1. **Cover Page**

Wisconsin Highway Research Program

Field Aging and Moisture Sensitivity Study

Wisconsin Highway Research Program
<u>LIMITED USE DOCUMENT</u>

University of Wisconsin - Madison

January 22, 2016

2. Summary Page

Project Title:	Field Aging and Moisture Sensitivity Study
Proposing Agency:	The Board of Regents of the University of Wisconsin System University of Wisconsin-Madison Office of Research and Sponsored Programs 21 N. Park St., Suite 6401 Madison, WI 53715-218 608-262-3822
Person Submitting the Proposal:	Hussain Bahia, PhD
Proposal Written By:	Hussain Bahia, PhD Erik Lyngdal, MSc *UW Madison* Dan Swiertz, PE *Bitumix Solutions* Signe Reichelt, PE *Behnke Materials Engineering*
Proposal Date:	January 22, 2016
Principal Investigator:	Hussain U. Bahia Professor Department of Civil and Environmental Engineering 3350 Engineering Hall 1415 Engineering Dr. Madison, WI 53706
Administrative Officer:	Kim Moreland Director of Research & Sponsored Programs 21 N. Park St., Suite 6401 Madison, WI 53715-218 608-262-3822
Proposed Contract Period:	21 months
Total Contract Amount:	$150,000
Indirect Cost Portion at:	15%

Technical Oversight Committee (TOC) Member Disclosure*:*
Subcontractor: Signe Reichelt, Behnke Materials Engineering, Flexible Pavement TOC Member

3. Table of Contents

4. Research Plan

4.1 Background

Asphalt pavements exhibit significant changes in physical and mechanical properties over time as a result of aging of the asphalt binder. Literature suggests that the performance based changes in asphalt mixtures are dependent on the binder chemistry and rheology, climatic conditions, aggregates source, and mixture volumetrics. Binder changes are due primarily to two phases of aging: the loss of volatile components coupled with high temperature oxidation, called short-term aging; and progressive, in-place oxidation at ambient pavement temperatures, called long-term aging (Bell, AbWahab, Cristi, & Sosnovske, 1994). In addition, recent research has shown that the interactive effects between the aggregates (particularly the P200 material) and the asphalt binder significantly change the rate of asphalt aging (Moraes, 2014). Laboratory protocols for estimating the effects of rate and extent of aging on performance of asphalt mixtures in the field is an ongoing research topic on a national scale. The ongoing NCHRP 09-54 project is one such study that is attempting to better predict long term aging of asphalt mixtures. A major objective of this WHRP research study will be to reconcile field and laboratory mixture performance data to propose a laboratory aging protocol for Wisconsin mixtures.

A second objective of this study is to evaluate the moisture sensitivity of Wisconsin mixtures using the Hamburg Wheel Tracking Test (HWTT). The HWTT test has shown utility for predicting the moisture sensitivity of asphalt mixtures using the Stripping Inflection Point (SIP), which is defined as the number of wheel passes that corresponds to the intersection of the initial creep slope and stripping slope. The stripping slope is considered to be the indicator of significant accumulation of moisture damage. Current WisDOT protocol is to use the AASHTO T283/ASTM D4867 Modified Lottman Test, in which vacuum saturated samples are conditioned for extended periods in a hot water bath and tested for indirect tension strength. The strength of conditioned samples is compared to that of unconditioned samples and the ratio between the values (Tensile Strength Ratio) is considered to be an indication of moisture damage potential. Lower ratios correspond to greater potential of moisture induced damage. The limits are empirically based and the details of how an agency chooses to run the procedure (conditioning times, temperatures, and use of a freeze-thaw cycle) result in a test that can take up to one week to complete. In contrast to the T283 procedure, several HWTT tests can be run in a single day, and material requirements are much less as compared to the T283 procedure. In addition, the HWTT is considered a better representation of field loading conditions since it utilizes a moving wheel as compared to indirect tension load in the T283 procedure. The advantages of the HWTT appear to outweigh the increased cost of the HWTT equipment when compared to the T283 equipment.

4.2 Research Objectives

The objectives of this research are first to perform a comprehensive review of laboratory aging protocols and select the method that best represents aging of mixtures produced in the field, and second is to define the testing requirements for the HWTT as they pertain to estimating performance of mixtures in Wisconsin. The following specific objectives are defined based on the request for proposal by WHRP:

- Plan and oversee the construction of a field test strip which will be used to supply plant produced mixtures for measuring field aging effects (short and long term) on changes in performance related properties of mixtures and extracted binders.
- Develop laboratory short and long term aging protocols that will simulate field aging effects measured on plant produced mixtures from the field strip by comparing mixture and extracted binder properties to those of laboratory produced mixtures.
- Determine the effects of changing binder grade, binder content, filler content and mixture traffic designation on mixture aging as measured by rutting and cracking resistance, as well as on moisture resistance potential.
- Define the optimum testing requirements for the HWTT in terms of sample preparation, test temperature, and specification criteria for Wisconsin mixtures that will give a good representation of actual field performance.

4.3 Research Approach

The proposed research approach takes into consideration the feasibility of changing certain mix design factors, such as binder content and filler content, for plant produced mixtures. Since such factors are considered critical for aging effects and moisture damage in this study, these factors will be explored in laboratory based test matrices. In addition, the findings of ongoing WHRP Project 0092-15-04: Analysis and Feasibility of Asphalt Pavement Performance-Based Testing Specifications for the Wisconsin Department of Transportation will be considered in the selection of performance test methods used in this study. As such, the test methods outlined in this proposal will be more clearly defined as the results of this study are made available.

4.3.1 Work Plan & Experimental Approach

The proposed work plan has been divided into five distinct tasks, as shown in Figure 1 and outlined in detail in the following sections.

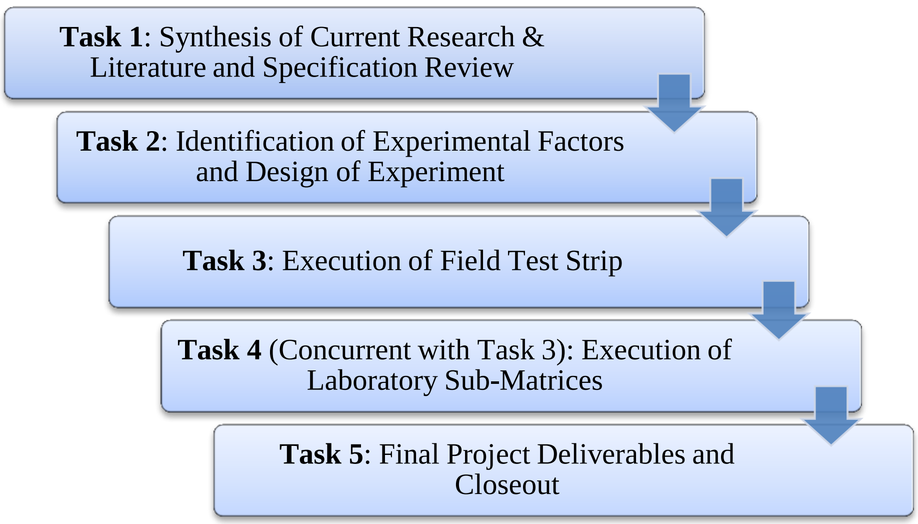

Figure 1. Proposed flow chart of work plan

Task 1: Synthesis of Current Research & Literature and Specification Review

Work during this task will focus on identifying ongoing and completed research addressing aging protocols for asphalt mixtures. Emphasis will be placed on recent WHRP and NCHRP reports and practice-ready journal articles as well as ongoing efforts on pilot projects within WisDOT. The central study identified in a preliminary literature review to support this approach is the NCHRP Report 815: Short Term Laboratory Conditioning of Asphalt Mixtures, which identified short- and long-term aging protocols for asphalt mixtures and discerned the effects of several mix design and production variables on the performance of aged mixtures. This study included nine field sites, including three in the Midwest, so the results can easily be leveraged for the development of the experimental design in this study (Newcomb, et al., 2015). The study reviewed in detail research on long- and short-term aging and suggested short term oven aging (STOA) and long term oven aging (LTOA) protocols based on field data.

Findings from this study indicated that the STOA protocols selected could, in general, simulate the volumetrics and short term performance characteristics of plant mixed, laboratory compacted mixtures, including performance in the HWTT (a central test for this project). Correlation to field cores was much weaker, which the authors attribute partially to sample thickness and mold configuration. Note that the recommended STOA protocol deviates from AASHTO R30 (Version 2015), which specifies short term performance samples be conditioned for four hours prior to compaction (Newcomb, et al., 2015). WisDOT also uses the four hour conditioning time for short term performance samples (Hamburg). For the purposes of this project, the STOA protocols of two hours indicated in the NCHRP study appear to be suitable starting points for this research and offer a time savings, however the WisDOT standard of four hours can be included if the panel agrees.

In terms of LTOA, the findings from the NCHRP report suggest that the degree of aging is more sensitive to test temperature than time and that the STOA + 5 days at 185 °F procedure was equivalent to approximately 16,000 Cumulative Degree Days (CDD) while the STOA + 2 weeks at 140 °F was equivalent to approximately 9,100 CDD, based on mixture stiffness. When CDD is converted to in-service time, the STOA + 5 days at 185 °F procedure results in the simulation of 22 months of service in colder climates such as Wisconsin, while the STOA + 2 weeks at 140 °F procedure results in the simulation of 12 months of service in the same climate (Newcomb, et al., 2015). No long term aging of loose mixtures was conducted during this study, although recent WisDOT experience has indicated long term aging of loose mixtures may significantly cut down on the aging time required.

Practitioner experience with the current AASHTO R30 LTOA protocol of 5 days at 185 °F (85 °C) indicates that the test protocol is not practical for production testing and can slow laboratory work by occupying ovens for five continuous days. Because of the need for a quicker, more practical LTOA protocol, recent work on WisDOT pilot projects has identified another alternative: 12 hours at 135 °C (275 °F) conducted on loose mix. This allows practitioners the ability to collect or produce mix, condition the mixture overnight, and test the next day, facilitating quicker turnaround during production. This procedure allows for significant time savings during production, but concerns exist regarding whether the procedure is representative of mixtures in the field. Based on this ongoing research, the research team will propose that the standard R30 method be used as a control, and the developmental loose mix aging protocol be included for analysis. A summary of the selected STOA and LTOA protocols for review during this research are shown in Table 1.

Table 1. Selected Short- and Long-term Oven Aging Protocols

Aging Simulation	Loose Mix or Compacted Sample	Protocol (Reference)
Short Term (STOA)	Loose Mix	2 hours at 275 °F (HMA) (Newcomb, et al., 2015)
Long Term (LTOA)	Loose Mix	R30 STOA + 12 hours at 135 °C (WisDOT Pilot)
	Compacted Sample	STOA + either: 5 days at 185 °F 2 weeks at 140 °F (Newcomb, et al., 2015)

In addition to a critical review of research projects, the research team will also review State specifications to identify if alternative aging protocols are being used nationwide. Similarly, the team will review the specification of performance tests for asphalt mixtures used throughout the country. This will help identify which tests are most widely used and the criteria specified. This task will be particularly useful for the objective of defining run parameters and a test matrix for the HWTT.

A major consideration in this research will be the practicality and availability of aging protocols and performance test methods to facilitate ease of contractor use and minimal additional monetary investment in equipment. One of the concepts that may be proposed is to use an aging rate limit rather than the final aging index. It is clear from the data in the NCHRP 815 report that the rates of aging of mixtures exhibit a linear or near-linear relationship with time and thus the rate of aging could be an important aging indicator (Newcomb, et al., 2015). Limits on rate of aging derived from a protocol of a few days could therefore be considered a practical test for acceptance of mixtures, while a shorter aging period may be used during production. Figure 2 shows an example of how an aging ratio can be calculated using mixture stiffness, although several other mixture or binder parameters have been shown to exhibit a similar trend.

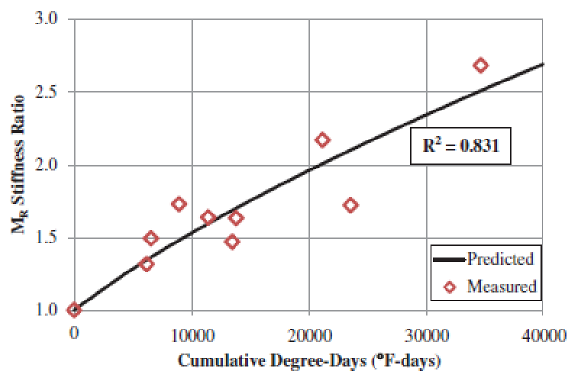

Figure 2. Stiffness ratio for select NCHRP 09-52 mixtures. Similar trends exist for HWTT rut depth resistance parameter and extracted binder modulus (Newcomb, et al., 2015).

Task 2: Identification of Experimental Factors and Design of Experiment

The research team has identified several major factors that are believed to affect the aging rate potential of asphalt mixtures based on review of the literature. These factors have been divided between ‘mix design’ factors and ‘production and pavement’ factors for the purposes of this project and are shown in Table 2 and Table 3, respectively. Given the budget restraints of the proposed project, not all factors can be effectively studied during this research, and these factors are identified in the table. Some factors, such as aggregate type (absorption), may be best studied by a lab sub-matrix since changing aggregate sources on a field project may be impractical or costprohibitive. For the purposes of the field project, all factors will be listed and prioritized based on a literature review and on expert opinions. After prioritization, the project resources will be allocated to cover the most important factors that could be feasibly studied in the lab, in the field, or both.

Table 2. Mix Design Factors Affecting Aging from Literature Review

Mix Design Factors Affecting Aging*	Explanation	Potential for Control in Experimental Plan
Binder Source*	Aging potential is dependent on crude source (Bell, AbWahab, Cristi, & Sosnovske, 1994; Newcomb, et al., 2015)	--
Modification (Additives)	Additives (esp. low temperature modifiers) may show significant aging susceptibility and rates of aging (Golalipour, 2013; Newcomb, et al., 2015)	Plan to use neat (unmodified) for control and modified grades: 58-28S or 58-34S (neat) 58-28H or V or 58-34H or V Lab sub-study on LT modifiers
Recycled Material Content	RAP/RAS binder stiffening effect and extent/rate of blending (Swiertz, Mahmoud, & Bahia, 2011)	Control (no recycle) Per contractor design (usually 15-25% ABR) to identify effects of RAP/RAS on aging
Binder Content (Apparent Film Thickness)	Thicker films may slow oxidative aging (a diffusion process) (Kandhal & Chakraborty, 1996)	Complete mix design at two AV levels without changing JMF aggregate ratios
Filler (P200) Content	Interaction of filler and asphalt affects the aging potential/rate (Moraes, 2014)	Adjust the dust to effective binder ratios by metering baghouse fines
Mix Design Level	Likely changes the binder content and total surface area of aggregates since gradation and aggregate properties will change (such as angularity)	Complete mix design at: LT (or MT), and MT (or HT)
Aggregate Absorption	Increases apparent film thickness initially due to volumetric design procedures (Newcomb, et al., 2015)	Use two sources of coarse aggregate if possible (such as granite and limestone) May not be economically feasible for field study.
Aggregate Mineralogy**	May change binder chemical structure (*adsorption* of certain molecular compounds) (Moraes, 2014)	

*Factor not considered in field study due to challenge or economic feasibility in controlling variable
**Factor might be easier to adjust with lab produced mixtures using the same gradation as the field site. Usually changing aggregate sources in the field is not economically feasible.

Table 3. Production and Pavement Factors Affecting Aging from Literature Review

Production/Construction Factors Affecting Aging*	Explanation	Potential for Control in Experimental Plan
Plant Temperature*	WMA vs. HMA plant temperatures have been shown to affect aging rate (Newcomb, et al., 2015)	Not easily controlled if a single test strip is to be constructed
Storage Time at Plant	Bulk storage keeps temperatures higher; longer storage, more plant aging	Sample mixtures right out of mix drum; Storage for 2 hours (R30 short term requirement); Sample at field (record time)
Lift thickness*	Upper layer exposed to air; oxidation considered a diffusion process	--
Mixture Compacted Density (Air Permeability)*	Denser mixtures should slow rate of oxidative aging due to oxygen ingress	Monitor density, but can't necessarily control

*Factor not considered in this study due to challenge or economic feasibility in controlling variable

The sampling protocol proposed for this research will aim to capture several phases of the short- and long-term aging processes in the field. Plant mixed samples will, at a minimum, be collected before entering the paver on site (with the time recorded) to simulate the short term aging process. Sufficient samples will be collected to facilitate the production of samples for several performance test methods (Plant Mixed, Laboratory Compacted (PMLC) samples). Samples will be immediately cooled and delivered to the UW lab for testing. In addition, raw materials will be sampled from the same contractor to produce laboratory samples, which will be aged according to the selected STOA and LTOA protocols (Laboratory Mixed, Laboratory Compacted (LMLC) sample). An example of this process is depicted in Figure 3 for the development of the STOA protocol.

In addition to comparing mixture performance for the PMLC and LMLC samples, binder will be extracted and recovered (AASHTO T164 and ASTM D5404, respectively) for rheological characterization for both sample types and selected mixtures. Based on the comparison, a recommendation for a STOA protocol can be made. LTOA protocols would ideally be selected by coring the pavement after designated time periods (6 months, 12 months, 24 months, etc.) and comparing the mixture performance and extracted binder properties with LMLC specimens. However, since the time window between test strip construction and the end of the project is less than 12 months and given budget constraints, the identification of a LTOA protocol to simulate field performance will have to be based on the field condition survey after the first winter and potentially coring if WisDOT deems this acceptable.

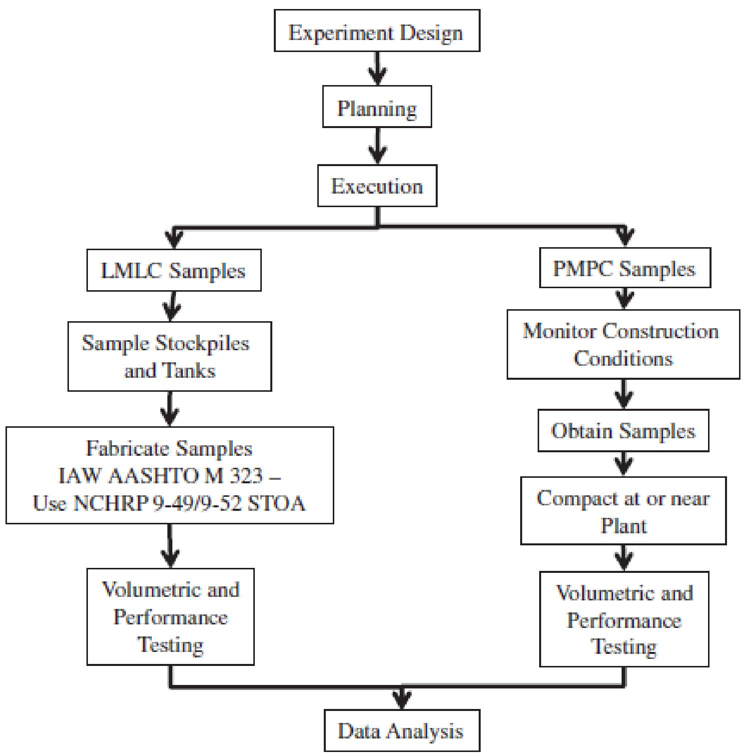

Figure 3. Recommended flow chart for determining STOA procedure (From NCHRP Report 815)

Design of Field Experiment

The final decision on which factors to include and at what levels will be made after consultation with WisDOT and after consideration of ongoing WHRP projects (namely project ID 0092-15-04). From that decision, a final testing matrix will be proposed. For the purposes of this proposal, the experimental design shown in Table 4 is considered as a starting point for this research.

Each mixture type will be sampled up to twice for determination of a STOA protocol (once at paver and potentially once at plant if deemed necessary) and extra mix will be collected for development of a LTOA protocol. These mixtures will be compared to a third set of mixtures based on raw materials collected from the contractor and prepared in the laboratory and aged according to the STOA and LTOA protocols selected. It is anticipated that one STOA protocol (2 hours at compaction temperature) and two LTOA protocols (2 hours STOA + 12 hours at 135 °C (loose mix) and 2 hours STOA + 120 hours at 85 °C (compacted)) will be evaluated. Care will be taken to ensure ovens are not overloaded and samples are exposed equally to moving air within the ovens. Based on the factors identified in Table 4, the preliminary layout for the field test strip plan is shown in Figure 4.

Table 4. Preliminary Experimental Design for Field Test Strip (Factors Subject to Change)

Factor	Levels	Description
Mix Traffic Level	2	LT and MT OR MT and HT Depending on traffic design for chosen project
Asphalt Content*	2 (for single traffic level)	High and Low (Ex.:4.5% and 3.5% Design AV)
Binder Grade	1	Per Location (PG 58-28 or PG 58-34)
Filler Level**	2	Design and Design + High (or Low) (Dependent on design; AC constant)
Modification Level***	2 (Neat and H or V)	PG58-28S or 58-34 S PG 58-28H or V or 58-34H or V
Recycle Content	1 (include control test section)	Per contractor design (15-25% ABR)
Total Potential Mixtures	6 + 1 dust content change + 1 control = 8 mix types (Sample each at plant and/or at paver; replicate each mixture in laboratory)	

*Dependent on mix design, but range of 1% selected to show more differentiation
**Feasibility of controlling P200/Pbe in field should be discussed; factor could be considered lab-only
*** Factor could be considered lab-only depending on outcome of discussions with WisDOT

	Control							
Traffic Level	LT	LT	LT	LT	LT	MT	MT	MT
Binder Mod.	58-28S	58-28S	58-28S	58-28S	58-28H	58-28S	58-28S	58-28H
Design AV	4.0%	4.0%	4.0%	3.5%	4.0%	4.0%	3.5%	4.0%
P200/Pbe	Design	Design	High/low P200	Design	Design	Design	Design	Design
Recycle	Neat	Recycle	Recycle	Recycle	Recycle	Recycle	Recycle	Recycle

Figure 4. Example test strip plan based on preliminary identification of factors (factors subject to change)

The performance tests and protocols to be conducted will be based on the findings of the ongoing WHRP Project 0092-15-04, which is scheduled for completion during summer of 2016 and a literature review. In general it is expected that the performance test methods will, at a minimum, include the HWTT (per the RFP) using STOA samples, a version of the SCB for intermediate temperature characterization using STOA + LTOA samples, and the DCT for low temperature characterization using STOA + LTOA samples (Table 5). This testing proposal aligns well with current WisDOT special provisions for high recycled materials content mixtures.

Table 5. Outline of Selected Preliminary Performance and Asphalt Binder Test Methods

Test Method	Associated Pavement Temperature Range	General Aging Condition
Volumetrics (Gmb, Gmm, AV, VMA, Apparent Film Thickness, Pbe)	NA	All
Recovery and Testing of Binder	All	All
HWTT (AASHTO T324; final procedure determined during this study)	High / Moisture Susceptibility	STOA
SCB* "LSU" Procedure (ASTM Ballot), OR "ICT" or "I-FIT" (IDOT) Procedure (AASHTO Ballot, IDOT 405)	Intermediate/Low	STOA + LTOA$_{A**}$ STOA + LTOA$_{B**}$
DCT ASTM D 7313-07	Low	STOA + LTOA$_{A**}$ STOA + LTOA$_{B**}$
		STOA***

*SCB procedure subject to change based on discussions with WisDOT and TOC committee members.
**LTOA$_A$ is loose mix aging for 12 hours at 135 °C; LTOA$_B$ is current AASHTO R30 guidelines
***STOA samples used to establish baseline for rate of aging study and as potential for development of acceptance mixture test for plant produced samples

Identification of Hamburg Wheel Tracking Test Protocol for Wisconsin Mixtures

Before construction of the field test strip and execution of the laboratory aging studies, a laboratory experiment will be conducted to determine the most effective testing protocol for the HWTT as it applies to Wisconsin mixtures. The RFP clearly indicates that "finer graded surface mixes are not performing well in this test", yet continue to show satisfactory field performance. Extensive work conducted by the research team using the HWTT has shown that the test method itself is not necessarily fundamentally biased when testing finer mixtures, given the success of 4.75 mm, 9.5 mm, as well as 12.5 mm NMAS mixtures in this test. As such, the focus of this sub-matrix of testing will be determining why finer graded mixtures produced using *Wisconsin* mix designs may show poor results in this test.

To complete this study, the selected contractor mix design for the field study will be used as the baseline for comparison. A thorough literature review of state specifications will be conducted as this could help identify how other states are dealing with similar mixtures. From the literature review, a laboratory test matrix will be finalized to determine the factors most influencing the results of this test. In addition, typical fine mixtures used in WI will be compiled in a database to evaluate if the packing of aggregates in fine mixes is considered inferior, in terms of the Bailey Method parameters, which is causing this perceived poor performance in the HWTT. Since the HWTT is conducted in a wet environment, the average film thickness of such mixes as compared to mixtures with a coarse aggregate blend will also be evaluated as a potential cause. It is possible that the thinner films in fine graded mixtures are the primary cause of this trend. A recent study by NCHRP (NCHRP 20-07/Task 361) has been completed that may shed some light on this issue and is expected to be published in the next few months. This study covered this specific topic: Hamburg Wheel-Track Test Equipment Requirements and Improvements to AASHTO T 324. It is expected that this report will be available soon and it will be used to understand what variables are important for the HWTT results.

Based on an initial review of the literature and experience with the HWTT by the research team, the following laboratory testing matrix is proposed. The matrix will be built off of the mix design submitted by the contractor for the field project selected by WisDOT and will represent a 'representative fine graded Wisconsin mixture'. Several of the mix design factors will be changed in the laboratory in attempt to isolate the root cause of the observations made by WisDOT. All mixtures will be aged according to the proposed STOA protocol before testing.

Table 6. Laboratory HWTT Experimental Design

Factor	Level	Explanation
Mix Design Level	1	Per selected field project
Binder Grade	1	Per selected field project
Modification Level	2	Neat (S), and Heavy Traffic (H)
Asphalt Binder Content	3	Contractor Design, and Design ± 1% AV
Mineral Filler (P200) Content	2	Contractor Design, and "High" Level
Recycled Materials Content	2	Virgin (None), and Contractor Design
Total Mixtures for HWTT Sub-Study	**24**	

The test will be run following standard AASHTO T324 protocol, per the RFP. Two options for specification development are given in the RFP and include holding the temperature constant (50 °C) and adjusting the test criteria, or adjusting the test temperature and maintaining the same performance limit (similar to the M320 binder grading procedure). If this test is to predict field performance, using a test temperature representative of the surrounding climate (and thus, binder grade) is logical as this will not bias results when using softer grades for colder regions like Wisconsin. Given that Wisconsin plans to use a single high temperature climatic grade (PG 58 based on AASHTO M332) beginning with the 2016 season, this essentially equates to using the same test temperature in the HWTT for all testing.

One potential specification could be keeping the maximum allowable rut depth (10.0 mm, for example), while varying the minimum number of wheel passes to match the design traffic level/intensity for the mixture. For example, in heavy traffic situations, where a PG 58H binder is specified, the minimum number of passes the mixture with this binder must withstand, before reaching the limit of 10.00 mm, will be greater than that of a mixture with PG 58S binder. The maximum rut depth should be chosen based on considerations of perceived serviceability (factors such as hydroplaning potential should be considered).

The outcome of this laboratory testing may indicate that a 'balanced mix design' approach is needed to satisfy the HWTT requirements as well as a cracking based test like the SCB. For example, it is well known that increasing the asphalt binder content (up to a certain point) will generally increase durability but reduce rutting resistance. Final factor and level determination will require consultation with contractors, WisDOT staff, and TOC members.

Task 3: Execution of Field Test Strip

As stated in the RFP, WisDOT will identify a project for construction of the test strip in the 2017 construction season. The research team has subcontracted with Behnke Materials Engineering (BME) to be the primary point of contact for the field site work, including working with the contractor in sampling the mixtures, coordinating traffic control whenever required, and sampling the raw materials from the contractor. Mixtures and raw materials will be sampled following standard AASHTO or WisDOT modified sampling protocols. The qualifications of BME and their relationship with contractors in Wisconsin and WisDOT make them ideally suited for this task.

Task 4: Execution of Laboratory Sub-Matrices

With the exception of the asphalt binder extraction and recovery and the DCT testing, all laboratory testing will be conducted at the UW Laboratory. Asphalt extraction and recovery will be conducted at the Bitumix Solutions Laboratory, an AASHTO accredited laboratory. The DCT testing will be conducted by the BME laboratory, which is also an AASHTO accredited materials testing laboratory. For a complete listing of laboratory certifications and personnel qualifications, see Sections 7, 9, and 10.

Task 5: Final Project Deliverables and Closeout

Based on the findings from Tasks 1 through 4, the final project report and closeout presentation will be drafted and submitted during this task. In addition to the final report and presentation, a kick-off meeting is planned, and a project memorandum and presentation for the final experimental designs to be conducted is planned for Task 2. Table 7includes a summary of all planned deliverables.

4.3.2 Expected Contribution from WisDOT Staff

Per the RFP, a maximum commitment of 40 hours by WisDOT staff and TOC members is expected for this project, primarily in discussions for development of the final work plan and the technical review of findings and reports.

4.3.3 Other Equipment and Materials

No major equipment or materials purchases are anticipated in order to fulfill this proposal. It is not anticipated that any WisDOT equipment will be needed as part of this study.

4.4 Anticipated Research Results and Implementation Plan

The anticipated result of this research project will be a testing database from which a final research report will be generated. The findings will directly impact contractors and researchers designing, testing, producing, and constructing asphalt mixtures in the State of Wisconsin. Specific research results will attempt to include the following items:

1. Most effective HWTT protocol to reliably estimate moisture resistance of Wisconsin mixtures.
2. Most effective short term and long term aging protocols to estimate field aging of mixtures in Wisconsin.
3. Summary of effects of mixture variables including binder content, binder grade, filler content and mixture traffic designation on HWTT results and aging potential as measured by a cracking performance test.
4. Recommendation for potential changes to WisDOT Standard Specifications and Materials Manuals.

5. Time Requirements/Schedule

The total project duration is 21 months, consisting of 18 months for research and an additional 3 months for review and approval of final project deliverables. The anticipated start date is October 1, 2016 and the anticipated end date is June 30, 2018. Based on this timeframe, the project schedule is provided in Table 7. The proposed schedule for TOC meetings and submission of deliverables are denoted by the codes D and M. In addition to the deliverables provided in the schedule, the research team will submit quarterly reports according to WisDOT guidelines.

Table 7. Project Schedule

Task	Quarter						
	1	2	3	4	5	6	7
	10/16-12/16	1/17-3/17	4/17-6/17	7/17-9/17	10/17-12/17	1/18-3/18	4/18-6/18
1. Synthesis of Current Research/Lit. & Specification Review	M1						
2. Design of Experiment		D1, M2					
3. Execution of Field Work Plan			TBD by WisDOT Project Selection				
4. Execution of Laboratory Testing Sub-Matrix							
5. Final Project Deliverables and Closeout						D2	D3, M3

Summary of Deliverable and Meeting Codes:

- **M1:** Project kick-off meeting held with Project Oversight Committee
- **D1, M2:** Project memorandum and interim presentation at full TOC meeting.
- **D2:** Submission of draft final report and other project deliverables.
- **D3, M3:** Project closeout presentation to full TOC and delivery of final report.

A research team consisting of UW-MARC staff and industry representatives with a wide range of experience including mixture design and testing, mixture production, field quality control, and specification drafting has been assembled for this proposal. The research team and specific involvement in the project is described in Table 8.

Table 8. Summary of Research Team and Responsibilities

Team Member	Role	Responsibilities
Dr. Hussain Bahia	Principal Investigator	• Project Management and Reporting • Communication with TOC • Detailed Analysis of Data • Preparation of Project Deliverables
Erik Lyngdal	UW-MARC Lead	• Laboratory testing leader • Data analysis • Technical reporting and review • Data Analysis and Reporting
Signe Reichelt, PE	BME Lead (Subcontract)	• Development of work plan • Coordination of field sampling program • Coordination of select laboratory testing • Review of technical documents
Dan Swiertz, PE	Bitumix Solutions Lead (Subcontract)	• Development of Work Plan • Oversight of Data Analysis • Review of Project Deliverables • Development of Implementation Plan

In addition to the personnel listed in Table 8, a graduate student and the support of undergraduate hourly staff was budgeted to support materials testing and sample preparation. The distribution of hours by task for the project team is provided in Table 9.

Table 9. Project Team – Distribution of Hours by Task

INDIVIDUALS	TASK					TOTAL HOURS
	1	2	3	4	5	
Principal Investigator: Hussain Bahia	55	55	9	9	55	182
Researcher: Erik Lyngdal	91	91	36	36	109	364
UW Graduate Student/Senior Staff	182	46	455	182	46	910
UW Hourly Students/Junior Staff	0	0	218	146	0	364
Subcontract Lead (BME): Signe Reichelt	0	0	100	30	0	130
Subcontract Senior Staff (BME)	0	0	50	20	0	70
Subcontract Laboratory Technician (BME)	0	0	180	140	0	320
Subcontract Lead (BS): Dan Swiertz	18	18	35	18	36	125
Subcontract Laboratory Technician (BS)	0	0	139	0	0	139
TOTALS	346	209	1223	581	246	2605

6. Project Budget

Table 1 Work Effort by Task

1 2 3 4

	TASKS					Total	Fringes	Total Salaries and Fringes
Personal	1	2	3	4	5			
Hussain Bahia	$ 4,838	$ 4,838	$ 806	$ 806	$ 4,838	$ 16,126	$ 5,967	$ 22,093
Rsearch Associate	$ 1,969	$ 1,969	$ 788	$ 788	$ 2,363	$ 7,875	$ 2,914	$ 10,789
Graduate Student	$ 3,788	$ 947	$ 9,471	$ 3,788	$ 947	$ 18,942	$ 4,527	$ 23,470
Hourly worker	$ -	$ -	$ 2,100	$ 1,400	$ -	$ 3,500	$ 84	$ 3,584
TOTALS	$ 10,595	$ 7,754	$ 13,165	$ 6,782	$ 8,147	$ 46,444	$ 13,492	$ 59,935

						Year 1	Year 2	Totals
Total Salaries, Wages and Fringes	$ 14,019	$ 10,499	$ 16,069	$ 8,311	$ 11,038	$ 40,586	$ 19,349	$ 59,935
Sub-Contracts								
Bitumix Solutions	$ 1,786	$ 1,786	$ 8,705	$ 1,741	$ 3,571	$ 12,277	$ 5,312	$ 17,589
Behnke Materials & Engineering LLC	$ -	$ -	$ 28,571	$ 16,339	$ -	$ 28,571	$ 16,339	$ 44,910
Subtotal	$ 1,786	$ 1,786	$ 37,277	$ 18,080	$ 3,571	$ 40,848	$ 21,652	$ 62,500
Other Direct Costs								
Tuition Remission (Graduate Student)	$ 3,000	$ -	$ -	$ 3,000	$ -	$ 3,000	$ 3,000	$ 6,000
	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ 3,000	$ -	$ -	$ 3,000	$ -	$ 3,000	$ 3,000	$ 6,000
Materials and Supplies								
	$ -	$ 1,500	$ -	$ -	$ -	$ 1,500	$ -	$ 1,500
	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ -	$ 1,500	$ -	$ -	$ -	$ 1,500	$ -	$ 1,500
Travel								
	$ -	$ -	$ -	$ -		$ -	$ -	$ -
	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Communications								
	$ -	$ -	$ -	$ -	$ 500	$ -	$ 500	$ 500
	$ -	$ -	$ -	$ -	$ -	$ -		
Subtotal	$ -	$ -	$ -	$ -	$ 500	$ -	$ 500	$ 500
TOTAL DIRECT COSTS	$ 18,805	$ 13,784	$ 53,345	$ 29,391	$ 15,109	$ 85,934	$ 44,501	$ 130,435
TOTAL INDIRECT COSTS (Provide Rate and Base)	$ 2,821	$ 2,068	$ 8,002	$ 4,409	$ 2,266	$ 12,890	$ 6,675	$ 19,565
TOTAL CONTRACT COST	$ 21,625	$ 15,852	$ 61,347	$ 33,800	$ 17,376	$ 98,824	$ 51,176	$ 150,000

Budget Justification

1. **Staff Benefits**
   a. **Fringe Benefit Rates:** All fringe benefit rates included in the budget are in accordance with the current rates established by the UW-Madison Office of Research and Sponsored Programs. More information is available at (https://www.rsp.wisc.edu/rates/index.html).
   b. **Tuition Remission:** UW-Madison Office of Research and Sponsored Programs Notice 2006-3 requires an annual tuition remission of $12,000/yr. for graduate students assigned to the project. The proposed budget includes tuition remission proportional to the total amount of time allocated for a graduate student to work on the project (25% or $6000 for two academic years).
2. **Materials and Supplies - $1500 (1% of project budget)**
   a. **Containers and shipping:** The proposed study requires collection of aggregate materials to conduct a laboratory testing. Funds were allocated to transport the raw materials from selected HMA plant to the University of Wisconsin's laboratory.
   b. **Miscellaneous laboratory supplies:** The proposed study requires a significant amount of laboratory testing. Therefore, funding was allocated to purchase laboratory supplies that will be allocated towards preparation of materials for testing.
3. **Communication - $500 (0.3% of project budget)**
   a. Funds were budgeted for communication and printing of formal documents. The RSP requires printing of seven hard copies of a final report to be submitted at the end of the contract date.

7. Qualifications of the Research Team

Hussain U. Bahia – *Principal Investigator – UW Madison*
Dr. Bahia received his Ph.D. degree in the area of Pavement Materials and Design from the Pennsylvania State University in 1991. He joined the faculty at the University of Wisconsin-Madison in 1996 to teach and conduct research in the area of pavement materials and design. Prior to joining the UW faculty he served as the Director of Research and Engineering Services of the Asphalt Institute in 1995- 1996. He also served for four years after earning his Ph.D. on the faculty of Penn State University from 1991 to 1994. He has served as the PI or co-PI on several Wisconsin DOT projects (more than ten major studies), projects with the FHWA (four major studies), and numerous projects funded by private industry (more than twenty studies). He is has served as the PI for the NCHRP 9-10 project from 1996 to 2000 and the NCHRP 9-45 project from 2007 to 2011. Dr. Bahia also served as a member of the NCHRP project panels for project 9-19 and project 9-23. In addition to technical involvement with WisDOT and FHWA, Dr. Bahia served as the Technical Director of WHRP from 2004 – 2012 and is thus aware of the mission of the WHRP program and experienced in administration of projects funded by WHRP.

Erik Lyngdal-*Research Associate-UW Madison*
Mr. Lyngdal is currently employed by the University of Wisconsin's Modified Asphalt Research Center (MARC) as a research associate. Prior to joining the MARC group as a researcher, he earned his M.S. degree in civil engineering from the University of Wisconsin-Madison during the spring of 2014. His primary focus of research as a graduate involved evaluating current asphalt binder PG+ (PG "plus") testing specifications currently being implemented or researched in the United States. In his role as a research associate, Mr. Lyngdal manages several projects related asphalt binder and mixture performance testing. Current activities Mr. Lyngdal is responsible for at MARC include a federal pooled fund study (solicitation number 1360), database management for the Western Cooperative Testing Group, industrial partnerships and laboratory management. His role in each of the aforementioned MARC activities call upon his diverse skillset to oversee laboratory testing, data analysis, communication, graduate student guidance and understanding of laboratory equipment used for testing asphalt materials.

Dan Swiertz – *Bitumix Solutions*
After earning his M.S. degree in civil engineering from the University of Wisconsin – Madison while studying with the Modified Asphalt Research Center (MARC), Mr. Swiertz was employed with MARC as a research engineer working on various projects within the Asphalt Research Consortium and in industry. His research focused on the effects of recycled asphalt on virgin binder properties as well as effects of mixture design on pavement noise and friction. Mr. Swiertz is currently employed with the Asphalt Technologies Group/Bitumix Solutions Laboratories in Portage, WI as the Director of Mix Design Laboratories. His work focuses on asphalt binder and emulsion formulation, new product development and implementation, quality control, and technical consultation. Both labs are independently AASHTO accredited and certified by WisDOT and the Combined State Binder Group. Mr. Swiertz is a registered Professional Engineer in the State of Wisconsin and holds the following WisDOT highway technician certifications: AGGTEC-1, HMA-IPT, HMA-TPC, and HMA-MD.

Signe Reichelt – *Behnke Materials Engineering*
Ms. Reichelt has been with Behnke Materials Engineering since 2012. Before joining BME, she had distinguished herself as both a construction professional and a researcher. In 2004, she was involved in the Mechanistic Empirical Pavement Design of the Marquette Interchange in Milwaukee by helping choose mix designs and determine thicknesses for the Perpetual Pavement structure. Then in 2012, Ms. Reichelt helped design and produce the SMA mix used on the Mitchell Interchange Project south of Milwaukee. Most recently, she is the principle investigator on the WHRP 0092-15-09 Field Compaction and Density Validation Study. She is well versed in HMA production facilities, mix design and laydown. Ms. Reichelt is currently involved in the WisDOT High Recycled Pilot projects where she helped write and implement the specifications for HMA Aging, Hamburg, DCT and SCB. Prior to joining the private sector, Ms. Reichelt worked in the UW-Madison Asphalt Binder Testing Lab. She is published in the 2000 Transportation Review Board article Effects of Film Thickness on the Rheological Behaviors of Asphalt Binders and Wisconsin DOT Report FEP-01010 Evaluation of a Hot Mix Asphalt Perpetual Pavement. She has been a member of the WisDOT Technical Team Committee since 2002. As a member of this Committee, she works to improve the asphalt industry by writing and implementing new specifications for WisDOT. From 2003 to 2009, and again in 2012 to present, Ms. Reichelt is a member of the WisDOT Flexible Pavements Technical Oversight Committee. She has also been a member of the Association of Asphalt Pavement Technologists since 2005.

8. Other Commitments of the Research Team

Table 10. Other Commitments of the Research Team

Hussain Bahia, Ph.D.		
Commitments	Percentage of Time	
	Committed	Available
Dept. of Civil, Construction, & Environmental Engineering	25%	
Pooled Fund Study (0092-14-20), TPF-5 (302) "Modified Binder (PG+) Specifications and Quality Control Criteria"	5%	
WisDOT 0092-15-04, 09/14-08/16 "Analysis and Feasibility of Asphalt Pavement Performance-Based Testing Specifications for the WisDOT"	5%	
Modified Asphalt Research Center (MARC)	10%	
QA/QC Qatar*	5%	
Time Available		50%

* The commitment will reduce significantly starting at the end of spring 2016 if project is awarded

Erik Lyngdal		
Commitments	Percentage of Time	
	Committed	Available
Modified Asphalt Research Center (MARC) Management/Activities	35%	
Pooled Fund Study (0092-14-20), TPF-5 (302) "Modified Binder (PG+) Specifications and Quality Control Criteria"	30%	
Time Available		35%

Daniel Swiertz, PE		
Commitments	Percentage of Time	
	Committed	Available
Bitumix Solutions (Non-consulting duties)	70%	
UW Madison Lecturer Duty	5%	
Time Available		25%

Signe Reichelt, PE		
Commitments	Percentage of Time	
	Committed	Available
Behnke Materials Engineering, LLC (Managerial)	75%	
Time Available		25%

9. Equipment and Facilities

UW-Madison, Modified Asphalt Research Center

The Asphalt research facilities of the College of Engineering are part of the Wisconsin Structures and Materials Laboratory. The facilities are housed within the Engineering building on the main campus in Madison. The facilities total area dedicated for asphalt testing is approximately 1600 square feet. All necessary equipment required for complete SuperPave analysis of asphalt cements, asphalt mixtures volumetric design, and mixture performance testing are available at the asphalt laboratory. The following sections include details of equipment available.

Asphalt Binder Laboratory

The Asphalt Binder Laboratory has state-of-the-art SuperPave testing equipment to characterize asphalt binders using both standard and non-standard tests. Specifically, the laboratory has the ability to perform MSCR performance-graded asphalt binder specification testing (AASHTO M 332) and also conduct advanced rheological and damage characterization of asphalts.

Asphalt Mixture Laboratory

The Asphalt Mixture Laboratory includes all equipment necessary to conduct standard SuperPave volumetric mixture design procedures and to characterize mixture performance. For preparation of samples and evaluation of mixture behavior during construction the laboratory is equipped with two SuperPave Gyratory compactors. For mixture characterization the lab maintains two servo-hydraulic testing machines for performing testing according to SuperPave and mechanistic design procedures. One of the testing systems is equipped with an environmental chamber and allows measuring the low and intermediate Indirect Tension (IDT) mixture testing, repeated creep, dynamic modulus, and SCB testing. The temperature control allows maintaining sample temperatures from -40°C to 80°C. The lab also includes an instrumented environmental chamber to evaluate the volume change of asphalt mixtures at low temperatures as a means to evaluate potential for thermal cracking.

Behnke Materials Engineering
BME maintains a complete AMRL accredited asphalt material testing laboratory, capable and certified to perform all tests associated with HMA design, production and placement. BME is accredited for the following procedures:

- AASHTO R18
- AASHTO T11 (Materials Finer than 75-µm (No. 200) Sieve by Washing)
- AASTHO T27 (Sieve Analysis of Fine and Coarse Aggregate)
- AASHTO T84 (Specific Gravity and Absorption of Fine Aggregate)
- AASHTO T85 (Specific Gravity and Absorption of Coarse Aggregate)
- AASHTO T164 (Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt)
- AASHTO T166 (Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt)
- AASHTO T209 (Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt)
- AASHTO T269 (Percent Air Voids in Compacted Dense and Open Asphalt Mixtures)
- AASHTO T312 (Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor)

BME performs AMRL proficiency samples for the following procedures:

- AASHTO T104 (Soundness of Aggregate by Use of Sodium Sulfate
- AASHTO T96 (Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine)
- AASHTO T304 (Uncompacted Void Content of Fine Aggregate)
- AASHTO T308 (Determining Asphalt Binder Content of Hot Mix Asphalt by the Ignition Method)
- AASHTO T30 (Mechanical Analysis of Extracted Aggregate)

The BME facility is equipped with the following equipment to run the above mentioned tests and more:

- Superpave Gyratory Compactor (Brovold – Baby Pine)
- Reflux AC Extractor (H-1495)
- Centrifuge Extractor (H-1857A & AC-0208)
- Direct Compact Tension Tester (Brovold - ASTM 7313)
- Hamburg (AASHTO T324)
- Semi Circular Bend (Brovold - Illinois Procedure & WisDOT Procedure)
- Ignition Oven (Carbolite – and have access to a NCAT Oven at S.T.A.T.E. Testing)
- Tensile Strength Ratio
- CPN Nuclear Density Gauges
- NCAT Asphalt Permeameter
- Coring equipment and core saws
- Pressure Aging Vessel & Vacuum Oven (Prentex - AASHTO R28)
- Bending Beam Rheometer (Cannon – AASHTO 313)
- Dynamic Shear Rheometer (Anton Paar – AASHTO T315)
- Brookfield Rotational Viscometer (AASHTO T316)
- Rolling Thin Film Oven (Cox and Sons – AASHTO T240)
- Recovery-Rotoary Evaporator (Buchi – ASTM D5404)

Bitumix Solutions/Asphalt Technologies Group
The Bitumix Solutions and Asphalt Technologies Group (ATG) Laboratories are sister laboratories located in Portage, WI, about 35 miles north of the UW Madison campus, facilitating efficient sample transport between laboratories. The Bitumix Laboratory is a full service, AASHTO accredited/WisDOT certified mix design laboratory while the ATG laboratory is a fully AASHTO accredited Superpave binder and asphalt emulsion testing laboratory. Accreditation details for both laboratories are available online at www.amrl.net.

10. Technician and Laboratory Certification

The Behnke Materials Engineering and Bitumix Solutions laboratories are fully AASHTO accredited as well as certified with WisDOT and the Combined State Binder Group. All field technicians associated with this project are certified with the Wisconsin Highway Technician Certification Program at the AAGTEC-1 and HMA-IPT levels at a minimum. Personnel profiles, including HTCP certification numbers will be made available upon request. UW-MARC laboratories are not AASHTO accredited, however the center maintains annual calibration of testing equipment and participates quarterly in the Combined States Group Round Robin Testing Program and also leads round robin testing of asphalt binders and mixtures for the Rocky Mountain User Producers Groups.

11. References

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