications of asphalt. There are three capabilities envisioned for GPR measurements with THMAO at this time: (1) reliable measurement of mat thickness, (2) reliable prediction of mat density, and (3) ability to identify areas of low density. In regard to mat thickness, GPR is a reliable technique and has been thoroughly investigated for this purpose. Regarding the second and third capabilities, one should distinguish between these two, as the first goal requires high sensitivity of GPR to air void variations, whereas for the latter, a high level of sensitivity is not needed as long as the equipment is capable of mapping areas of high density and low density without specifically being capable of providing actual density values. Based on the results from these demonstration projects, it appears that GPR is capable of addressing the second goal, as it clearly delivered the lowest dielectric value for the highest air void. Whether the equipment is also capable of achieving the former goal is a question needing further investigation and GPR measurements at a wider range of dielectric constants and densities.

GPR is a very useful tool for quality control of asphalt concrete, especially when the asphalt concrete is placed in thin layers. The system can be used to check mat thickness as well as uniformity in compaction and density. For thin layers, taking cores for density measurements is difficult and requires multiple steps of trimming and density measurement, assuming proper core could be obtained. GPR is a useful replacement for coring thin layers, as it presents a way of continuous monitoring of compaction uniformity, and if properly calibrated provides a reliable estimate of mat density. It is recommended that for thin asphalt layers, such a system be utilized. Use of GPR could potentially be included in the PennDOT specification for asphalt concrete placed in thin layers.

Pavement Condition Evaluation

The pilot projects were subject to a number of condition evaluations after placement. The results of those evaluations were submitted to PennDOT in a series of reports. Pavement condition assessment was conducted by both the research team and Pennsylvania Department of Transportation Bureau of Maintenance and Operations (PennDOT BOMO). Assessment by the research team included the following:

- Visual survey
- Crack measurement
- Rut measurement (twice during the project)
- Friction measurement (twice during the project)
- Texture measurement (twice during the project)

Measurements by BOMO included the following:

- Ride quality (IRI)
- Rutting
- Friction (skid)
- Videologging

Table 2 shows the dates of site visits by the research team as well as dates of BOMO measurements. Details of pavement condition survey are presented in a series of reports submitted to PennDOT after each site visit.

Table 2 Dates of Distress Survey and Pavement Condition Assessment of the thin overlay projects

Project	Dates of Penn State Survey	Dates of Skid Measurements by BOMO	Dates of Pavement Condition Measurements by BOMO
SR 0022, Dauphin	11/08/12, 11/19/13, 04/24/14, 10/23/14, 05/20/15, 11/04/15, 04/18/16	03/29/12, 08/28/12, 06/3/14, 10/06/14, 04/24/15, 10/23/15, 04/20/16	04/04/12, 07/31/12, 09/12/12, 11/05/13, 06/03/14, 09/18/14, 04/06/15, 10/14/15
SR 0230, Lancaster	11/19/13, 04/04/14, 10/17/14, 04/23/2015, 11/03/15, 04/19/16	06/03/13, 08/19/13, 06/03/14, 10/06/14, 04/30/15, 10/01/15, 04/11/16	05/20/13, 07/11/13, 06/3/14, 09/19/14, 04/28/15, 10/14/15
SR 0220, Lycoming	04/10/14, 10/08/14, 04/28/15, 10/27/15, 04/20/16	07/1/13, 11/18/13, 05/27/14, 09/16/14, 04/13/15, 10/6/15, 04/13/16	06/24/13, 11/21/13, 06/2/14, 09/24/14, 07/27/15, 10/22/15

Rutting Assessment

The THMAO placement at all three sites has effectively improved the extent of wheel path rutting, as reported by the BOMO videologging profile summaries. Measurements by the research team as well as those by BOMO indicate that rutting remains low at all three sites, and is not of concern. The mixes have performed very well in this regard. Including all sites, for the left wheel path, the range for rutting is 0.08 to 0.16 inches and for the right wheel path, 0.07 to 0.12 inches, based on measurements of the research team. BOMO results indicate an average range of 0.07 to 0.14 inches for the left wheel path and a range of 0.06 to 0.11 inches for the right wheel path, for all projects combined. All reported numbers are based on measurements obtained in October 2015.

Cracking/raveling Assessment

Fatigue-related cracking and raveling have been minimal and are of little concern for all three projects. Since the first evaluation to date, it has been found that reflective cracking is the only dominant type of distress in all three roads. These are the reflection of cracks from the concrete joints or underlying cracks. The first set of cracks began appearing just a few months after placement. In SR 0022 and SR 0230, the cracks increased in number and became wider with time. For these two projects after placement of thin asphalt, the pavement was sawed and sealed at the joint locations, but in cases where this was not done or in cases where the seal was misplaced or conducted improperly, the cracks appeared, and some of them widened with time, resulting in progressive deterioration of the pavement condition. In both roads, the developed cracks were sealed at a later time. For SR 0022, hot-pour crack seal was applied, and for SR 0230 spray seal was used. In both cases some cracks were missed at the time of sealing. Raveling has been low at these sites. At SR 0230, sporadic locations could be identified where raveling could be rated as moderate, as loss of fines is quite noticeable.

Friction Assessment

For each pilot project, skid tests were conducted by PennDOT BOMO seven times during the life of this research. Furthermore, friction measurements were conducted by the research team twice during the course of the project. Penn State measurements were achieved using a dynamic friction tester. Friction values for all three projects from Penn State measurements ranged between 0.60 and 0.62, calculated for a speed of 12 miles per hour. The BOMO skid data indicate significant improvement in skid resistance after placement of thin asphalt overlay for all three projects. For SR 0022, prior to thin asphalt placement, skid numbers were in the range of 20 to 30. After placement of thin overlay, the numbers exceeded 50. For SR 0230, the skid values increased from 30-level to 50-level after placement of thin asphalt overlay. Among the three projects, SR 0220 delivered the smallest increase in skid resistance after placement of thin asphalt overlay. On average, the skid numbers changes from an average of 44 to an average of 52 after placement. There has been a gradual decrease in friction with time for SR 0220, and the skid resistance numbers have dropped to levels similar to those observed prior to THMAO paving, even though the skid numbers are still at an acceptable level.

Assessment of Ride Quality

Similar to skid resistance, the ride quality has been significantly improved after placement of the thin asphalt, as evidenced by international roughness index (IRI) and based on BOMO measurements. The ride quality has slightly deteriorated with time for SR 0022 and SR 0230 but it still remains well above the level prior to thin asphalt placement. For SR 0220, the IRI has maintained almost the same level since placement of thin asphalt.

Assessment of Surface Texture

The surface texture was measured using the Circular Track Meter (CMT). The charge-coupled device (CCD) laser displacement sensor used by this equipment is mounted on an arm that rotates above the road surface. The measurement results are used to report different surface texture indices. The CTM device can be used to measure the macrotexture of the test surfaces. The measured texture profile is then used to calculate the international standard mean profile depth (MPD) parameter, which is a direct macrotexture parameter. During the last measurement in October 2015, the average MPD was found to be 0.69 mm for SR 0022, 0.64 for SR 0230, and 0.43 for SR 0220. Higher MPD is more desirable, as it tends to deliver high friction and better skid resistance. For SR 0220, BOMO skid measurements delivered the lowest values among the three projects, consistent with the lowest MPD values obtained with CMT. Lower MPD for SR 0220 could be the result of finer gradation used at this site compared to the other two sites, as well as the fact that the sandstone was contaminated with limestone. In revising specifications for 6.3-mm mixes, consideration was given to aggregate gradations as a result of skid and MPD values obtained during this research.

EVALUATION OF PILOT PROJECTS WITH THIN OVERLAY – LAB WORK

The laboratory work of this research was conducted to verify the mix design and aggregate skid level, evaluate tack coat strength, and measure performance characteristics of the mix. Testing was conducted on specimens prepared from loose samples received at the job site on the date of construction, the cores procured after placement and compaction, and the materials directly received from PennDOT.

Gmm and Gradation Verification

Due to the short time period between initiation of the SR 0022 project and paving operation, no mix verifications were conducted for the first project, other than performance testing on the mix and on the tack coat, as will be discussed later. For the second (SR 0230) and third (SR 0220) projects, the theoretical maximum specific gravity of the mix (G_{mm}) was determined in the Northeast Center of Excellence for Pavement Technology (NECEPT) laboratory at Penn State and compared with the value reported in the job mix formula (JMF). The difference between the NECEPT Gmm measurement from field-procured loose material and JMF Gmm was well below the AASHTO d2s value of 0.018 or 0.029. The former value (0.018) is based on one replicate for one material and 344 laboratories participating, and the latter value is based on one replicate for one material and 134 laboratories participating. The gradation of the mix aggregate from the ignition oven closely matched that of the JMF for both projects.

Verification of Aggregate Skid Resistance Level

Aggregates for evaluation and petrographic analysis were obtained through burning the asphalt in the ignition oven. The specimen was broken loose in a hot oven before conducting the burn-off test. The aggregate obtained from burn-off was washed and separated in different sizes, retained on #6.3-mm sieve through material passing #16 mesh. The material was then processed for petrographic and mineralogy investigation. Details of petrographic evaluations were provided and submitted in three separate reports.

For SR 0022 aggregate, it was found that the geological provenance for most of the clasts was a sandstone-dominated clastic sedimentary setting, with minor input from a crystalline metamorphic terrane (the source of vein and/or pegmatitic quartz). The limestone was so out-of-place that it could be considered a contaminant. The "fines" (< #16 mesh) consisted mainly of sub-angular to sub-rounded quartz grains, analogous to a medium- to coarse-grained, salt-free, beach sand. The coarser mesh (> #16) splits were dominated by a porous, relatively cohesive sandstone. The aggregate was considered a good "E" stone product.

For SR 0230 aggregate, the geological provenance for most of the clasts was a sandstone-dominated clastic sedimentary setting. The "fines" (< #16 mesh) consist mainly of sub-angular to sub-rounded quartz grains, analogous to a medium- to coarse-grained, salt-free, beach sand. It was verified that the aggregate met the requirements for a skid resistance level rating of E.

For SR 0220 aggregate, the samples were contaminated with limestone dust, possibly because the material was processed in a crusher and screening facility specific to a limestone quarry operation. Material from one stockpile consisted of very fine-grained to micritic limestone from a relatively uniform source that also hosts secondary calcite veins, with PennDOT classification of LS-L. The second stockpile also consisted of limestone with interbeds of magnesium limestone, with PennDOT classification of LS-L. Material from the third stockpile represented a low-rank graywacke ("dirty" sandstone) in which relatively well sorted quartz grains were separated by interstitial chlorite in a matrix-supported texture. The equant habit with subangular to angular edges and "rough" surfaces and texture should ensure a plucking quality desirable in an E stone. A PennDOT classification of SS-E is appropriate. Slight contamination with limestone is of some concern with this aggregate.

Performance Testing

The mix was subjected to two types of performance tests: wheel tracking to capture moisture damage resistance and rutting, and Texas Overlay Tester to evaluate cracking potential.

Testing with Hamburg Wheel Tracking Device (HWTD)

The Hamburg Wheel Tracking Device (HWTD) measures the combined effects of rutting and moisture damage by rolling a steel wheel across the surface of an asphalt concrete test specimen that is immersed in hot water. Each steel wheel makes 20,000 passes or until 20 mm of deformation is reached. The measurements are customarily reported versus number of wheel passes. The wheel makes 50 passes per minute. The load applied by the wheel is 158±5 lb. The rut depth in the mix must not exceed 12.5 mm after 20,000 cycles for the mix to be considered rut resistant.

For the SR 0022 mix, no stripping inflection point was observed, while approximately 5 mm of rutting was obtained after 20,000 wheel passes, indicating an excellent performance. For the SR 0230 mix, no stripping inflection point was observed, while approximately 6 mm of rutting was obtained after 20,000 wheel passes, indicating an excellent performance. For SR 0220, a stripping inflection point was observed at approximately 11,000 cycles for the section with no fiber in the mix, and at approximately 16,400 cycles for the section with fiber. Rutting was roughly 12.5 mm after 17,000 cycles for the no-fiber section, and roughly 8 mm after 20,000 cycles for the fiber section. However, field observations of SR 0220 as of today have not shown any noticeable rutting in the field for either the no-fiber section or the fiber section.

Texas Overlay Tester

The overlay test is used to measure mix brittleness and determine if an asphalt mix is susceptible to fatigue or reflective cracking. The testing system includes two adjacent blocks which support the specimen. One block is stationary while the other applies tension by moving away from the stationary block. In the test, direct tension is repeatedly applied to the specimen until failure occurs. The applied load has triangular waveform and its magnitude is dictated by the specimen deformation, which is limited to 0.025 inch per load application. The total duration for one load cycle (reaching the maximum and returning to initial position) is 10 seconds, and the test is conducted at 77°F. The test is continued until the load level is reduced to 7% of the original value, which is defined as failure point, or until 1,000 cycles are reached. A mix that takes 500 cycles before failure is considered resistant to cracking. All three mixes for this project passed this limit. On average, the number of cycles to failure for the mixes of SR 0022, SR 0230, and SR 0220 were at minimum 842, 942, and 1,000, respectively.

Tack Coat Evaluation

A strong bond between the asphalt layer and the underlying pavement is important to prevent slippage of the top layer and premature failure of the pavement. The need for a strong bond becomes more important in thin layers as higher shear stresses are induced at the interface. The cationic slow-setting emulsion with hard base asphalt (CSS-1h) was used in all three projects to develop the needed bond between the thin asphalt and the underlying layer. Laboratory tests were conducted on the field cores to assess the magnitude of this bond. Testing was conducted using direct shear at 77°F and 122°F. The results for SR 0022 and SR 0220 indicated adequate strength of the tack coat and the bond. On average, shear strength (peak stress) results for these two projects exceeded 45 psi, which is the selected criterion for deciding the quality of the interface shear strength when tested at deformation rate of 0.04 inches/minute, and test temperature of 77°F. For SR 0230, high variability in results was observed and none of the cores passed the 45-psi limit. Close attention must be paid to the performance of this road in terms of debonding. At the time of this writing, there is no evidence of delamination or debonding in the field for any of these projects, based on pavement condition surveys to date. Details of tack coat evaluation are provided in three reports, titled Verification of Job Mix Formula.

DEVELOPMENT OF SPECIFICATIONS, GUIDELINES, AND BEST PRACTICES

Findings from the thin asphalt pilot projects as well as review of existing literature resulted in modifications to some PennDOT specifications. This work also resulted in the development of design and construction guidelines and best practices for construction of 6.3-mm thin asphalt overlays. These documents were submitted to PennDOT in separate reports, and the reader is encouraged to refer to those documents for details. The specification on 6.3-mm thin asphalt mixes is proposed to be part of PennDOT Construction Specification 408. The guidelines are proposed for inclusion in the PennDOT Pavement Policy Manual (Publication 242). The best practices document is a stand-alone document.

IMPLEMENTATION ROADMAP

Successful implementation of the specifications developed for 6.3-mm thin asphalt overlays requires a well-developed plan in which a set of necessary steps to be executed are clearly defined. It is proposed that implementation take place gradually to increase the chances of success. The plan is proposed to include the following elements.

1. Identify Requirements for Implementation
2. Develop Implementation Schedule
3. Conduct Technology Transfer
4. Develop/Execute Performance Monitoring
5. Develop/Execute Measures of Success

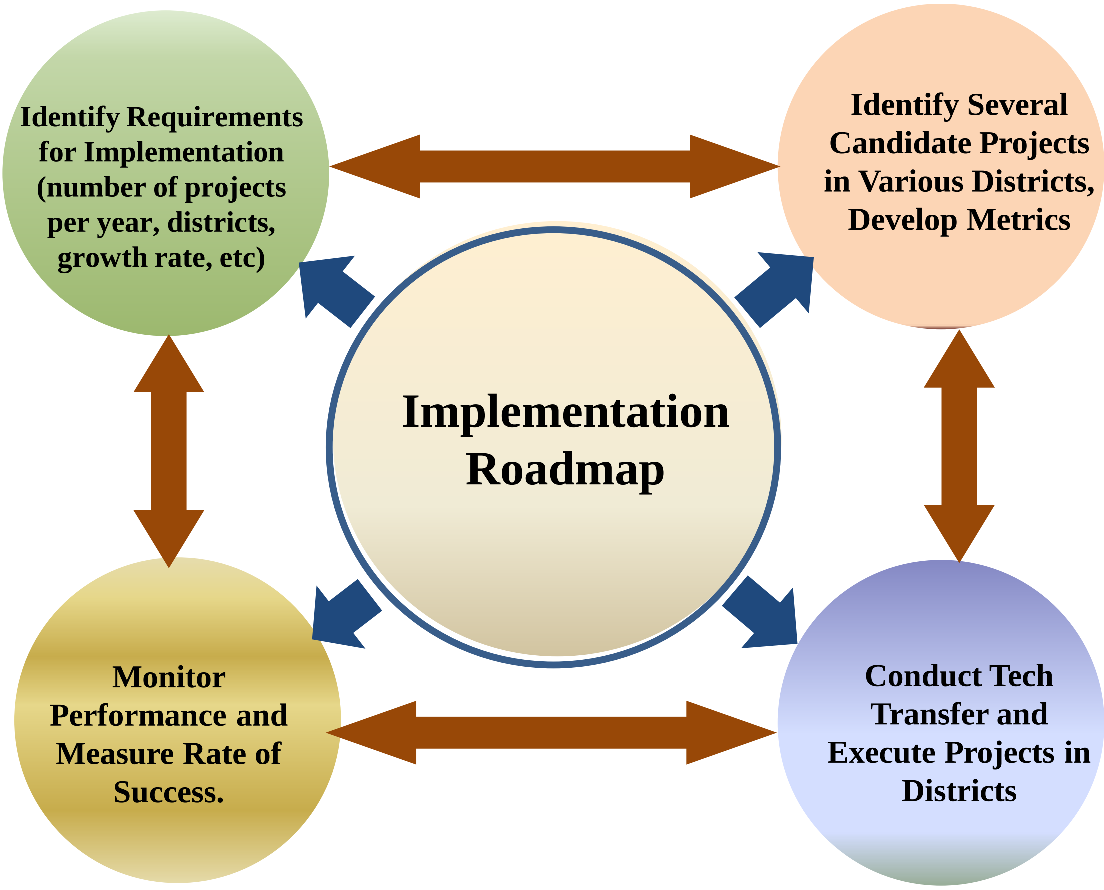

Figure 4 Elements of implementation roadmap for thin asphalt overlay

Identify Requirements for Implementation and the Scope

The first step will be to establish a clear road map. Before action takes place in production, it is essential to identify the requirements, the goal, and the path that needs to be taken. It must be known which districts will be participating and how many preservation projects will be considered to establish implementation. What are possible risks and constraints associated with established requirements? What kind of contingency plan is considered? Any constraints in time, space, and resources must be identified and addressed before attempting the implementation. To the greatest extent possible, the key players must attempt to identify the risks and the approach in responding to those risks. Contingency plans may be needed in case of risks with large impact. Such a risk management plan includes actions to be taken if, as the projects progress, it appears that changes are needed.

Develop Implementation Schedule

Upon identification of requirements to achieve implementation, a time frame must be set to conduct the selected number of projects within each district that will be participating in the program, and the expected trend in growth of usage. The time for execution of the plan must be realistic, and be communicated and coordinated with the district. This time frame should also include the time needed for subsequent training and technology transfer.

Technology Transfer/Training

Parallel to development of the implementation schedule, a half-day webinar should be developed in the form of a PowerPoint presentation, along with handouts, to review the developed specifications and discuss the best practices for construction of thin asphalt overlays. The training will consider which projects are proper candidates for thin asphalt overlay and which are not. The webinar could be targeted toward upper-management-level people as well as technicians and personnel directly involved with the production and placement of the thin overlay mix.

Performance Monitoring

It is foreseeable that the first few projects will possibly run into issues that could not have been anticipated in the beginning. Tracking details of relevant activities and making diligent remarks of observations during production and placement of the thin overlay mix will assist with any further modifications needed to specifications. A documentation form could be developed to be used for inclusion of important details, and to assist the personnel involved with the project for proper recording of the whole process. Regular communication among parties involved with implementation will be vital during performance monitoring.

Metrics/Benchmark to Measure Success

Upon completion of the overlay projects, it is important to assess the level of success; as such, assessment will help in any further modifications to specifications. It is often difficult to quantify the level of success for projects of this nature and to establish well-defined, quantified metrics to measure success. Possibly, the best approach will be to consider a combination of comments from personnel involved in production during the construction of projects, which cannot be properly quantified, with quantifiable measures such as test results before and after production, and percent within limits found for different parameters. Another important measure of success will be the impact of new specifications on the required time for design and production, the level of resources needed, and the cost of implementation. Furthermore, one could also determine the success rate by determining which projects out of the total could be considered a success. In any event, a team of experts must be formed to develop acceptance criteria and interpret/analyze data and information gathered under performance monitoring.