Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures:

Illinois Department of Transportation (IDOT)

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ABR	asphalt binder replacement
AJMF	adjusted JMF
ALF	Accelerated Loading Facility
AMPT	Asphalt Mixture Performance Tester
ASTM	American Society for Testing and Materials
CBM	Central Bureau of Materials
DOT	Department of Transportation
BMD	Balanced Mix Design
COV	coefficient of variation
ESAL	equivalent single axle load
FHWA	Federal Highway Administration
FI	flexibility index
HMA	hot-mix asphalt
HWT	Hamburg Wheel test
IAPA	Illinois Asphalt Pavement Association
ICT	Illinois Center for Transportation
IDOT	Illinois DOT
I-FIT	Illinois Flexibility Index test
ILS	interlaboratory study
JMF	job mix formula
LTA	long-term aged
MESAL	million ESAL
MOT	Ministry of Transportation
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NMAS	nominal maximum aggregate size
OBC	optimum asphalt binder content
PAV	pressure aging vessel
PEP	Performance Engineered Pavements
PG	performance grade
RAP	reclaimed asphalt pavement
RAS	reclaimed asphalt shingles
SHA	state highway agency
SMA	stone-matrix asphalt
TFHRC	Turner-Fairbanks Highway Research Center
TS	tensile strength
TSR	TS ratio
TxDOT	Texas Department of Transportation
U.S.	United States
UIUC	University of Illinois at Urbana-Champaign
VFA	voids filled with asphalt binder

VMA	voids in the mineral aggregate

BACKGROUND

Balanced mix design (BMD) is one of the programs that supports the Performance Engineered Pavements (PEP) vision of the Federal Highway Administration (FHWA) that unifies several existing performance focused programs. This vision incorporates the goal of long-term performance into structural pavement design, mixture design, construction, and materials acceptance. In November 2019, FHWA published FHWA-HIF-20-005 Technical Brief, *Performance Engineered Pavements*. It provides an overview of the several initiatives that encompass the concept of PEP.

The BMD combines binder, aggregate, and mixture proportions that will meet performance criteria for a diverse number of pavement distresses for given traffic, climate, and existing pavement conditions. In December 2019, FHWA published FHWA-HIF-19-103, *Index-Based Tests for Performance Engineered Mixture Designs for Asphalt Pavements*. This informational brief provides practitioners with information about index-based performance tests that can be implemented within a BMD process.

In August 2018, the National Cooperative Highway Research Program (NCHRP) Project 20-07/Task 406, *Development of a Framework for Balanced Mix Design*, included a draft American Association of State Highway and Transportation Officials (AASHTO) Standard Practice for Balanced Design of Asphalt Mixtures with a nine step process for evaluating and fully-implementing a performance test into routine practice. The provisional AASHTO Standard Practice PP 105-20 describes four approaches (A through D) for a BMD process. The following is a brief description of the four approaches:

- ***Approach A—Volumetric Design with Performance Verification***. This approach starts with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) for determining an optimum asphalt binder content (OBC). The mixture is then tested with selected performance tests to assess its resistance to rutting, cracking, and moisture damage at the OBC. If the mix design meets the performance test criteria, the job mix formula (JMF) is established and production begins; otherwise, the entire mix design is repeated using different materials (e.g., aggregates, asphalt binders, recycled materials, and additives) or mix proportions until all of the volumetric criteria are satisfied.

- ***Approach B—Volumetric Design with Performance Optimization***. This approach is an expanded version of Approach A. It also starts with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) for determining a preliminary OBC. Mixture performance tests are then conducted on the mix design at the preliminary OBC and two or more additional contents. The asphalt binder content that satisfies all of the cracking, rutting, and moisture damage criteria is finally identified as the OBC. In cases where a single binder content does not exist, the entire mix design process needs to be repeated using different materials (e.g., aggregates, asphalt binders, recycled materials, and additives) or mix proportions until all of the performance criteria are satisfied.

- ***Approach C—Performance-Modified Volumetric Design***. This approach begins with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) to establish initial component material properties, proportions, and binder content. The performance test results are then used to adjust either the initial binder content or mix component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, and additives) until the performance criteria are satisfied. For this approach, the final design is primarily focused on meeting performance test criteria and may not have to meet all of the Superpave volumetric criteria.

- ***Approach D—Performance Design***. This approach establishes and adjusts mixture components and proportions based on performance analysis with limited or no requirements for volumetric properties. Minimum requirements may be set for asphalt binder and aggregate properties. Once the laboratory test results meet the performance criteria, the mixture volumetrics may be checked for use in production.

The process identified in NCHRP Project 20-07/Task 406 involves nine essential steps for moving a performance test from concept to full implementation:

(1) Draft test method and prototype equipment.
(2) Sensitivity to materials and relationship to other laboratory properties.
(3) Preliminary field performance relationship.
(4) Ruggedness experiment.
(5) Commercial equipment specification and pooled fund purchasing.
(6) Interlaboratory study (ILS) to establish precision and bias information.
(7) Robust validation of the test to set criteria for specifications.
(8) Training and certification.
(9) Implementation into engineering practice.

While some of these nine steps can be adopted directly by a state highway agency (SHA) based on the level of effort completed regionally or nationally (e.g., steps 1, 4, and 5), others would need to be checked, expanded or redone using available (local) materials (e.g., steps 2, 3, 6, and 7). Steps 8 and 9 would need to be done by each SHA as part of its full implementation effort.

There is widespread recognition and desire by SHAs and the asphalt paving industry to use performance testing to complement volumetric properties to help ensure satisfactory pavement performance. Some SHAs have used the BMD process as part of mixture design and acceptance on select demonstration projects or have well developed BMD specifications, performance test methods and practices in place. These SHAs have valuable experiences and lessons learned that can facilitate the implementation of a BMD process or a performance test of asphalt mixtures into practice to improve long-term pavement performance.

OBJECTIVE

The primary objective of this overall effort was to identify and put forth positive practices used by SHAs when implementing BMD and performance testing of asphalt mixtures. To accomplish this objective, information was collected through site visits and other means with seven key agencies. Illinois Department of Transportation (IDOT) graciously agreed to host a virtual site visit.

SCOPE AND OUTCOMES

The scope of each virtual site visit included: a pre-visit kickoff web conference and review of agency documents (policy, specifications, research reports, etc.); and a two to four-day virtual site visit to obtain detailed understanding of agency best practices and lessons learned for BMD and performance testing of asphalt mixtures that can facilitate the implementation of a BMD process into practice at other SHAs. The outcomes of each virtual site visit were to include:

1. A brief report to each FHWA Division Office and SHA visited on the observations and any recommendations identified.
2. A summary document of positive practices compiled from specific reviews in all of the SHAs visited.
3. A short, informational brief with the key highlights.
4. An accompanying PowerPoint presentation.
5. Depending on observations, research need statements may be developed for consideration.

This document is the brief report on the observations and recommendations identified through the IDOT virtual site visit.

GENERAL INFORMATION SPECIFIC TO IDOT

IDOT typically places 4–8 million tons of asphalt mixture a year (about 4.2 million tons of asphalt mixture were placed in 2019). The gas tax and fee increases approved in 2019 are anticipated to sustain the placement of about 7–8 million tons a year. The IDOT standard asphalt mixtures are specified in standard specifications SECTION 1030. HOT-MIX ASPHALT. The specifications comprise High Equivalent Single Axle Load (ESAL) mixtures, Low ESAL mixtures, and stone-matrix asphalt (SMA) mixtures. A summary of the asphalt mixtures along with their applications is shown in table 1. The primary differences in the specifications for the High ESAL and Low ESAL mixtures are their gradation and allowable asphalt binder contents.

IDOT specifications for hot-mix asphalt (HMA) currently require the Hamburg Wheel test (HWT) for rutting performance evaluation using the Illinois modified AASHTO T 324. The HWT has been fully implemented into specifications since 2012. Effective January 2021, the Illinois Flexibility Index test (I-FIT) will be required during asphalt mixture design verification and production testing for all HMA mixtures.

Table 1. Asphalt Mixture Types Used by IDOT.

Mixture Type		Application
High ESAL	IL-19.0	• Binder course.
	IL-9.5	• Binder and Surface course.
	IL-4.75	• Binder course.
Low ESAL	IL-19.0L	• Binder course.
	IL-9.5L	• Binder and Surface course.
SMA-12.5, SMA-9.5	≤ 10 MESALs	• Binder or surface course.
	> 10 MESALs	• Binder or surface course.

Reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) are widely used in asphalt mixtures in Illinois. With the increase use of such materials, asphalt mixtures started to experience premature failure or did not perform as originally intended. The permanent deformation resistance of the asphalt mixtures was improved in the presence of RAP and RAS, as demonstrated with low rut depths in the HWT. Softer performance grade (PG) of asphalt binders were used with certain levels of RAP and RAS. IDOT's adoption of the HWT, which promoted increased levels of RAP and RAS, raised concerns that asphalt mixtures with, in particular, increased RAP and RAS contents, are drier, brittle, and more susceptible to premature cracking. Accordingly, IDOT started, and in coordination with the industry, to examine the use of a cracking performance test to complement the HWT during asphalt mixture design verification and production. A cracking test was needed to mainly address the commonly observed reflective cracking in asphalt pavement overlays. IDOT funded and coordinated relevant research with the Illinois Center for Transportation (ICT) at the University of Illinois at Urbana-Champaign (UIUC) to assure rational implementation of performance testing.

BMD APPROACH

In January 2016, IDOT developed a Special Provision for Hot-Mix Asphalt – Mixture Design Verification and Production (Modified for I-FIT Data Collection) to require the use of the I-FIT to identify the cracking resistance properties of as-produced HMA by using the flexibility index (FI) parameter. In January 1, 2020, the special provision was revised to expand I-FIT testing, including surface mixtures that have been long-term aged (LTA), to all HMA mixtures but only for information purposes. In September 2020, the special provision was again revised to make I-FIT a contract requirement for all HMA mixtures and will be inserted into all HMA paving contracts beginning in January 2021.

Figure 1 shows a flowchart of the overall BMD that highlights the major steps for undertaking an asphalt mixture design according to IDOT specifications. The requirements for volumetric design and performance testing for all asphalt mixtures are summarized in table 2 and table 3. The HWT criteria is based on plan PG of asphalt binder; thus taking into consideration both climate and traffic conditions. The I-FIT criteria is the same for all asphalt mixtures, except as proposed for IL-4.75 and SMA mixtures. The tensile strength ratio (TSR) criteria is the same for all asphalt mixtures.

The IDOT's BMD for designing all asphalt mixtures and approving JMFs follows Approach A *Volumetric Design with Performance Verification*. Approach A was chosen because volumetric requirements need to be met first. If the asphalt mixture designer understands the role of each component in mixture volumetrics, then they will understand what is needed to create a stable and durable mixture. Thus, IDOT has no immediate plans to relax any of the volumetric requirements.

During mixture design, the contractor submits prepared samples to IDOT for performance verification testing. Table 4 summarizes the required testing, and number and size of prepared samples to be submitted by contractor. It should be noted that, during asphalt mixture verification, Illinois Districts and contractors may complete the moisture resistance testing (unconditioned and conditioned indirect tensile strength) prior to the I-FIT and HWT.

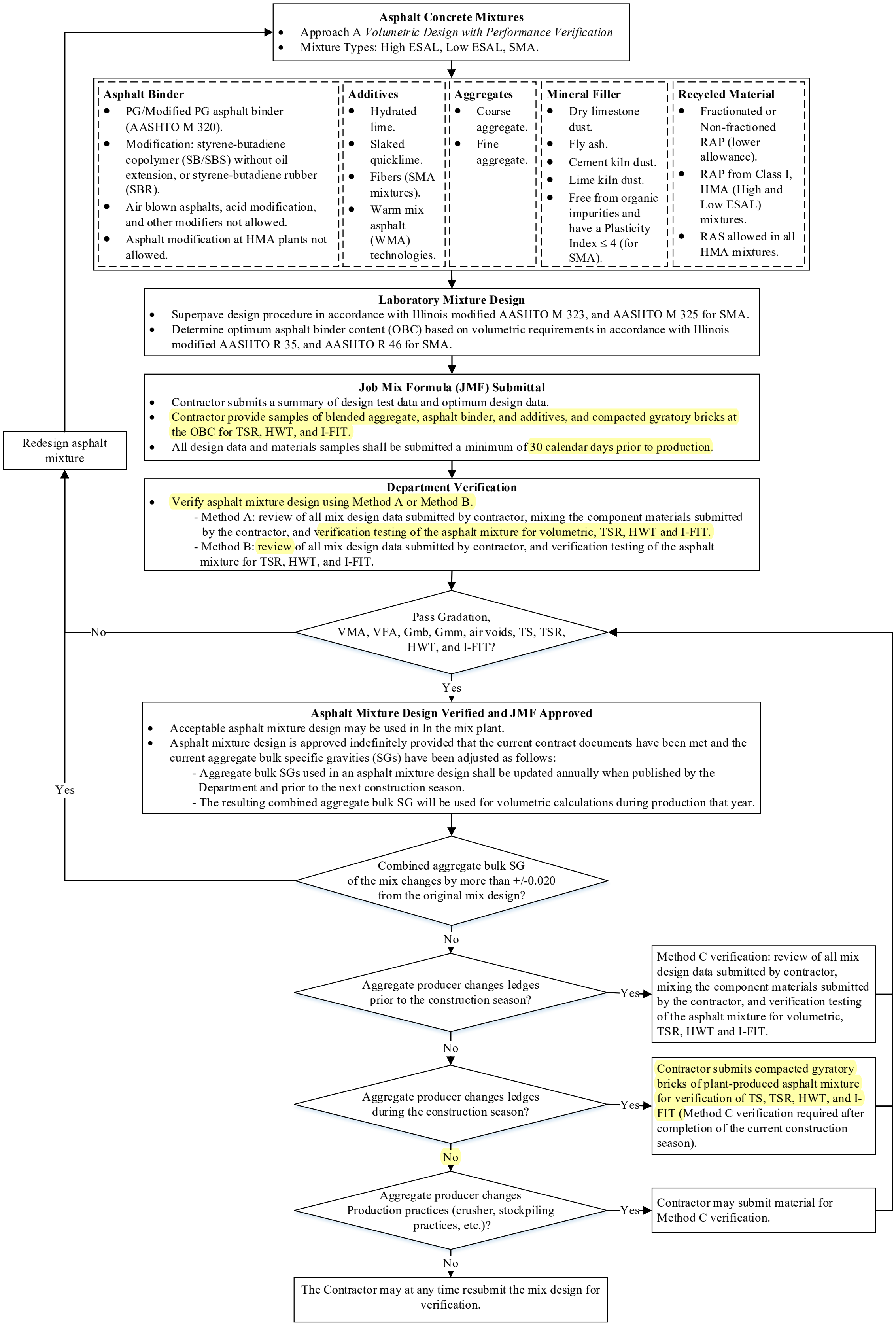


Figure 1. Chart. Overview of IDOT asphalt mixture design process.

Table 2. Mix Design Volumetric Requirements.

Mixture Type		N_{design}	Asphalt Binder Content (%)	Design Target Density (%)	VMA (Minimum %) Nominal Maximum Aggregate Size (NMAS) (mm)				VFA (%)	Dust-to-Asphalt Binder Ratio	Drain-down (%)
					19	12.5	9.5	4.75			
High ESAL	IL-19.0	50	–	96.0	13.5	–	–	–	65–78	≤ 1.0	–
		70	–	96.0	13.5	–	–	–	65–75	≤ 1.0	–
		90	–	96.0	13.5	–	–	–	65–75	≤ 1.0	–
	IL-9.5	50	–	96.0	–	–	15.0	–	65–78	≤ 1.0	–
		70	–	96.0	–	–	15.0	–	65–75	≤ 1.0	–
		90	–	96.0	–	–	15.0	–	65–75	≤ 1.0	–
	IL-4.75	50	–	96.0	–	–	–	18.5	76–83	≤ 1.0	≤ 0.3
Low ESAL	IL-19.0L	30	4.0–8.0	96.0	13.5	–	–	–	–	≤ 1.0	–
	IL-9.5L	30	4.0–8.0	96.0	–	–	15.0	–	65–78	≤ 1.0	–
SMA	≤ 10 MESALs	50	–	96.0	–	16.0	–	–	75–80	–	≤0.3
	> 10 MESALs	80	–	96.0	–	17.0	–	–	75–80	–	≤0.3

–Not applicable.

Table 3. Mixture Design Performance Testing Requirements.

Mixture Type		HWT (Illinois Modified AASTO T 324), ≤ 12.5 mm Rut Depth at a Minimum Number of Wheel Passes				FI (Illinois Modified AASHTO T 124)		TS (Illinois Modified AASTO T 283), psi			
								Conditioned		Uncon-ditioned	TSR
		PG 58-xx (or lower)	PG 64-xx	PG 70-xx	PG 76-xx (or higher)	Short Term Aging	Long Term Aging#	Non-Polymer PG	Polymer modified PG$		
High ESAL	IL-19.0	≥ 5,000	≥ 7,500	≥ 15,000	≥ 20,000	8.0	4.0*	≥ 60	≥ 80	≤ 200	≥ 0.85
	IL-9.5					8.0	4.0*				
	IL-4.75			≥ 10,000^	≥ 15,000^	12.0	–				
Low ESAL	IL-19.0L	–	–	–	–	8.0	4.0*				
	IL-9.5L	–	–	–	–	8.0	4.0*				
SMA	≤ 10 MESALs	≥ 5,000	≥ 7,500	≥ 15,000	≥ 20,000	16.0	10.0				
	> 10 MESALs					16.0	10.0				

–Not applicable.
^Beginning in 2021.
#Required for surface courses only beginning in 2022.
*Production mixture requirement. Mixture design long term aging FI is minimum of 5.0.
$Except polymer modified PG XX-28 or lower asphalt binders shall have a minimum TS of 70 psi.

Table 4. Required Samples for Verification Testing.*

Mixture Type		HWT	I-FIT	TS
High ESAL	Binder Mixture	2–160 mm tall bricks.	1–160 mm tall bricks.	6–95 mm tall bricks.
	Surface Mixture	2–160 mm tall bricks.	2–160 mm tall bricks.	6–95 mm tall bricks.
Low ESAL	Binder Mixture	–	1–160 mm tall bricks.	6–95 mm tall bricks.
	Surface Mixture	–	2–160 mm tall bricks.	6–95 mm tall bricks.

* Prepared samples are compacted gyratory bricks with 7.5 ± 0.5% air voids.
–Not applicable.

IDOT currently allows asphalt binders to be modified with either a styrene-butadiene copolymer without oil extension, or a styrene-butadiene rubber. Air blown asphalts, acid modification, and other modifiers are not allowed. Asphalt modification at the plants is also not allowed.

The industry push for allowing the use of other types of modifiers, prompted IDOT to initiate in 2018 the ICT project R27-196 *Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements* to develop a systematic asphalt binder screening protocol. This includes a long-term aging procedure for modified asphalt binders with rheological and chemical characterization methods. It is anticipated that preliminary thresholds established in ICT project R27-162 *Chemical and Compositional Characterization of Recycled Binders* (2015–2017) will be validated and fine-tuned as part of this study.

The ICT project R27-196 was planned to be completed in 2020 but got delayed until 2021 because of the COVID-19 pandemic. Preliminary findings from the on-going study shows promising results for the difference in critical temperatures for low temperature testing (ΔTc) as a potential component of a screening test for modified asphalt binder performance. The ΔTc is based on creep stiffness (Tcont, S) and m-value (Tcont, m), calculated as ΔTc = (Tcont, S) – (Tcont, m). A strong correlation between ΔTc and FI is observed (from the 2019 IDOT I-FIT daily shadow testing project and noting that the plots represent data from an asphalt binder parent company) and an initial threshold value of greater than or equal to -5.0°C after two cycles of pressure aging vessel (PAV) will likely be established (figure 2). This study is also evaluating other rheological and chemical tests to characterize the effects of modifiers in asphalt binders.

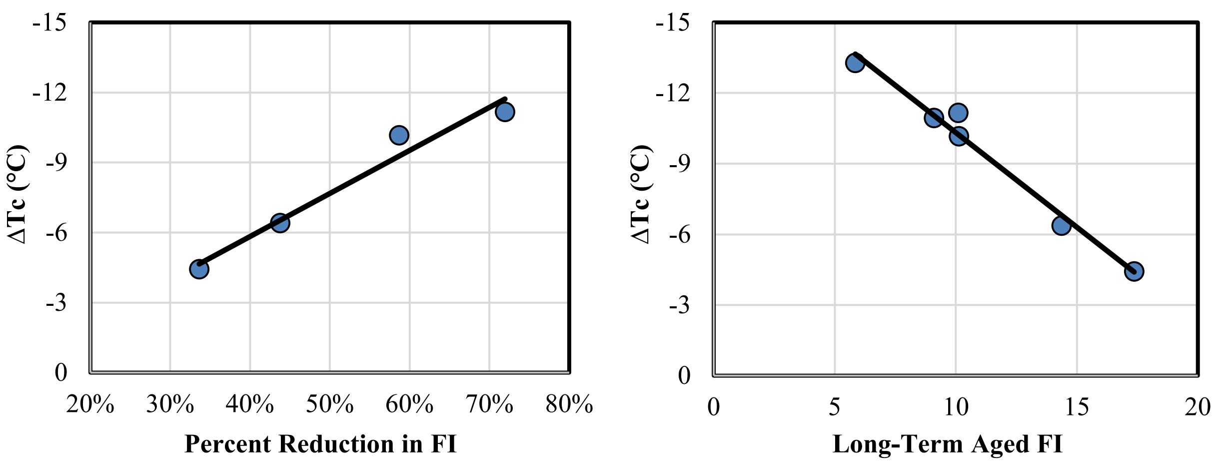


Figure 2. Graph. Example of observed relationship between ΔTc and FI.

In comparison to AASHTO M 323, "Standard Specification for Superpave Volumetric Mix Design" and AASHTO R 35, "Standard Practice for Superpave Volumetric Design for Asphalt Mixtures," the following key modifications are implemented by IDOT to their volumetric design criteria (table 2 and table 5):

- Specified lower number of gyrations for design of all asphalt mixtures including the High ESAL, Low ESAL, and SMA mixtures.
- Specified a range of asphalt binder content for Low ESAL mixtures.
- Increased the voids in mineral aggregate (VMA) requirement by 0.5% for all the 19.0 mm asphalt mixtures and by 2.5% for the 4.75 mm mixtures.
- Specified a draindown requirement for IL-4.75 mixture and SMA.
- In general maintained or increased the requirement for voids filled with asphalt (VFA).

- Except for SMA mixtures, reduced the dust-to-asphalt binder ratio requirement (IDOT uses dust-to-asphalt binder ratio as opposed to dust-to-effective asphalt binder ratio).

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by allowing more asphalt binder into the mixture without jeopardizing its resistance to rutting (the lower the N_{design} and the higher the VMA, the higher the asphalt binder content for a given air void level).

Table 5. Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Mixture Type					
	IL-19.0	**IL-9.5**	**IL-4.75**	**IL-19.0L**	**IL-9.5L**	**SMA**
Number of Design Gyrations (N_{des})	↓	↓	↓	↓	↓	↓
Density at N_{des}	↔	↔	↔	↔	↔	↔
Density at Maximum Number of Gyrations (N_{max})	↔	↔	↔	↔	↔	↔
Design Asphalt Binder Content	–	–	–	Range	Range	–
Voids in Mineral Aggregate (VMA)	↑	↔	↑	↑	↔	↑
Voids Filled with Asphalt (VFA)	↑UL / ↔	↑UL / ↔	↑	–	↔	↑
Dust-to-asphalt binder ratio[1]	↓	↓	↓	↓	↓	–
Draindown (%)	–	–	Min	–	–	–
HWT Passes at 12.5 mm Rut Depth	Min	Min	Min	–	–	Min
FI – short-term aging	Min	Min	Min	Min	Min	Min
FI – long-term aging	Min	Min	–	Min	Min	Min
TS – Conditioned	Min	Min	Min	Min	Min	Min
TS – Unconditioned	Max	Max	Max	Max	Max	Max
TSR	Min	Min	Min	Min	Min	Min

[1]IDOT uses dust-to-asphalt binder ratio as opposed to dust-to-effective asphalt binder ratio.
–Not applicable or not specified; Min=minimum; Max=maximum; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit.

SELECTION OF PERFORMANCE TESTS

Table 6 summarizes the performance tests currently used by IDOT for their BMDs of asphalt mixtures. In general, some asphalt mixtures in Illinois were becoming too brittle as a result of higher asphalt binder replacement (ABR) levels with RAP and/or RAS. Asphalt mixtures were first evaluated using only a stability/rutting test (i.e., HWT) without a cracking test. In 2020, both HWT and I-FIT minimum criteria were in place for design of asphalt mixtures. While HWT criteria was in place for production, shadow I-FIT testing was conducted in 2020 during which contractors were not required to meet any limits for FI during production.

Table 6. Summary of Performance Tests Considered by IDOT for BMD.

Elements	Stability/Rutting	Durability/Cracking	Moisture Damage/Stripping
Test Name	Hamburg Wheel test (HWT)	Illinois Flexibility Index test (I-FIT)	Tensile Strength (TS)
Test Method	IL-Modified AASHTO T 324	IL-Modified AASHTO TP 124	IL-Modified AASHTO T 283
Test Criteria	Refer to table 3.	Refer to table 3.	Refer to table 3.
Test Implemented in Asphalt Mixture Design	Yes.	Yes.	Yes.
Aging Protocol	Conditioning in accordance with Illinois modified AASHTO R 30 (refer to table 7).	Conditioning in accordance with Illinois modified AASHTO R 30 (refer to table 7).	Conditioning in accordance with Illinois modified AASHTO R 30 (refer to table 7).
Notes/Comments	Compacted gyratory bricks are interchangeable between HWT and I-FIT. Test specimens specific to each test are cut from gyratory bricks.	Compacted gyratory bricks are interchangeable between HWT and I-FIT. Test specimens specific to each test are cut from gyratory bricks.	No freeze-thaw (F-T) cycle (IL found no F-T to be more harsher than including one F/T cycle in most cases).

Table 7. Summary of Short and Long-Term Conditioning of Laboratory and Plant-produced Asphalt Mixtures by IDOT.*

Conditioning	Mixture Type	Laboratory-produced Mixture			Plant-produced Mixture		
		Volumetrics	TS	HWT or I-FIT	Volumetrics	TS	HWT or I-FIT
Short-Term	HMA	1 or 2 hours of loose mixture at compaction temperature	1 or 2 hours of loose mixture at compaction temperature	1 or 2 hours of loose mixture at compaction temperature	0 hours	0 hours	0 hours
	WMA	1 or 2 hours of loose mixture at compaction temperature	1 or 2 hours of loose mixture at compaction temperature	3 or 4 hours of loose mixture at compaction temperature	0 hours	0 hours	2 hours of loose mixture at compaction temperature
Long-Term	HMA	0 hours	0 hours	I-FIT = 72 hours on compacted and notched specimen at 95°C	0 hours	0 hours	I-FIT = 72 hours on compacted and notched specimen at 95°C
	WMA	0 hours	0 hours	I-FIT = 72 hours on compacted and notched specimen at 95°C	0 hours	0 hours	I-FIT = 72 hours on compacted and notched specimen at 95°C

*When two different values are present within a single cell, the correct value is based on whether low or high absorptive aggregates are used.

The HWT procedure was modeled after the method used by Texas Department of Transportation (TxDOT). TxDOT has successfully used the HWT in their mixture design selection for several years. Several individuals from IDOT traveled to Texas in April 2011 to learn about HWT program in Texas. The HWT was fully implemented by IDOT in 2012.

The I-FIT procedure was developed in the research study ICT project R27-128 *Testing Protocols to Ensure Performance of High Asphalt Binder Replacement Mixes Using RAP & RAS* (2013–2015) that was sponsored by IDOT. The Illinois modified AASHTO T 283 for moisture damage evaluation has been conducted by IDOT since the 1980's.

The top three factors for IDOT in selecting a performance test are: material sensitivity, field validation, and repeatability. The test should be sensitive to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), air voids, and aging. IDOT recognizes that a test that is considerably sensitive to materials will likely have a higher variability in test results. Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of IDOT's motivations for implementation of performance tests. In the selection process, consideration was also given to the capability of the performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures (based on historical field performance of asphalt mixtures). The test results of local asphalt mixtures should not contradict known and observed field pavement performance. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications.

Other important factors for IDOT are sample preparation, specimen conditioning and testing time, and equipment cost. The duration needed for sample preparation, specimen conditioning, and testing have been key considerations for IDOT in the development of test criteria and the implementation of performance tests into the specifications. This is tied to the ability of testing aged specimens that are representative of a future critical pavement condition for cracking while keeping in mind the need for a quick turnaround time for test results. The aim was also to maintain a low-cost for specimen fabrication and testing equipment. Having qualified and trained technicians help to reduce the impact this factor might have on the overall implementation effort of performance tests.

IDOT has one operational Asphalt Mixture Performance Testers (AMPT) at the Central Bureau of Materials (CBM). IDOT was part of the initial pooled fund study TPF-5(178): Implementation of the Asphalt Mixture Performance Tester (AMPT) for Superpave Validation. IDOT does not have any specification requirements based on performance testing in AMPT. The AMPT has been primarily used to conduct dynamic modulus and flow number (AASHTO T 378), as well as overlay test (Tex-248-F).

IDOT has recently purchased most of the equipment to conduct direct tension cyclic fatigue on 100 mm diameter specimens (AASHTO TP 107) using the AMPT. It is anticipated to use the AMPT to update the characterization of asphalt mixtures used in Illinois for mechanistic pavement design inputs. IDOT has its own mechanistic pavement design method that was developed in the late 80s and is based on the characterization of asphalt mixtures using the flexural beam fatigue test.

PERFORMANCE TESTS DEVELOPMENT TO IMPLEMENTATION

The following section summarizes IDOT's experience with performance test implementation in terms of the nine essential steps identified in NCHRP Project 20-07/Task 406.

Step 1. Draft test method and prototype equipment.

Having Illinois modified test procedures available for AAHSTO T 324, AASHTO TP 124, and AASHTO T 283 supported efficient implementation of performance tests for asphalt mixtures. The AASHTO TP 124 for the I-FIT was originally developed in the ICT research study R27-128 that was funded by IDOT between 2013 and 2015.

IDOT revises and updates the Illinois test methods as deemed necessary based on new findings and through continuous communication and coordination with researchers, industry, vendors, etc.

Step 2. Sensitivity to materials and relationship to other laboratory properties.

The sensitivity of performance test results to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), volumetric parameters (e.g., air voids, VMA), and aging is an important factor for IDOT. Contractors need to be able to make informed decisions on what changes can be made to the asphalt mixture composition and proportions in order to improve performance and meet applicable specification limits.

IDOT has performance test equipment in CBM and in all nine District laboratories to evaluate mixture properties. IDOT completes in-house research studies to better understand asphalt mixture performance including testing of asphalt mixtures sampled from shadow and pilot projects. Furthermore, IDOT funds ICT research projects to evaluate new materials (e.g., asphalt binder modifiers, SMA mixtures with local aggregate) and to develop new test protocols (e.g., I-FIT). These ICT research studies provide information on performance test sensitivity. IDOT also attends conferences, webinars, etc. and reviews reports from FHWA, other SHAs, universities, and research centers to learn from their experiences with asphalt mixture performance tests using different component materials (aggregate and asphalt binder sources).

Currently, IDOT has large databases of HWT and I-FIT test results. For example, the I-FIT database includes more than 3,000 test sets that are being evaluated and analyzed. The following are some characteristics of the current I-FIT database:

- Four specimens are typically tested per asphalt mixture.
- The average reported FI value is based on the closest 3 tested specimens (trimmed mean).
- The database includes the 2016 pilot projects (laboratory-produced, plant-produced, and field core samples) and other various samples. The database also includes data from the other 70 plus projects constructed in 2017–2020.
- The database includes test results for LTA specimens; including those for the eleven 2019 shadow projects and all of the 2020 HMA projects, which were all shadow tested.

IDOT updates the analyses of test results on a regular basis. The following factors are studied in the I-FIT database analysis:

- Test specimen air voids content.
- Specimen type: laboratory-produced, plant-produced, field cores.

- Polymer-modification of asphalt binder and grade.
- Virgin asphalt binder low temperature PG.
- ABR.
- Total asphalt binder content.
- Virgin asphalt binder content.
- Design VMA.
- Test specimen VMA.
- NMAS.
- Volume of effective asphalt binder.

Figure 3 through figure 7 show for select factors the sensitivity of FI (it should be noted that these plots show pre–2020 data results). On the plots, the bar values represent the average FI (trimmed mean) and error bars represent one average standard deviation on either side of the average FI. Values at the bottom of each bar represent the number of test specimens represented in the trimmed mean. The following summarizes the findings from the database analyses relative to the five presented factors:

- Increases in ABR lead to reductions in FI.
- Lower asphalt binder low temperature PG increased FI.
- Increases in design VMA lead to increased FI.
- Increases in total asphalt binder content lead to increased FI.
- Increases in virgin asphalt binder content lead to increased FI.

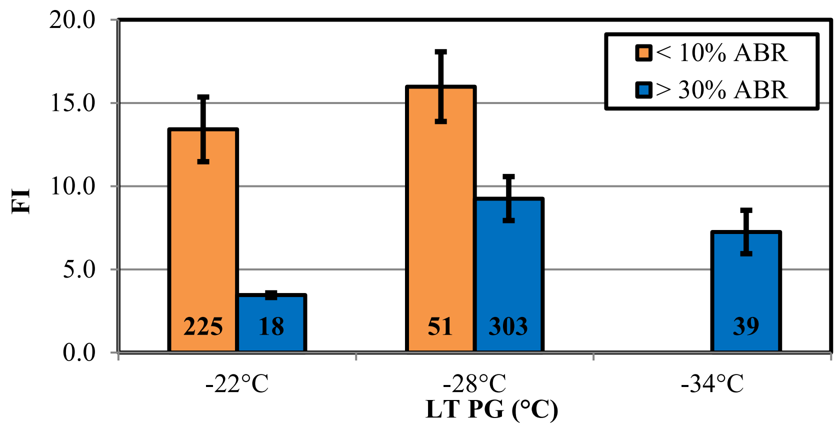
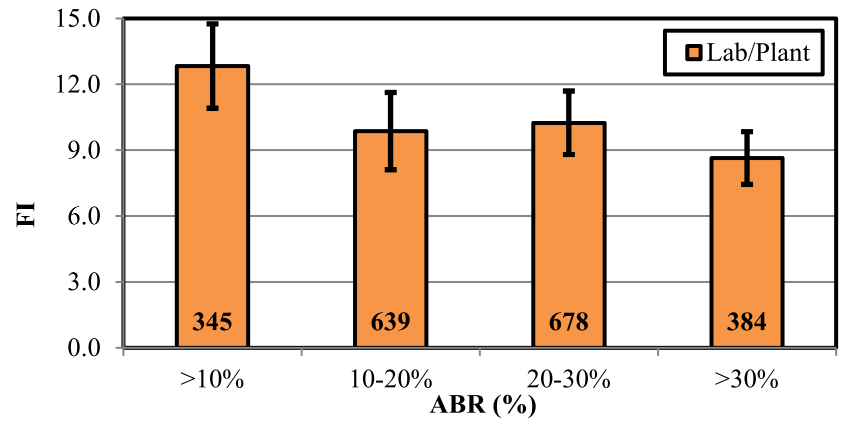
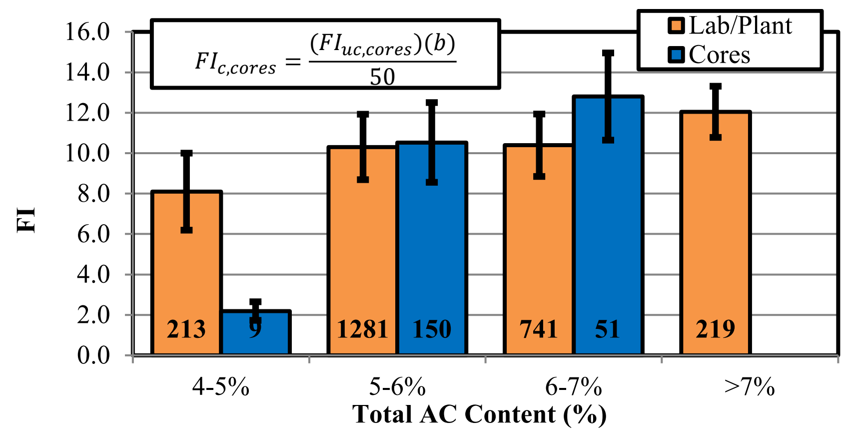


Figure 3. Graph. Effect of virgin asphalt binder low temperature PG.



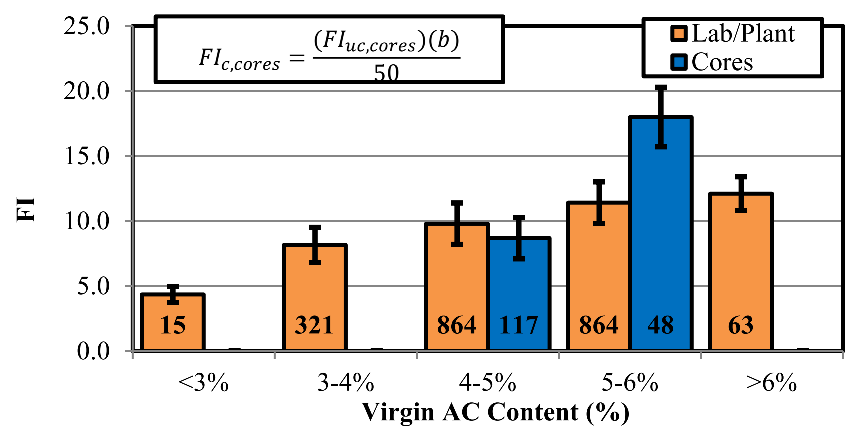
Note: 20–30% bar is a result of using lower high and low temperature grades (grade bumping is required with ABR > 20%).

Figure 4. Graph. Effect of ABR.



Note: cores are corrected for specimen thickness; $FI_{c,cores}$ = corrected *FI* for the cores; $FI_{uc,cores}$ = uncorrected *FI* for the cores; *b* = average thickness of I-FIT core specimen

Figure 5. Graph. Effect of total asphalt binder content.



Note: cores are corrected for specimen thickness; $FI_{c,cores}$ = corrected *FI* for the cores; $FI_{uc,cores}$ = uncorrected *FI* for the cores; *b* = average thickness of I-FIT core specimen

Figure 6. Graph. Effect of virgin asphalt binder content.

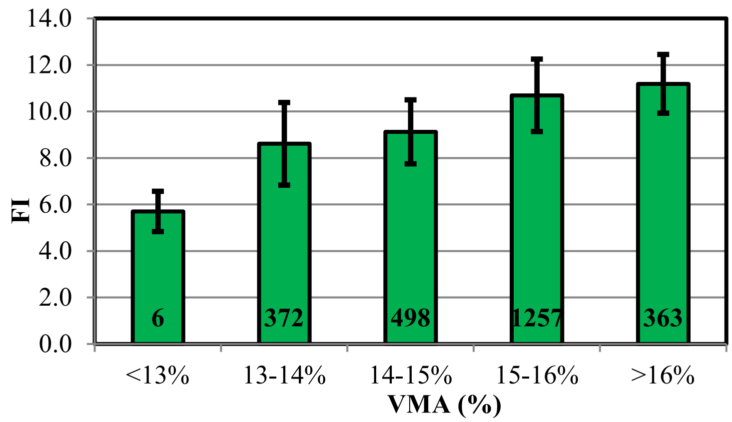


Figure 7. Graph. Effect of design VMA.

The databases are also used to refine and revise the performance test methods and their associated criteria as deemed necessary. IDOT will continue to populate performance test results into its databases. The sensitivity of performance tests to material properties will continue to be evaluated with the inclusion of new asphalt mixture test results, which will help in refining specifications and guidelines to design asphalt mixtures with satisfactory cracking resistance.

Step 3. Preliminary field performance relationship.

IDOT initially considered the TxDOT HWT pass criteria. After testing and evaluation of typical asphalt mixtures from Illinois, IDOT, and in collaboration with industry, modified the HWT pass criteria for Illinois mixtures. This resulted in the full implementation of the HWT in 2012 with a test criteria being based on the plan PG of asphalt binder.

The I-FIT initial criteria was determined as part of the ICT R27-128 study (2013–2015) by the researchers and a committee of IDOT and private industry members. The I-FIT criteria was based on I-FIT results from "good" and "poor" performing pavement cores from all nine Districts that were collected and evaluated under the ICT R27-128 study. Also as part of that study, I-FIT testing was conducted on asphalt mixtures that were used at the FHWA's Accelerated Loading Facility (ALF) at the Turner-Fairbank Highway Research Center (TFHRC). The I-FIT results correlated well with the fatigue cracking results and trends of the asphalt mixtures tested in the ALF. The initial I-FIT criterion for FI of 8.0 was then field validated in the ICT R27-161 *Construction and Performance Monitoring of Various Asphalt Mixes* (2014–2017) project.

Around 2002, the CBM conducted a study to determine the TSR criteria for 150 mm gyratory-compacted specimens by comparing to the existing TSR criterion of 0.75 for 4-inch Marshall-compacted specimens. Based on the findings from this in-house study, it was determined that a TSR criterion of 0.85 for 150 mm gyratory-compacted specimens is comparable to a 0.75 criterion for 4-inch Marshall-compacted specimens.

Step 4. Ruggedness experiment.

IDOT did not conduct or participate in any formal ruggedness testing. The NCHRP project 09-57A Ruggedness of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures (https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4471) recently completed a ruggedness study for the I-FIT (AASHTO TP124-18). The following seven factors were considered for the I-FIT in the ruggedness experiments: specimen thickness, notch depth, notch location, specimen height, air voids, loading rate, and test temperature. Based on this study, air voids and test temperature were the two significant factors for the I-FIT. The study recommended reducing the tolerance of air voids from +/-1% to +/-0.5%.

IDOT has looked at air void effects on I-FIT with multi-laboratory round robin data. Air voids do not seem to be a significant factor if the I-FIT procedure is completed on specimens between 6.0 and 8.0% air voids. The NCHRP project to determine the appropriate air voids of gyratory cylinders of various mixture types to allow acceptance based on air voids of gyratory cylinders rather than acceptance being based on the air voids of the individual semi-circular test specimens has an estimated completion date of April 30, 2021.

Step 5. Commercial equipment specification and pooled fund purchasing.

IDOT CBM and District laboratories are very well equipped to run and analyze all performance tests implemented for the BMD approach. This includes all necessary equipment for sample preparation, fabrication, and conditioning of asphalt mixture specimens. In 2010 and 2011, the CBM purchased 9 HWT machines from a single manufacturer. One machine was given to each District laboratory (Districts 2–9) and the CBM laboratory. District 1 purchased their own HWT equipment around the same time. In 2015 and 2016 the CBM purchased 10 I-FIT machines from a single manufacturer and 10 tile saws. An I-FIT machine and a tile saw were given to each District laboratory and the CBM laboratory. In general, funding resources for acquiring and installing new, necessary equipment in laboratories have not been a major issue for IDOT. A few district laboratories (e.g., District 6) had to rearrange their laboratory space in order to increase efficiency in laboratory operation. In general, state laboratories were designed and arranged for basic materials testing with minimal room for large and advanced equipment.

In total there are approximately 34 HWT and 30 I-FIT machines in IDOT, University laboratories, and private laboratories (e.g., contractors, consultants).

Step 6. Interlaboratory study (ILS) to establish precision and bias information.

The AASHTO T 324 and AASHTO T 283 performance tests have no information regarding the precision and bias of the test method. This may create a potential issue if two separate laboratories achieve different test results for the same asphalt mixture. Nonetheless, the IDOT test results are considered the test of record for any project.

IDOT completes HWT and I-FIT round robins on an annual basis. The round robins help to understand the variability in the test and to provide contractors with comparison data between their device, the IDOT District's device, and the CBM's device. These annual round robins provide valuable checks on equipment and technician performance.

The number of participating laboratories in the round robin studies can vary from year to year. For instance, in 2019, the Ontario Ministry of Transportation, Massachusetts Department of Transportation, and Vermont Agency of Transportation were added to the I-FIT Round Robin participants list (Wisconsin, Missouri, and Indiana Departments of Transportation have participated for multiple years). The number of participating laboratories in IDOT round robins for the past three years are summarized in table 8. The I-FIT and HWT round robins generally have over 30 and 20 laboratories participate per year, respectively.

Table 8. IDOT Round Robin Participants.

Test	No. of Participants			Laboratory Participants					
	2017	2018	2019	IDOT		Contractors / Consultants	University*		Other State DOT and Province MOT#
				CBM	Districts		UIUC	Auburn	
HWT	27	29	35	X	X	X	X	-	-
I-FIT	30	34	35	X	X	X	X	X	X

*National Center for Asphalt Technology at Auburn University
#DOT=department of Transportation; MOT = Ministry of Transportation.
–Did not participate in round robin.

The following summarizes the I-FIT round robin goals for each year. In all round robin studies a surface asphalt mixture was used in an attempt to minimize the impact of segregation.

- The 2017 I-FIT round robin goal was to evaluate the effects of (a) compaction, (b) specimen preparation (sawing), and (c) testing on FI variability. This was achieved by completing the following three sub round robin studies:
    - Round 1—Testing: ready to test I-FIT specimens that were cut from 160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
    - Round 2—Cutting and Testing: 160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory cut the 160 mm tall gyratory bricks into I-FIT test geometry and tested the I-FIT specimens.
    - Round 3—Compacting, Cutting, and Testing: loose asphalt mixtures were provided to each laboratory. Each participating laboratory compacted the gyratory samples to specified height, cut 115 mm gyratory into I-FIT test geometry, and tested the I-FIT specimens.
- The 2018 I-FIT round robin goal was to evaluate the effects of gyratory cylinder height (115, 150, and 160 mm) on FI. This was achieved by completing the following three sub round robin studies:
    - Round 1(A)—Testing: ready to test I-FIT specimens that were cut from 160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
    - Round 2(B)—Testing: ready to test I-FIT specimens that were cut from 150 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
    - Round 3(C)—Testing: ready to test I-FIT specimens that were cut from 115 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
- The 2019 I-FIT round robin goal was to evaluate the combined effects of compacting, preparing, and testing I-FIT specimens. A loose asphalt mixture was provided to each

laboratory. Each participating laboratory compacted the gyratory samples to a specified height (after identifying the weight needed to meet 7.0±1.0% air voids), cut gyratory samples into I-FIT test geometry, and tested the I-FIT specimens.

- The 2020 I-FIT round robin goal is to evaluate the variability of FI values in the as produced (short-term aged) and long-term aged conditions. The preliminary test results did not show a significant difference in the coefficient of variation (COV) of FI values for short-term and long-term conditioned specimens.

The data from the 2017–2019 IDOT I-FIT round robins were used to develop the precision statement as shown in the AASHTO TP 124. A bias statement is not possible because there is no universal reference in asphalt mixtures.

It should be noted that the precision statement developed for AASHTO TP 124 was based on 4 replicate specimens. However, the Illinois modified AASHTO TP 124 is based on the trimmed mean for three replicate specimens.

- When four individual I-FIT specimens with air voids that are within specification are tested, the FI value that is farthest from the average of the four test specimens shall be discarded as an outlier to lower the variability of the average FI value that is reported. The test specimen that is discarded as an outlier is removed from the calculations of average and COV for peak load, post-peak slope, fracture energy, and FI.

The precision and bias for the HWT have not yet been developed. IDOT can benefit from on-going studies at other SHAs.

Step 7. Robust validation of the test to set criteria for specifications.

The FHWA ALF data was used in the initial development of FI minimum criteria and was based solely on fatigue cracking. While this was vitally important, it did not account for reflective cracking that is the most commonly observed mode of distress in Illinois. Thus, The I-FIT procedure and FI threshold of 8.0 were further validated through ICT research project R27-161 *Construction and Performance Monitoring of Various Asphalt Mixes* (2014–2017).

A series of five experimental projects were constructed to better determine the life-cycle cost and performance of pavement overlays using various levels of ABR from use of RAP and RAS. The ABR for these asphalt mixture overlays varied from 15% to 48%. The ICT R27-161, which focused on reflective cracking, supported the use of 8.0 as a minimum value for FI. IDOT also completed I-FIT Pilot Projects in 2016 with annual coring and distress surveys to characterize pavement distress and I-FIT FI. These projects offered an opportunity to better understand the correlation between pavement distress observations and design, production, and field core FI values over time. Figure 8 shows the relationships between pavement transverse cracking and field core FI (corrected to core thickness) for the projects that were part of the ICT R27-161 research project.

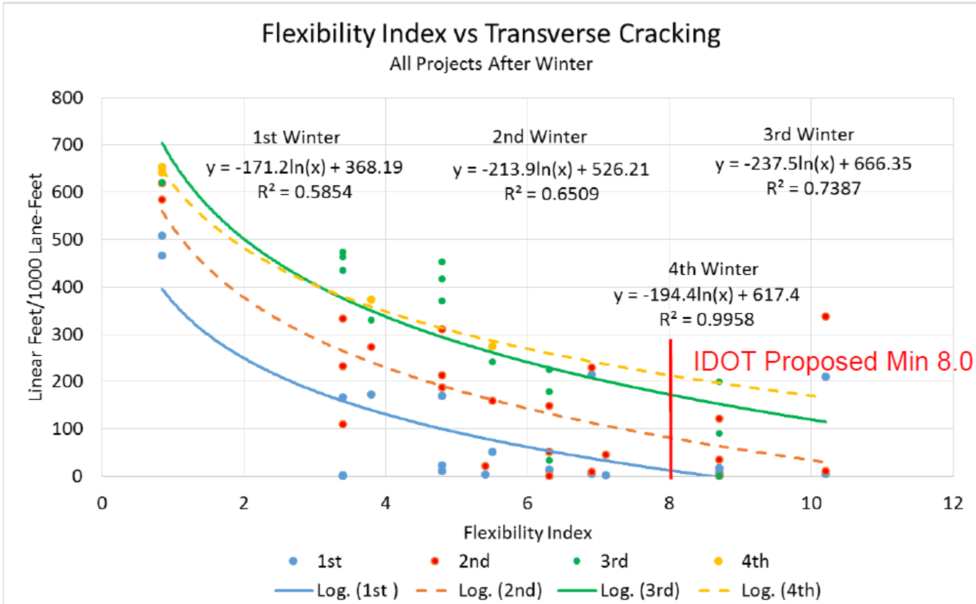


Figure 8. Graph. Pavement transverse cracking versus field core FI values.

IDOT continues to validate the HWT and I-FIT criteria by sampling and testing of asphalt mixtures, monitoring field pavement performance, and comparing the results.

Step 8. Training and certification.

Training technicians on the procedures and analysis of test results is necessary. IDOT requires all technicians to be trained and certified through the IDOT Quality Management Training Program that is managed and provided by Lake Land College. All three IDOT HMA Quality Management Programs require that industry be responsible for sampling, testing and documenting for specification compliance (Quality Control), and IDOT be responsible for random monitoring testing (Quality Assurance) and acceptance testing. The purpose of the training and certification program is to develop and maintain a pool of well-trained asphalt specialists for the state and contractors to design, test, and manage asphalt pavements. Training of both industry and IDOT employees is an integral part of this quality management program.

The IDOT Quality Management Training Program provides 5 training courses in testing and evaluating asphalt mixtures and aggregates. The training includes two courses on aggregates and three on asphalt mixtures as described below (https://www.lakelandcollege.edu/idot-quality-management-training-program/). The courses are revised regularly to include updated and new test methods. Individuals must pass both a written and a laboratory proficiency examination for the first three courses listed below and a written examination for the last two courses.

- *CET 020 Mixture Aggregate Technician.* This is a 3-days training course that is a prerequisite for CET 029 Hot Mix Asphalt Level I. The course covers the handling and testing of aggregates.
- *CET 027 Mixture Aggregate Technician Upgrade.* This is a 2-days training course that allows an individual, along with the CET 020 Mixture Aggregate Technician Course, to

administer and do the testing required for an aggregate producer participating in the Aggregate Gradation Control System.

- *CET 029 Hot Mix Asphalt Level I.* This is a 5-days training course that covers laboratory testing of HMA using Superpave technology and information on the production of HMA. The successful completion of this course will permit an individual to do the testing associated with contracts let under the Quality Management program.
- *CET 023 Hot Mix Asphalt Level II.* This is an advanced 5-days training course that covers proportioning, trouble-shooting, and laydown of HMA. Individuals completing this course are qualified to manage a Quality Control program for contracts let under the Quality Management program.
- *CET 031 Hot Mix Asphalt Level III.* This is a 5-days training course that covers Superpave mix design. Individuals completing this course will be able to do Superpave mix designs for HMA.

The Illinois-modified AASHTO T 324 (HWT), Illinois-modified AASHTO TP 124 (I-FIT), and Illinois-modified AASHTO T 283 (TS) are covered under the CET 029 Hot Mix Asphalt Level I training course and certification. Course manuals designed for understanding the testing requirements of IDOT are made available to participants. The course manuals are updated regularly and comprise detailed descriptions and photos of test methods including, equipment, sampling, specimen preparation, test procedure, etc. Instructional videos are also shared with the participants including two of them that are specifically made for HWT and I-FIT. The videos have been very effective and well accepted by participants. Individuals are required to be certified once. Efforts are underway between IDOT, industry, and Lake Land College to develop re-certification requirements.

Step 9. Implementation into engineering practice.

IDOT has been investing significantly in research over the years to support the implementation of performance tests and BMD for design and acceptance. IDOT originally introduced the HWT into routine asphalt mixture designs in 2012 in order to minimize the risk of designing mixtures that are prone to rutting and stripping. This was done in partnership with the industry following the purchase of equipment in 2010 and the use of HWT on pilot projects throughout the state.

The increase use of recycled materials (i.e., RAP and RAS) raised additional concerns with the typical asphalt mixtures being drier, brittle, and more prone to premature cracking. Thus, alternative asphalt mixture design approaches to optimize field pavement performance with respect to rutting and cracking were investigated. This led to the development of the BMD approach for all of IDOT's asphalt mixtures (the OBC is first selected based on volumetric requirements then verified based on the HWT and I-FIT requirements). IDOT has been funding ICT research projects to evaluate asphalt mixtures and to develop new test protocols (I-FIT). IDOT has also been conducting in-house research studies to better understand the performance of asphalt mixtures. Numerous pilot and shadow projects were also conducted. Figure 9 summarizes the I-FIT implementation timeline by IDOT. The following summarizes the major research studies that were undertaken to implement BMD into engineering practice:

- Assessment of the current IDOT mix design practice with respect to the use of RAP.

- ICT R27-011 *Determination of Usable Residual Asphalt Binder in RAP* (2006–2008).

- Development of the I-FIT to distinguish between asphalt mixtures in terms of potential cracking. Development and evaluation of protocols, procedures, and specifications for testing engineering properties and performance of asphalt mixtures with high amounts (up to 60%) of RAP and RAS.
    - ICT R27-128 *Testing Protocols to Ensure Performance of High Asphalt Binder Replacement Mixes Using RAP and RAS* (2013–2015).
        - A simple, reliable, and meaningful test (I-FIT) was developed to discriminate asphalt mixtures with different cracking susceptibility.
        - Principles of fracture mechanics were validated using digital image correlation technique.
        - FI was able to distinguish asphalt mixtures with high recycled content.
        - A 2D BMD approach was introduced (HWT and I-FIT).
    - ICT R27-161 *Construction and Performance Monitoring of Various Asphalt Mixes* (2014–2017).
        - Rigorous field performance monitoring of asphalt mixtures with recycled materials was conducted (13 surface asphalt mixtures with ABR ranges 15–60% were constructed between 2013 and 2015 in District 1—Chicago area).
        - Field transverse cracks correlated well with FI.
        - A 3D BMD approach was proposed by researchers to eliminate weak asphalt mixtures (HWT, I-FIT, and secant modulus).
    - ICT R27-162 *Chemical and Compositional Characterization of Recycled Binders* (2015–2017).
    - ICT R27-175 *Development of Long-Term Aging Protocol for Implementation of the Illinois Flexibility Index Test (I-FIT)* (2017–2019).
        - Selected the long-term oven aging protocol for compacted I-FIT specimens in a forced draft oven for 3 days at 95°C.
        - The long-term oven aging protocol assisted in distinguishing between asphalt mixtures based on their cracking susceptibility.
        - The long-term oven aging protocol assisted in distinguishing the influence of asphalt binder source, recycling content, aggregate source and asphalt mixture type.
        - Aging rate influenced by asphalt mixture volumetric properties.
- Understanding of the thermodynamic processes of heat transfer from virgin aggregate to RAP/RAS materials and energy consumption in an asphalt mixture plant to: reduce energy loss and emissions in a plant; and, maintain a temperature below that which would cause significant damage to the virgin and recycled asphalt binders.
    - ICT SP29 *Thermodynamics between RAP/RAS and Virgin Aggregates during Asphalt Concrete Production* (2015).
- Ensuring the repeatability and accuracy of the I-FIT results from different machine types using various asphalt mixtures.
    - ICT SP31 *Evaluation of I-FIT Results and Machine Variability using MnRoad Test Track Mixtures* (2016–2017).

- Machine compliance procedure was presented and should be considered to improve test accuracy and minimize errors beyond operator's control.
- Although the four evaluated devices showed some differences when standard material was tested, these were not enough to influence the asphalt mixture test outcomes.

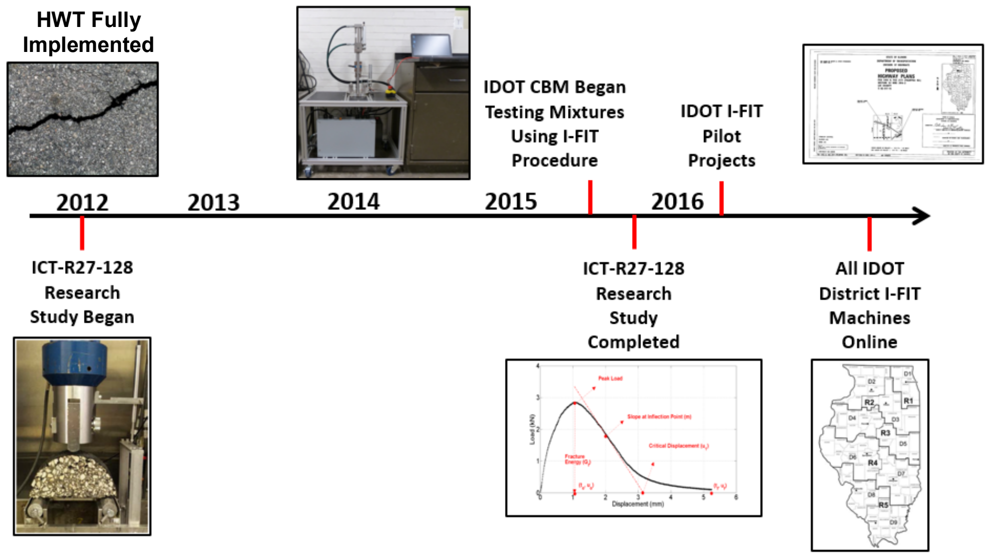


Figure 9. Chart. IDOT I-FIT implementation timeline.

IMPLEMENTATION OF PERFORMANCE TESTS ON PROJECTS

IDOT has been leading and investing significantly in the process to develop and implement a BMD for all of its asphalt mixtures. The following summarizes the major efforts in chronological order for full implementation of I-FIT as part of a BMD approach for asphalt mixtures in Illinois. IDOT has been conducting pilot and shadow projects throughout the state. The aims of the projects were two-fold: 1) to work out asphalt mixture design requirements, sampling, and testing logistics; and 2) to validate the established threshold criteria for I-FIT test parameter in particular. The pilot and shadow projects also facilitate the buy-in from the industry.

- 2016–IDOT planned for 1 pilot project per each of the 9 districts. This resulted in a total of 11 pilot projects that were conducted statewide (Districts 1 and 5 conducted two pilot projects each). Laboratory compacted specimens were tested during asphalt mixture design and production. Field cores were sampled and tested immediately after construction. Subsequent field cores are taken annually and tested as well. Pavement distress monitoring was conducted before construction and is being conducted every year since construction.
- 2017–IDOT planned for two I-FIT projects per district. This resulted in a total of 16 statewide. Laboratory compacted specimens were tested during asphalt mixture design and production. IDOT initiated the ICT R27-175 research study for the development of a long-term aging protocol for the implementation of the I-FIT. IDOT also conducted three I-FIT round robin studies (Round 1 Testing, Round 2 Cutting and Testing, and Round 3 Compacting, Cutting, and Testing).

- 2018–IDOT increased the number of I-FIT projects to a total of 32 projects statewide. In the same year, IDOT assembled an Implementation Task Force with Industry that comprised quality control managers, Illinois Asphalt Pavement Association (IAPA) representative, FHWA division office representative, and engineers from IDOT (Central Office and Districts). The task force agreed on the following main activities:
    - Increase ABR by 5% across the board for all asphalt mixtures.
    - Allow asphalt binder modifiers once an asphalt binder performance test is developed based on the findings from the ICT project R27-196 *Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements* (2018–2021).
    - Adopt "Perpetual Mix Designs" that are approved indefinitely. The initial asphalt mixture design verification must meet HWT and I-FIT in addition to volumetric and moisture damage requirements. The asphalt mixture design calculations are to be revised on an annual basis to incorporate the annually published aggregate bulk specific gravities.
    - Implement higher FI thresholds for SMA and IL-4.75 asphalt mixtures.
    - Annual round robin study.
- 2019–IDOT implemented I-FIT on all interstate projects with additional projects approved by Central Office for a total of 27 projects statewide. One I-FIT shadow project per district was also conducted for a total of 10 projects statewide. These shadow projects involved daily testing for I-FIT at short-term and long-term oven aging conditions (surface asphalt mixtures only) as well as daily testing for inline asphalt binder samples for ΔTc at 2 PAV cycles. The following were the goals of the I-FIT shadow projects:
    - Allow districts to gain experience with I-FIT after long-term oven aging of plant-produced asphalt mixtures.
    - Quantify the daily variation in production FI of asphalt mixtures.
    - Determine whether a minimum FI of 4.0 for long-term oven aged plant-produced asphalt mixtures can be met.
    - Determine whether the production FI for long-term oven aged plant-produced asphalt mixtures is driven by plant conditions or asphalt binder source.
- 2020–Original plan was a full Implementation of I-FIT that was postponed by industry in order to gain more experience and becomes reasonably comfortable with the performance test. Thus, IDOT conducted district shadow testing on all HMA projects including the short-term and long-term oven aging conditions for the I-FIT (surface asphalt mixtures only).
- 2021–IDOT is planning for the implementation of I-FIT thresholds in design and production for short-term aged specimens (including higher thresholds for SMA and IL-4.75 mixtures).
- 2022–Due to COVID-related delays to the ongoing research, IDOT plans to begin allowing terminally blended asphalt binder modifiers in non-polymer modified asphalt binders in conjunction with new asphalt binder performance testing protocol in January of 2022 and also implement FI thresholds after long-term aging for surface mixtures.

Based on the various projects completed thus far, reduction in FI values were generally observed for plant-produced asphalt mixtures. The following possible causes for the production-induced reduction in FI values were identified:

- Cold/wet stockpiles.
- Cold/wet RAP and RAS stockpiles.
- High production temperatures.
- Extended silo storage time.
- Long haul time.
- Lower asphalt binder content from design.
- Increased dust content.
- Time/temperature of asphalt binder storage.

Since the start of pilot projects in 2016, IDOT offered the contractors to have their asphalt mixtures tested for I-FIT. Test results were shared with the contractors, thus providing them with the opportunity to gain trust and comfort with the I-FIT. Select contractors took IDOT up on the offer and sent their asphalt mixtures to IDOT for testing. With time, fewer asphalt mixtures were sent by contractors to IDOT for testing. It should be noted that contractors had to send IDOT all asphalt mixtures for shadow testing on all projects constructed in 2020.

According to the special provision HOT-MIX ASPHALT – MIXTURE DESIGN VERIFICATION AND PRODUCTION (MODIFIED FOR I-FIT) (BDE) (effective January 2021) performance testing during production is to be conducted according to the following requirements. The start of asphalt mixture production and JMF adjustments can only initiate after the JMF has been approved as summarized in figure 1.

In the case of High ESAL mixtures, a test strip is completed at the beginning of production for each asphalt mixture according to the Manual of Test Procedures for Materials "Hot Mix Asphalt Test Strip Procedures." A test strip is not required for shoulder applications or asphalt mixtures with a quantity less than 3,000 tons (2,750 metric tons); however, such mixtures are still sampled on the first day of production for the HWT and I-FIT testing.

Before constructing the test strip, target values are determined by applying gradation correction factors to the JMF when applicable. The JMF becomes the adjusted JMF (AJMF) upon completion of the first acceptable test strip. The asphalt mixture placed during the initial test strip should be removed and replaced if determined to be unacceptable to remain in place.

Asphalt mixture representing the test strip is sampled, prepared/compacted, and delivered by contractor within two working days after sampling to IDOT district laboratory for HWT and I-FIT verification testing. The HWT and I-FIT results are required to meet performance tests criteria (table 3). Upon notification by IDOT of a failing HWT and I-FIT and prior to restarting production, the contractor should make necessary adjustments to the mixture production and submit another mixture sample for IDOT to conduct I-FIT and HWT. Upon consecutive failing HWT and I-FIT, no additional mixture is produced until passing the performance tests criteria. IDOT may conduct additional HWT and I-FIT on production asphalt mixtures.

In the case of Low ESAL mixtures (excluding Class D patches, pavement patching and incidental HMA), I-FIT testing will be performed during asphalt mixture production. The contractor will sample and deliver prepared samples to the IDOT district laboratory for I-FIT verification testing.

In 2021, Contractors will compact 160 mm gyratory cylinders to 7.5± 0.5% air voids. Districts will verify the gyratory cylinder air voids and prepare the HWT and I-FIT specimens. Placing air void requirements on the 160 mm gyratory cylinders is anticipated to reduce the reject rate.

The following summarizes the most relevant feedback comments recently received from the various IDOT Districts on shadow performance testing in 2020:

- Completing the I-FIT performance testing in less than three weeks is generally not an issue. All I-FITs have been done within 3 days to a week of the first day of asphalt mixture production.
- Similar to what it is done with HWT, prioritization would be needed in order to get the I-FIT completed within two days or sooner if it is implemented in the specification. More days would clearly be needed to complete testing for LTA specimens that requires three days of aging.
- Having an oven solely dedicated to I-FIT samples would accelerate the turnaround time for test results. In some other instances, having another water bath with scale and another HWT machine would be needed if the volume of testing were to increase. The long-term oven aging I-FIT in particular puts a strain on the water bath and oven space when having multiple plate samples and an abundance of cores to run.
- Having a full time technician tasked to the performance testing is likely needed.
- In the case of long-term oven aging I-FIT, samples needed to be prepared on a Monday or a Tuesday. If not, technicians had to wait until Friday to get the I-FIT samples in the oven for long-term oven aging of 72 hours at 95°C. This can delay the results.
- Dealing with more than one project at a time can cause some challenges in meeting a quick turnaround time.
- Getting the samples from the contractor in a timely manner is critical for a quick turnaround. The gyratory bricks for HWT and I-FIT needs to be dropped off to the district laboratory as soon as the following day of the first day of production.
- Having an initial fail for a performance test raise a time challenge as the district would need to wait for the asphalt mixture adjustment to perform a re-verification test.
- In one of the districts, establishing a satellite laboratory for the district field staff to assist in running cores took the pressure off the laboratory staff and allowed for the completion of performance testing.
- Meeting the air voids tolerances on I-FIT specimens can add to the challenge in having a quick turnaround time. I-FIT specimens can be out of tolerance on air voids after spending the time to cut and prepare the samples. Thus requiring the district to request another sample and repeat the entire preparation process. This has been lately addressed by specifying higher air voids on the gyratory cylinders with a tighter tolerance assuming that air voids decrease with test specimen preparation.

In general contractors were supportive of the BMD approach as a way to increase the life cycle of asphalt pavements. Continuous communication, dialogue, and partnering with industry helped in balancing both the agency and industry needs and concerns. Based on a contractor experience with pilot and shadow projects thus far, the following observations were made:

- Changes to asphalt mixtures to get acceptable performance testing values were material specific. In particular, the performance test results were found to be sensitive to the aggregate type and properties (e.g., specific gravities, absorptions, particle shapes), asphalt binder content, etc. This required adjustments to bin percentages or the use of different aggregate sources.
    - Contractors sometimes struggled with the changes needed to the asphalt mixture to get acceptable results in performance tests. Several asphalt mixtures were failing the FI criteria.
    - More flexibility in using additives and modifiers need to be provided to contractors in order to produce asphalt mixtures that are in compliance with specifications.
- It was more challenging for contractors to meet performance test criteria on plant-produced asphalt mixtures rather than for laboratory-produced asphalt mixtures during the design stage.
- The variability associated with I-FIT can be of challenge, especially when comparing test results obtained from two separate laboratories. However, this is not currently a major issue as all asphalt mixtures are being approved based on performance tests that are being conducted by IDOT.
- Many Contractors chose to invest in equipment, especially those operating in remote areas with limited or no services from consultants. Some contractors partnered in equipment purchasing and ownership.
- Laboratory workspace can be of challenge. This required one contractor to convert a storage room into a temperature controlled room that houses performance testing equipment. In one instance, the contractor had to acquire interchangeable table jigs due to space limitation.
- IDOT's support in testing and sharing test results with contractors for asphalt mixtures during pilot projects was very helpful. Contractors were able to gain comfort and trust with performance testing and learn how it impacts their own asphalt mixture designs and production.
- Contractors in Illinois have in general a challenge in acquiring qualified technicians and having to run performance tests added to that challenge as they require additional training on equipment and test result calculations.
- No issues or challenges in meeting in-place density requirements were observed or encountered.
- The partnership and continuous discussion between IDOT, industry, IAPA, and universities is key for a successful implementation of performance tests for design and production of asphalt mixtures.

OVERALL BENEFITS

The use of BMD on test field projects allows contractors to optimize the use of recycled materials and still be able to produce asphalt mixtures that are in compliance with IDOT specifications. The traditional volumetric-based mixture design did not provide optimum performance for asphalt mixtures with higher recycled materials content. In general, no problems were encountered with constructing asphalt pavements using a BMD mixture.

District 6, for example, benefited from the implementation of performance testing. Occasional permanent deformation and frequent tender asphalt mixtures were a recurring problem, especially, for High ESAL asphalt mixtures that used natural sand (rounded particles) with higher traffic loading. The district attempted to reduce the use of natural sand in their asphalt mixtures by artificially increasing the Ndesign for High ESAL mixtures at a lower traffic threshold than IDOT policy allowed. With the implementation of HWT, High ESAL mixtures designed at 50 gyrations, in particular, failed the performance test criteria. This forced the district to delay the implementation of the HWT for asphalt mixtures designed at 50 gyrations. "I initially opposed the implementation of HWT with most of our asphalt mixtures in the western part of the district failing the test criteria," said Greg Heckel, District 6 Materials Engineer. "The HWT limited the use of several of the aggregate sources commonly available in District 6, thus raising a concern with the ability of contractors to produce an acceptable and economical asphalt mixture for lower traffic loading conditions," said Heckel. Accordingly, District 6 provided the contractors a 2-year stepped implementation process with targets for each Superpave gyration level before fully implementing the HWT as part of mix design and production. "After contractors were able to figure out the changes needed to pass our performance test criteria, we got rid of tender asphalt mixtures and now have a very stable mixture with a much better field pavement performance at lower gyrations," commented Heckel; "contractors had to reduce the natural sand, increase the design VMA, and use more of the angular fine aggregates in their asphalt mixtures." A tender asphalt mixture refers to a mixture that is difficult to compact with a tendency to shove under the roller wheels and/or leave longitudinal cracks at the edge of the steel drums. This is mainly caused by a lack of friction between aggregate particles or a lack of shear strength in the asphalt mixture.

Based on his past experience with HWT and the observed benefits from its implementation, Heckel is fully supporting the implementation of I-FIT in design and production to complement the HWT. "This will allow to balance the asphalt mixture performance in terms of cracking and permanent deformation while giving contractors flexibility in selecting component materials," concluded Heckel. Adjustments to the asphalt mixtures made to pass the HWT resulted in better quality aggregates, aggregate structure and VMA. As a result, the I-FIT results have been passing in District 6.

FUTURE DIRECTION

In 2021, all High ESAL asphalt mixtures (i.e., greater than 30 design gyrations) will be required to meet HWT, I-FIT (short term aging), and TS criteria. Furthermore, all Low ESAL asphalt mixtures (excluding Class D patches, pavement patching, and incidental asphalt mixtures) will be required to meet I-FIT criteria. IDOT will also begin conducting an asphalt binder performance test in 2022 to coincide with the allowance of terminally blended asphalt binder modifiers (non-polymer modified asphalt binders only). In terms of training, IDOT is in discussions to develop a re-certification process for all IDOT quality management training program courses.

Currently, IDOT has two active research studies:

- ICT R27-196 *Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements* (2018–2021).

- ICT R27-216 *Optimizing the Use of Local Aggregates in Stone-matrix Asphalt (SMA)* (2020–2023)

The full implementation effort needs to be supplemented with proper communication, training, and education activities. Contractors will need to be educated on what changes can be made to the asphalt mixture composition or proportions in order to make informed and cost-effective decisions to improve performance and meet applicable specification limits.

POSITIVE PRACTICES, LESSONS LEARNED, AND CHALLENGES

The following is a list of positive practices, some lessons learned, and challenges from IDOT that can help facilitate the implementation of a performance test into practice. Positive practices are those successful efforts that were used by IDOT that could also be considered by other SHAs. Lessons learned are those efforts that, if IDOT had it to do over again, they would definitely reconsider. Challenges are those efforts that IDOT is still in the process of addressing.

Positive Practices

- The motivation for implementation of BMD in IDOT was primarily two-fold: 1) there were issues with tender asphalt mixtures and stability problems as a result of the use of natural sand (round particles) in asphalt mixtures; and 2) there was an immediate need to address the observed premature failures of asphalt pavements as a result of the use of recycled materials in asphalt mixtures.
- Partnering with and collaboration between IDOT, industry, and academia is integral for a successful and smooth implementation of performance tests as part of asphalt mixture design and acceptance. This involves good communication and continuous dialogue with the industry, knowledge transfer, and necessary education and training.
    - Internally, having a strong commitment, support, and contribution to the development effort of BMD have been imperative.
    - Establishing an Implementation Task Force with Industry that comprised quality control managers, IAPA representative, FHWA division office representative, and engineers from IDOT (Central Office and Districts) helped in accelerating the implementation efforts by involving key stakeholders in the related activities and decisions. Things did not always go smoothly, but IDOT took the lead in keeping the implementation effort moving forward.
    - Externally, having strong and established relationships with academia (i.e., ICT at UIUC) have been instrumental for carrying the various steps involved in the development of BMD. Having an established program through the state to support critical and pressing research was key in the development and implementation of performance tests and BMD.
    - Externally, having industry partners that are participating in pilot and shadow projects is accelerating the learning curve and practicality of the approach.
    - Communicating with contractors the impact of new specifications on the design and acceptance of their asphalt mixtures was key to facilitating implementation.
- The Implementation Task Force with Industry agreed on the following main activities:
    - Increase ABR by 5% across the board for all asphalt mixtures.

  - Allow terminally blended asphalt binder modifiers once an asphalt binder performance test is developed.
  - Adopt "Perpetual Mix Designs" that are approved indefinitely.
  - Implement higher FI thresholds for SMA and IL-4.75 asphalt mixtures.
- IDOT uses performance tests with all of its asphalt mixtures. It first fully implemented the HWT in 2012 and plans on fully implementing I-FIT short-term aging minimum criteria in 2021. I-FIT long-term aging minimum criteria will be implemented in 2022.
- IDOT has been going through a rigorous process for implementing BMD into engineering practice including: initial development and continuous improvement of performance tests; development of standard test method; conduct of pilot projects; development of correlations between FI and field pavement performance; shadow testing on statewide projects; and development and revision of specifications.
- Having test procedures available supported efficient implementation of performance tests for asphalt mixtures (Step 1).
  - Continuously improving and updating test procedures and analysis methodologies improves test repeatability.
  - Supporting the research effort to develop the I-FIT method.
- IDOT funded several research studies to evaluate the sensitivity of performance tests to material properties for typically used asphalt mixtures in Illinois (Step 2). This also involved IDOT building a large database of performance test results over the years.
  - Establishing a database of test results helps in understanding the performance of typical asphalt mixtures and in verifying the initial performance test criteria.
  - Analyzing of the I-FIT results led to the following general observations:
    - A reduction in FI is observed with the increase in ABR.
    - An increase in FI is observed with a lower asphalt binder low temperature PG.
    - An increase in FI is observed with an increase in design VMA.
    - An increase in FI is observed with an increase in total asphalt binder content.
    - An increase in FI is observed with an increase in virgin asphalt binder content.
- The top factors in selecting HWT, I-FIT, and TS were (Steps 3 and 7):
  - The HWT procedure was modeled after the method used by TxDOT. Several individuals from IDOT traveled to Texas in April 2011 to learn about HWT program in Texas. The HWT was fully implemented by IDOT in 2012.
  - The I-FIT was introduced to control the cracking performance of asphalt mixtures as IDOT districts started to use more recycled materials into their asphalt mixtures.
  - The material sensitivity, field validation, and repeatability were key considerations in the development and implementation of performance test into the specifications.
  - Sample preparation, specimen conditioning and testing time, and equipment cost were also important factors for IDOT in the development of test criteria and the implementation of performance tests into the specifications.

    - The ability of testing aged specimens that are representative of a future critical pavement condition for cracking with a quick turnaround time for test results is deemed vital.
    - Capability of a performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures is important. The test results of local asphalt mixtures should not contradict known and observed field pavement performance, or recognized correlations between the mode of distress under evaluation and volumetric properties.
    - The TxDOT HWT pass criteria was initially considered and modified after testing and evaluation of typical asphalt mixtures from Illinois and in collaboration with the industry. The HWT test criteria is based on the plan PG of the asphalt binder prior to grade bumping for high ABR.
    - The I-FIT initial criteria was determined as part of a research study by the researchers and a committee of IDOT and private industry members.
        - The I-FIT criteria was based on I-FIT results from “good” and “poor” performing pavement cores from all nine Districts.
        - The ALF results at the TFHRC provided IDOT with an additional verification of their FI criteria.
    - The initial I-FIT criterion for FI of 8.0 was then field validated in a follow up study by comparing asphalt mixture results to their field pavement performance.
    - An in-house study was completed to determine the TSR criterion for 150 mm diameter gyratory-compacted specimens.
- IDOT has been conducting several round robin studies to determine the single and multiple operator variability for I-FIT FI (Step 6).
    - The round robins help to understand the variability in the test and to provide contractors with comparison data between their device, the IDOT District’s device, and the CBM’s device.
    - The annual round robins provide valuable checks on equipment and technician performance.
    - The data from the 2017–2019 IDOT I-FIT round robins were used to develop the precision statement as shown in the AASHTO TP 124. A bias statement is not possible because there is no universal reference in asphalt mixtures.
- Having a training and certification program in-place for testing and evaluating asphalt mixtures and aggregates that is supported by IDOT facilitated the training of technicians on performance tests (Step 8).
    - Course manuals designed for understanding the testing requirements of IDOT are provided to participants.
    - The course manuals are updated regularly and comprise detailed descriptions and photos of test methods including, equipment, sampling, specimen preparation, test procedure, etc.
    - Instructional videos are also shown to the participants including two of them that are specifically made for HWT and I-FIT. The videos were very effective and well accepted by participants.
- Keys to implementation (Step 9) included:

  - Having statewide pilot and shadow projects and an incremental implementation over several years so that contractors can have an opportunity to gain experience and become familiar and comfortable with the process before full implementation.
  - Helping and supporting contractors with performance tests (conducting tests for the contractors, offering training on equipment and test result calculations) to gain knowledge about their own asphalt mixtures.
- There have been benefits:
  - Implementing the HWT excluded the use of tender asphalt mixtures and resulted in stable mixtures with a much better field pavement performance.
  - The BMD allowed contractors to use recycled materials while producing asphalt mixtures that are in compliance with specifications.

Lessons Learned

During the construction of the test projects, several lessons were learned related to the laboratory testing and plant operation processes.

- Laboratory testing processes:
  - Changes to asphalt mixtures to get acceptable performance testing values were material specific. In particular, the performance test results were found to be sensitive to the aggregate type and properties (e.g., specific gravities, absorptions, particle shapes), asphalt binder content, etc. This required adjustments to bin percentages or the use of different aggregate sources.
  - Completing I-FITs within 3 days to a week of the first day of asphalt mixture production has been possible.
    - Getting the samples from the contractor in a timely manner is critical for a quick turnaround.
    - LTA specimens require three days of aging.
  - Establishing a satellite laboratory for the district field staff to assist in running cores might be needed relief laboratory staff and allow for the completion of performance testing.
  - Having an oven solely dedicated to I-FIT samples and another water bath with scale accelerate the turnaround time for test results.
  - Having a full time technician tasked to the performance testing is needed and more efficient.
  - Samples for the long-term oven aging I-FIT had to be prepared on a Monday or a Tuesday. Otherwise, technicians had to wait until Friday to get the I-FIT samples in the oven for long-term oven aging of 72 hours at 95°C.
- Plant operation processes:
  - Plant-produced asphalt mixtures typically exhibited different performance test results than laboratory-produced asphalt mixtures during design which necessitated some modifications to the JMF during the test strip.
  - Contractors found it beneficial to invest in equipment, especially those operating in remote areas with limited or no services from consultants. Some contractors partnered in equipment purchasing and ownership.
- Proper planning for laboratory workspace is needed. This required one contractor to convert a storage room into a temperature controlled room that houses performance

testing equipment. In one instance, the contractor had to acquire interchangeable jigs for the saws due to space limitation.

Challenges

- The increased use of recycled materials raised additional concerns with the typical asphalt mixtures designed using only HWT being drier, brittle and more prone to premature cracking.
- Contractors sometimes struggled with the changes needed to the asphalt mixture to get acceptable results in performance tests. More flexibility in using additives and modifiers need to be provided to contractors in order to produce asphalt mixtures that are in compliance with specifications.
- It was more challenging for contractors to meet performance test criteria on plant-produced asphalt mixtures rather than for laboratory-produced asphalt mixtures during the design stage.
- The HWT performance test method lacks a precision statement, thus creating a potential issue if two separate laboratories achieve different test results for the same asphalt mixture.
- The results from performance testing are needed promptly to minimize risk to the department.
- Meeting the air voids tolerances on I-FIT specimens can impact the turnaround time. I-FIT specimens can be out of tolerance on air voids after spending the time to cut and prepare the samples.
- Having an initial fail for a performance test raise a time challenge as the district would need to wait for the asphalt mixture adjustment to perform a re-verification test.
- Acquiring qualified technicians to run performance tests can be a challenge.
- Dealing with more than one project at a time can cause some challenges in meeting a quick turnaround time.

RESEARCH AND DEPLOYMENT OPPORTUNITIES

IDOT suggests the following research and deployment topics:

- Training materials and hands-on workshops on testing, analysis, and interpretation of performance test results including the influence of changes in asphalt mixture components, composition, and proportions during design or production on performance.
- Continuous support for ruggedness studies of new and existing performance tests.
- Development of a guideline illustration and outlining the process for materials and information that need to be collected for full implementation of performance testing. Such a guideline is imperative for SHAs that are looking into establishing and implementing performance testing and BMD.

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