Index-Based Tests for Performance Engineered Mixture Designs for Asphalt Pavements

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FOREWORD

The Federal Highway Administration (FHWA) has a Performance Engineered Pavements (PEP) vision that unifies several existing performance focused programs under a single vision. This vision seeks to incorporate the goal of long-term performance into the structural pavement design, construction, and materials acceptance of our nation's pavement infrastructure. Performance Engineered Mixture Design (PEMD) is one of the programs that supports that performance vision. This informational brief provides practitioners with information about index-based performance tests that can be implemented within a PEMD process to help improve performance and prolong service life of asphalt pavements. It is aimed to serve as a general overview and to provide context for PEMD process and how it fits into the big picture.

The FHWA has an ongoing Accelerated Implementation and Deployment of Pavement Technologies (AIDPT) Program, which includes the deployment of innovative technologies to improve pavement performance and reduce agency risk. This report was prepared under *Development and Deployment of Innovative Asphalt Pavement Technologies* Cooperative Agreement with the University of Nevada, Reno.

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There is a widespread recognition and desire need by agencies and asphalt paving industry to use performance testing to complement volumetric properties and help ensure satisfactory asphalt pavement performance. Accordingly, there has been several initiatives throughout the nation to develop Performance Engineered Mixture Design (PEMD) processes for asphalt pavements. This informational brief provides practitioners with information about index-based performance tests that can be implemented within a PEMD process to help improve performance and prolong service life of asphalt pavements. It is aimed to serve as a general overview and to provide context for PEMD process and how it fits into the big picture.

A five-step procedure guideline is presented in this document for the selection and incorporation of performance tests in an index-based PEMD process for asphalt mixture design and acceptance. Seven evaluation factors and associated hierarchical levels are identified and presented as part of an approach for screening and assessing the overall appropriateness of specific performance tests for use in an index-based PEMD process. The approach is demonstrated on selected performance tests using illustrative examples and following certain assumptions. State highway agencies (SHAs) and contractors can make use of the suggested five-step procedure guideline presented in this informational brief for their own selection of performance tests, depending on their specific needs, goals, capabilities, and resources, as part of an index-based PEMD process.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
APA	asphalt pavement analyzer
AQC	acceptance quality characteristic
ASTM	American Society for Testing and Materials
COV	coefficient of variation
DOT	Department of Transportation
BMD	Balanced Mix Design
DCT	disc-shaped compact tension
FHWA	Federal Highway Administration
HWTT	Hamburg wheel-tracking test
ILS	interlaboratory study
JMF	job mix formula
NCHRP	National Cooperative Highway Research Program
OBC	optimum asphalt binder content
OT	overlay test
PEMD	Performance Engineered Mixture Design
PEP	Performance Engineered Pavements
PRS	performance related specifications
QA	quality assurance
SCB	semi-circular bend
SHA	state highway agency
U.S.	United States

Symbols

CT_{Index}	cracking tolerance index
D^R	pseudo energy-based fatigue failure criterion
E^*	dynamic modulus
ESALs	equivalent single axle loads
FI	flexibility index
Flow	Marshall flow
FN	flow number
$G\text{-}R_m$	mixture Glover-Rowe
G_c	critical fracture energy
G_f	fracture energy
I	index parameter
J_c	critical strain energy release rate
M	mechanistic-oriented parameter
N	cycles to failure
N_{OT}	number of cycles until failure
NF	number of passes to failure
NSIP	number of passes to stripping

P	laboratory-developed performance model.
RD	rut depth
S	Hveem stability
S_{app}	cracking index parameter
SIF	stripping inflection point
Stability	Marshall stability
TS	indirect tensile strength
TSR	indirect tensile strength ratio
β	cracking resistance index
ε_p	permanent axial strain
ε_{vp}	viscoplastic strain (permanent strain)

INTRODUCTION

The Federal Highway Administration (FHWA) has a Performance Engineered Pavements (PEP) vision that unifies several existing performance focused programs under a single vision. This vision seeks to incorporate the goal of long-term performance into the structural pavement design, construction, and materials acceptance of our nation's pavement infrastructure. Performance Engineered Mixture Design (PEMD) is one of the programs that supports that performance vision. This informational brief provides practitioners with information about index-based performance tests that can be implemented within a PEMD process to help improve performance and prolong service life of asphalt pavements. It is aimed to serve as a general overview and to provide context for PEMD process and how it fits into the big picture.

The Superpave mixture design method for asphalt mixtures was originally intended to have three levels based on the anticipated 20-years pavement design traffic. A volumetric mixture design process was envisioned for low-volume design traffic. For moderate- to high-volume design traffic, varying degrees of mixture performance tests were envisioned in addition to volumetric design. However, proposed performance tests in this original effort were not then viable, thus were never implemented by state highway agencies (SHAs). As a result, the Superpave mixture design method, as currently implemented, has been based solely on volumetric properties.

Currently most SHAs use the Superpave method as specified in the American Association of State Highway and Transportation Officials (AASHTO) M 323, "Standard Specification for Superpave Volumetric Mix Design" and AASHTO R 35, "Standard Practice for Superpave Volumetric Design for Asphalt Mixtures" to identify the optimal aggregate blend and its corresponding optimum asphalt binder content. Many states also have local modifications or adjustments to those national standards. The AASHTO standard practice is also used for preliminary selection of asphalt mixture parameters as a starting point for mixture analysis and performance prediction analyses.

The need for performance testing for asphalt mixture design and quality assurance (QA) has increased in recent years with increased use of innovative and recycled materials (e.g., reclaimed asphalt pavement, reclaimed asphalt shingles, recycling agents), mostly driven by economic and environmental benefits. The traditional volumetric-based mixture design may not provide optimum performance for asphalt mixtures, in particular for those including such materials. Nor does it provide a performance optimization process for specific mixture design applications considering factors other than traffic and climate. Examples include location of the asphalt mixture within the pavement structure (e.g., surface course or intermediate/binder course), asphalt mixture design for reflective cracking relief interlayer, and condition of the existing pavement if the asphalt mixture is for overlay application. Performance testing can be used to define the boundaries of acceptable asphalt binder contents that result in ultimate performance against primary modes of distress (i.e., durability/cracking and rutting); thus avoiding the design and production of dry asphalt mixtures.

Accordingly, a number of SHAs and asphalt paving contractors have examined the possible use of asphalt mixture performance tests in design and acceptance. Agencies and the industry are looking for performance tests to more accurately relate to expected field pavement performance than volumetrics alone, to improve the performance of all asphalt mixtures. Consequently, there have been many recent research efforts toward the development and advancement of implementable and reliable asphalt mixture performance tests that could be adopted for more routine use, depending on the respective project and roadway characteristics. The availability of such performance tests is also important to asphalt paving contractors involved in alternative project delivery methods (e.g., design-build-maintain, public-private partnership) for highway construction projects. In such cases, the contractors could benefit from having reliable performance prediction capabilities as more risks shift from SHAs to private sector.

WHAT IS A PERFORMANCE ENGINEERED MIXTURE DESIGN?

The Performance Engineered Mixture Design (PEMD) is a comprehensive engineering analysis and testing of asphalt mixtures on constituent materials and/or mixtures to meet or exceed the pavement design requirements and performance lifecycle. PEMD seeks to achieve the combination of binder, aggregate, and mixture proportions that will meet performance criteria for a diverse number of pavement distresses and a specified level of traffic, climate, and pavement. The PEMD process for asphalt mixtures can be categorized as index-based PEMD or predictive PEMD. SHAs may consider establishing project selection criteria for applying index-based or predictive PEMD as part of a decision making process. The following selection criteria can be considered:

- Project scope, i.e., full reconstruction versus major (e.g., full depth reclamation) or minor (e.g. mill and overlay) rehabilitation.
- Highway functional classification (principal arterial, minor arterial, etc.) and project traffic level (low, moderate, or high volume).
- Project length and asphalt tonnage.
- Asphalt concrete layer location (e.g., surface versus base course) and function (e.g., binder versus wearing surface course) in the pavement structure.
- Outcome of a risk-based cost-benefit analysis for the project.

The index-based PEMD process, which is similar to what many call the Balanced Mix Design (BMD) process, is an asphalt mixture design process that uses performance tests on appropriately conditioned specimens to address primary modes of distress while taking into consideration asphalt mixture aging, traffic, climate, and location of the mixture within the pavement structure. The BMD process focus has been on using performance tests to balance asphalt pavement rutting performance with durability/cracking performance; and, to make tradeoffs between the two distresses to maximize overall pavement performance.

The predictive PEMD process acknowledges a broader spectrum of performance and diverse number of pavement distresses for a specified traffic, climate, and pavement structure. It captures the desire to improve performance and advance the state of practice beyond balancing two distresses toward an approach to predict pavement performance life using mechanistic response models.

The FHWA encourages agencies to incorporate performance testing into their asphalt mixture design evaluation, verification, and acceptance process. The main focus to date has been on the incorporation of performance tests into the asphalt mixture design and approval process.

Acceptance testing using performance tests allows SHAs to compare the characteristics and properties of a produced asphalt mixture to those determined as part of an index-based or predictive PEMD process. The added value with the use of predictive PEMD as part of an asphalt mixture design and QA Program, is the ability to further utilize within a performance related specifications (PRS) program as the basis for acceptance and price adjustment. PRS lets SHAs compare design expectations to what was constructed and pay for the produced and constructed product accordingly. PRS involves an improved understanding of performance among all parties including the risks on both the owner and the contractor.

Index-based PEMD State of the Practice

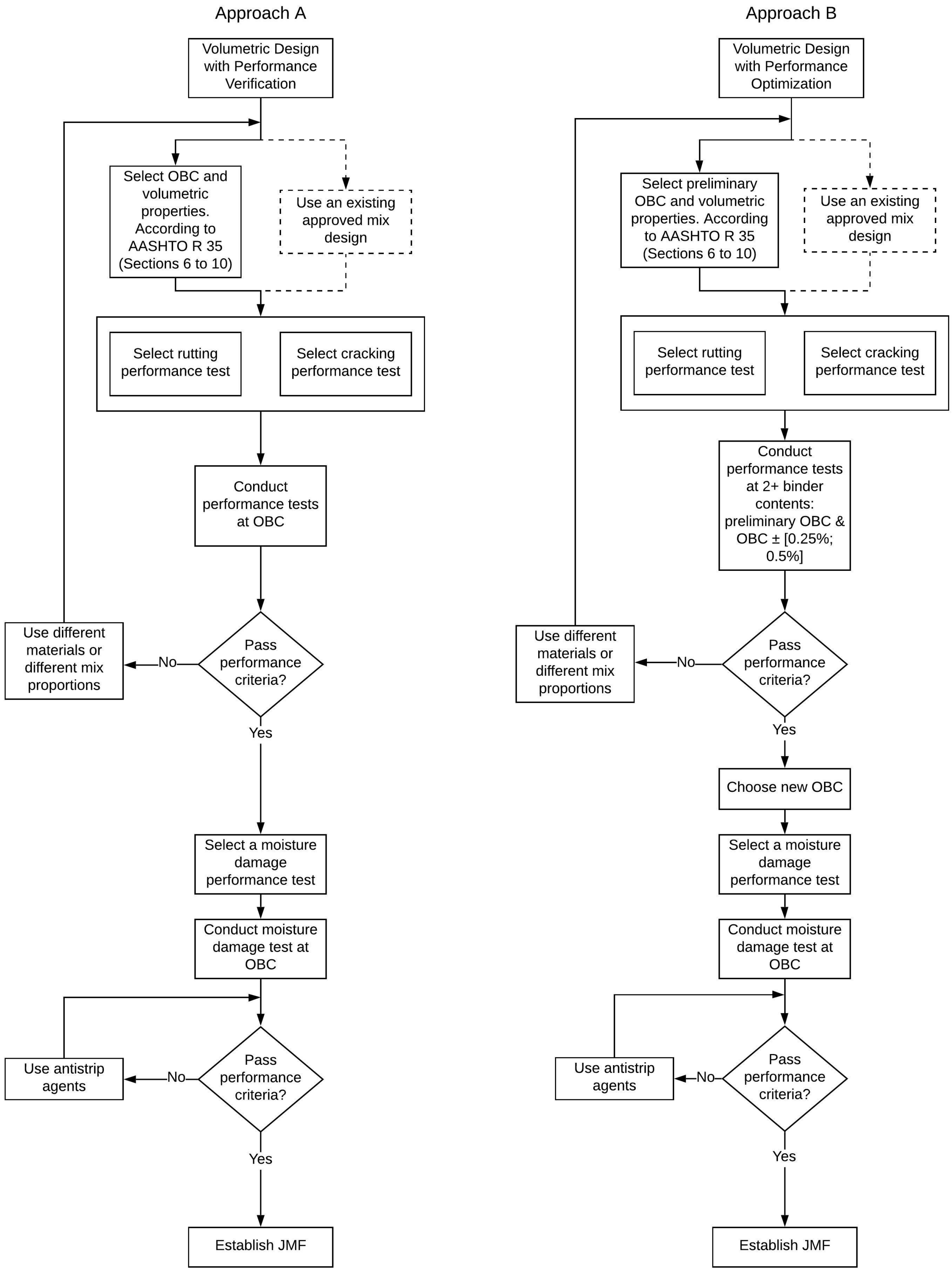
The products of the National Cooperative Highway Research Program (NCHRP) Project 20-07/Task 406, *Development of a Framework for Balanced Mix Design*, include a draft AASHTO Standard Practice for Balanced Design of Asphalt Mixtures with a nine step process for evaluating and fully-implementing a performance test into routine practice. The AASHTO Standard Practice describes four approaches (A through D) for an index-based PEMD (i.e., BMD) process. Figure 1 and figure 2 show flow charts of the index-based PEMD process approaches used to produce asphalt mixtures that satisfy performance testing practices and to develop asphalt mixture job mix formulas (JMFs). The following is a brief description of the four index-based PEMD process approaches:

- ***Approach A, Volumetric Design with Performance Verification***. The Superpave asphalt mixture design at the optimum asphalt binder content determined in accordance with AASHTO R35 should meet the additional performance test criteria.

- ***Approach B, Volumetric Design with Performance Optimization***. Adjustments by up to plus or minus 0.5% for the preliminary asphalt binder content may be determined in accordance with AASHTO R 35 to meet the target performance test criteria.

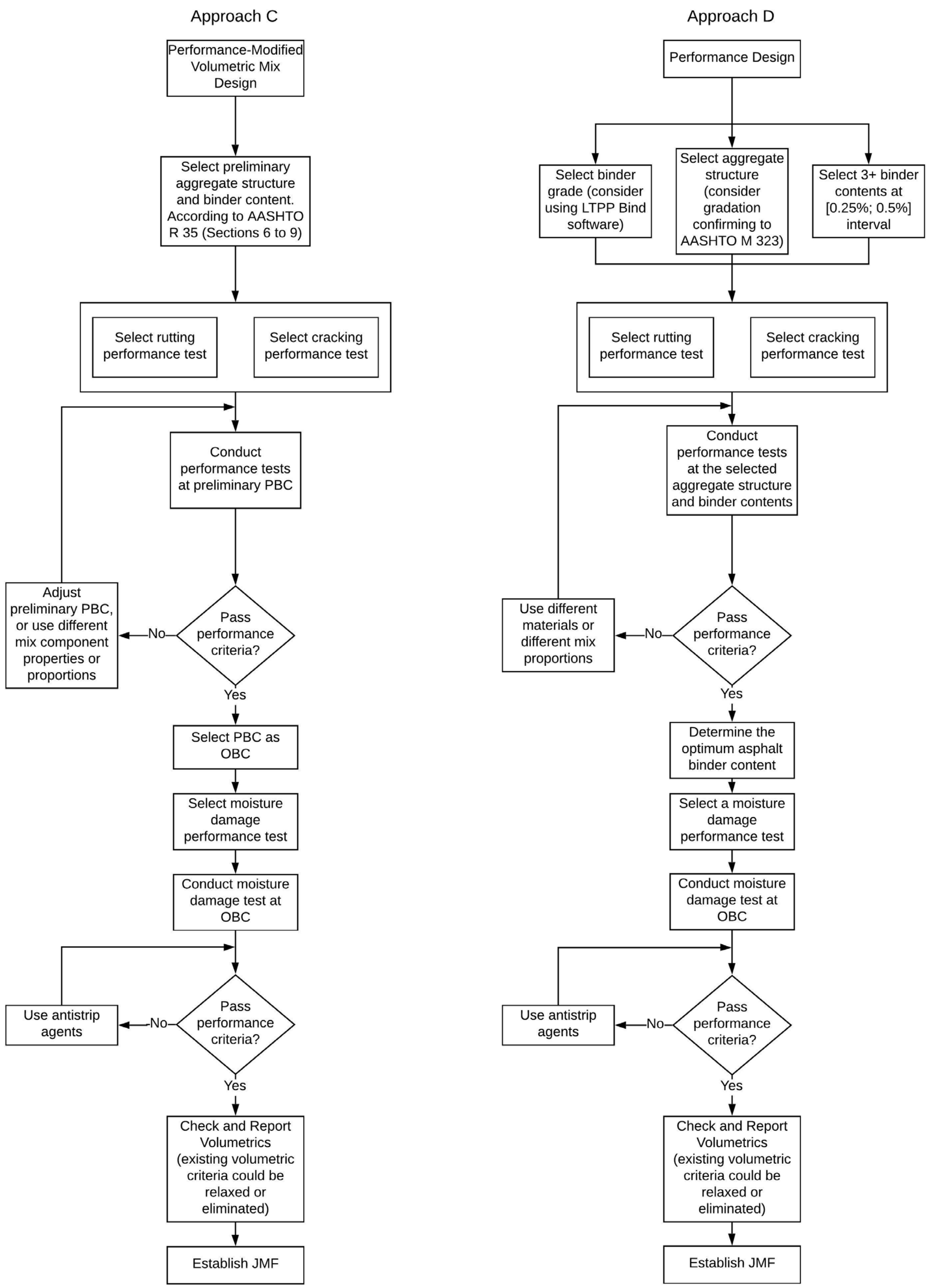
- ***Approach C, Performance-Modified Volumetric Design***. AASHTO R 35 is used through the evaluation of trial blends to establish a preliminary aggregate structure and asphalt binder content. Performance testing is then used to adjust either the preliminary binder content or mixture component properties or proportions in order to meet the target performance test criteria. In this approach, the final asphalt mixture design is primarily focused on meeting performance test criteria and may not have to meet all Superpave volumetric criteria.

- ***Approach D, Performance Design***. Asphalt mixture components and proportions are established and adjusted 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 asphalt mixture properties measured using laboratory performance tests meet the performance criteria, the asphalt mixture volumetrics may be checked for use in production.



Notes: OBC = optimum asphalt binder content; JMF = job mix formula

Figure 1. Chart. State-of-the-practice for index-based PEMD approaches A and B (based on draft AASHTO Standard Practice for Balanced Design of Asphalt Mixtures).



Notes: OBC = optimum asphalt binder content; PBC = preliminary asphalt binder content; JMF = job mix formula

Figure 2. Chart. State-of-the-practice for index-based PEMD approaches C and D (based on draft AASHTO Standard Practice for Balanced Design of Asphalt Mixtures).

A successful implementation of an index-based PEMD process involves the use of laboratory performance tests with well-established criteria. It also involves development and validation of correlations between performance test results and the corresponding field pavement performance. The performance test criteria should be established for available (local) materials based on project characteristics such as the asphalt mixture intended application and serviceability, the climate at the pavement location, the pavement traffic level, etc. Considerations should also be given to the location of the asphalt mixture within the pavement structure, aging condition of the asphalt mixture, as well as the type of the asphalt mixture specimens: laboratory-mixed, laboratory-compacted; field-mixed, laboratory-compacted; or field-mixed, field-compacted (cores).

ASPHALT MIXTURE PERFORMANCE TESTS

Performance tests are the basis for the PEMD process. Depending on the test method and configuration, a performance test can result in an index parameter, a mechanistic-oriented parameter, a laboratory-developed performance model, or a combination of these. Index parameters, such as Hamburg wheel-tracking test (HWTT) rut depth or overlay test (OT) cycles to failure, need to be correlated to field pavement distresses, and are used by an SHA in the index-based PEMD as go/no-go (pass/fail) design and acceptance. If an asphalt mixture fails one or more of the set performance criteria, JMF (e.g., aggregate structure, binder grade) adjustments would be needed.

On the other hand, mechanistic-oriented parameters, such as creep compliance from indirect tensile testing or a damage characteristic curve from cyclic fatigue testing, are combined with mechanistic models in order to evaluate asphalt mixture resistance to individual distresses. A mechanistic-oriented parameter can also be used as part of an index parameter for an index-based PEMD and acceptance scenario. A mechanistic-oriented parameter can also be used to predict pavement performance under given traffic and climate conditions in a predictive PEMD and acceptance scenario; thus, providing the ability to develop PRS.

The laboratory-developed performance models are developed based on performance test results and measurements, such as the plastic strain relationship included in the AASHTOWare™ Pavement ME design and analysis method. They are typically calibrated with field distresses and used to predict distresses in a pavement structure under given traffic and climate conditions.

Table 1 through table 3 provide examples of asphalt mixture performance tests that can be used in a PEMD process for stability/rutting, durability/cracking, and moisture damage/stripping, respectively. For each test, the standard test method, performance test outcome (i.e., index parameter—*I*, mechanistic-oriented parameter—*M*, or laboratory-developed performance model—*P*), and definition of the index parameter are provided. Table 2 also includes information on the type(s) of cracking that a test is intended to address. The list of performance tests is not intended to be comprehensive and can be subject to periodic updates. The following criteria were used for selecting the list of performance tests:

Table 1. Examples of stability/rutting performance tests for PEMD.

Test Name	Test Method	Test Outcome (I, M, P)[1]	Index Parameter	Index Definition or Performance Criteria
Asphalt Pavement Analyzer (APA)	AASHTO T 340	I	*RD*	Rut depth
Dynamic Modulus	AASHTO T 342/ AASHTO T 378/ AASHTO TP 132	I, M	E^*	Dynamic modulus
			$G\text{-}R_m$	Mixture Glover-Rowe
Flow Number	AASHTO T 378	I, P	*FN*	Flow number
			ε_p	Permanent axial strain
Hamburg Wheel-Tracking Test (HWTT)	AASHTO T 324	I	*RD*	Rut depth
			NF	Number of passes to failure
Hveem Stability	AASHTO T 246	I	*S*	Hveem stability
Resistance to Plastic Flow	AASHTO T245	I	*Stability*	Marshall stability
			Flow	Marshall flow
Stress Sweep Rutting	AASHTO TP 134	I, P	ε_{vp}	Viscoplastic strain (permanent strain)
			ATR (ESALs)	Allowable traffic for rutting (equivalent single axle loads)

[1]I=index parameter; M=mechanistic-oriented parameter, P=laboratory-developed performance model.

Table 2. Examples of durability/cracking performance tests for PEMD.

Test Name	Test Method	Test Outcome[1]	Index Parameter	Definition or Performance Criteria	Cracking Types
Direct Tension Cyclic Fatigue	AASHTO TP 107/ AASHTO TP 133	I, M, P	D^R	Pseudo energy-based fatigue failure criterion	Bottom-up fatigue Top-down
			S_{app}	Cracking index parameter	
Disc-Shaped Compact Tension (DCT)	ASTM D 7313	I	G_f	Fracture energy	Thermal Reflection
Dynamic Modulus	AASHTO T 342/ AASHTO T 378/ AASHTO TP 132	I, M	E^*	Dynamic modulus	Bottom-up fatigue Thermal
			$G\text{-}R_m$	Mixture Glover-Rowe	
Flexural Bending Beam Fatigue	AASHTO T 321	I, M, P	*N*	Cycles to failure	Bottom-up fatigue
Illinois Flexibility Index	AASHTO TP 124	I	*FI*	Flexibility index	Bottom-up fatigue Top down Reflection
Indirect Tensile Cracking[2]	ASTM D8225	I	CT_{Index}	Cracking tolerance index	Thermal Reflection
Overlay Test (OT)	Tex-248-F/ NJDOT B-10	I	N_{OT}	Number of cycles until failure	Bottom-up fatigue Reflection
			G_c	Critical fracture energy	
			β	Crack resistance index	
Semi-Circular Bend (SCB)	AASHTO TP 105/ ASTM D8044	I	*J*	Critical strain energy release rate	Bottom-up fatigue Thermal

[1]I=index parameter; M=mechanistic-oriented parameter, P=laboratory-developed performance model.
[2]formerly known as IDEAL-CT.

Table 3. Examples of moisture damage/stripping performance tests for PEMD.

Test Name	Test Method	Test Outcome (I, M, P)[1]	Index Parameter	Index Definition or Performance Criteria
Hamburg Wheel-Tracking Test (HWTT)	AASHTO T 324	I	*RD*	Rut depth
			SIF	Stripping inflection point
			NF	Number of passes to failure
			NSIP	Number of passes to stripping inflection point
Indirect Tensile Strength Ratio	AASHTO T 283	I	*TS*	Indirect tensile strength
			TSR	Indirect tensile strength ratio

[1]I=index parameter; M=mechanistic-oriented parameter, P=laboratory-developed performance model.

- A published or draft standard test method from AASHTO, American Society for Testing and Materials (ASTM), or SHA should exist for the test.

- The performance test should have an established index parameter for design or acceptance criteria.

- The performance test should have been adopted as part of an asphalt mixture design process, research, or acceptance criteria by an SHA.

PERFORMANCE TEST SELECTION CONSIDERATIONS

The subsequent step-by-step guidelines can be followed by an SHA or a contractor when selecting performance tests for inclusion in an index-based PEMD process:

- ***Step 1.*** Identify the primary asphalt pavement modes of distress (e.g., bottom-up fatigue cracking, reflection cracking, rutting, moisture damage) to be considered as part of the index-based PEMD process. Considerations should be given to the intended application (e.g. new construction, major rehabilitation, mill and overlay), to the mixture design, and to information regarding commonly-observed field distresses.

- ***Step 2.*** Identify candidate performance tests that can be or have historically been used to estimate asphalt mixture resistance to the pavement modes of distress identified in Step 1. Considerations should be given to the failure mechanisms of the targeted modes of distress and their associated performance tests.

- ***Step 3.*** Assess the overall appropriateness of each of the candidate performance tests identified in Step 2 for routine use in an index-based PEMD process based on the needs, capabilities, resources, etc., of SHA and contractor. In this step, consideration should be given to the following evaluation factors: sample preparation, specimen conditioning and testing, training needs and applicability, equipment cost, repeatability, material sensitivity, and field validation. At the end of this step, a performance test can be selected for each of the targeted modes of distress for further evaluation in Step 4.

- ***Step 4.*** Assess the readiness of the selected performance tests for full implementation for available (local) materials in accordance with the process identified in NCHRP Project 20-07/Task 406. This process 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; and, (9) implementation into engineering practice. All nine steps should be completed for each performance test selected through a collaborative effort between an SHA and asphalt paving industry. It should be noted that some of these nine steps can be adopted directly by an SHA based on the level of effort completed regionally or nationally (e.g., steps 1, 4, and 5), while 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. While this process can be lengthy and costly, it is critical for a proper and successful complete implementation of the selected performance tests and associated specifications into routine practice.

- ***Step 5.*** Evaluate the implementation impacts of multiple performance tests on the current SHA and industry practice for designing and accepting asphalt mixtures. For example, an SHA or a contractor can examine the additional time and resources needed to complete an asphalt mixture design following the index-based PEMD process in terms of the number of operating equipment, number of qualified personnel, testing sequence timing, etc. Additional considerations can be related to the effort and activities related to establishing reliable criteria for the test index parameters based on local correlations between performance test results and field pavement performance. An SHA or a contractor can also evaluate the risks and responsibilities associated with the use of the selected index-based performance tests as part of mixture design approval and construction QA Program (process control and quality control, agency acceptance, independent assurance, etc.). The viability of implementing performance tests for asphalt mixture design verification, acceptance during production, and the impact on current practice can be examined and evaluated. Considerations can also be given to the potential differences in properties of asphalt mixtures designed using the index-based PEMD process as compared to those which have historically been designed based on acceptance quality characteristics (AQCs) and specifications.

As mentioned in Step 3 above, seven evaluation factors are recommended for consideration by an SHA or contractor for the purpose of assessing the overall appropriateness of performance tests for use in an index-based PEMD process. For instance, three hierarchical levels (Level A, B and C) can be established for each considered factor to enable proper comparisons of selected performance tests. The three hierarchical levels can be defined as follows:

- Level A indicates the most beneficial level to an SHA or a contractor. Attributes to this level can be: least specimen conditioning and testing time, lowest cost, etc.

- Level B indicates an intermediate level. Attributes to this level can be: medium duration for specimen conditioning and testing, moderate cost, etc.

- Level C indicates the least beneficial level to an SHA or a contractor. Attributes to this level can be: most training needs, lowest repeatability, etc.

Table 4 is an example of three hierarchical levels for each of the seven recommended factors. Note that these are individual evaluation factors that can be redefined by an SHA or contractor. Their relative importance likely would vary among different SHAs and contractors depending on their specific needs, goals, and capabilities. While the following example contains multiple assumptions, it illustrates a potential framework for evaluation.

Table 4. Sample hierarchical levels of evaluation factors for selection process of index-based performance tests.

Selection Process	Evaluation Factor	Level A	Level B	Level C
Sample preparation	Sample preparation and Instrumentation (Number of activities per test sample).	Low (≤ 2)	Medium (≤ 5)	High (≥ 6)
Specimen conditioning and testing	Specimen conditioning time.	≤ 2 hours	≤ 5 hours	> 5 hours
	Testing time.	≤ 0.5 hour	≤ 5 hours	> 5 hours
Training needs and applicability	Training effort.	Low	Moderate	High
	Data analysis complexity.	Simple	Fair	Complex
	Lab-molded specimens and field cores.	Yes	–	No
	Field acceptance/quality control in mobile laboratory.	Yes	–	No
Equipment cost	New equipment acquirement.	≤ $40,000	≤ $100,000	> $100,000
	Existing equipment modification.	≤ $15,000	≤ $40,000	> $40,000
Repeatability	Single laboratory coefficient of variation (COV).	≤ 10%	≤ 25%	> 25%
Material sensitivity	Status of existing national and local sensitivity analyses.	Good	Fair	Poor
	Sensitivity significance level to acceptable changes in asphalt mixture component properties/proportions, air voids, and aging.	High	Moderate	Low
Field validation (based on status of existing efforts)	Status of existing national and local efforts.	Good	Fair	Poor
	Mechanistic/Mechanistic-Empirical analyses.	Yes	–	No

– indicates not applicable.

The seven evaluation factors used in this example are further described as follows:

- ***Sample preparation***. Assessed based on the level of effort needed for sample preparation and instrumentation. For example, there are three suggested levels depending on the number of activities for coring/drilling, cutting (including trimming and notching), and gluing (including gluing for specimen platens and instrumentation): Level A indicates no more than two activities per test sample are needed (e.g., a maximum of 2 cuts per sample with no coring or gluing activities), Level B indicates three to five activities per test sample are needed, and Level C indicates six or more activities are needed. In this example, each of the following is counted as a single activity: coring, drilling a single hole, one saw cut, simultaneous gluing of platens, and gluing of studs for instrumentation. Furthermore, considerations should be given to the impact of the number of replicate test specimens used to generate valid results on sample preparation efforts.

- ***Specimen conditioning and testing***. Assessed based on the duration of time used for specimen conditioning and testing. For instance, specimen conditioning is illustrated by three levels depending on compacted asphalt mixture conditioning time: Level A for conditioning time less than or equal to 2 hours, Level B for conditioning time between 2 and 5 hours, and Level C for conditioning time greater than 5 hours. Test completion is demonstrated by three levels depending on the testing time: Level A for testing time less than or equal to 0.5 hour, Level B for testing time between 0.5 and 5 hours, and Level C for testing time greater than 5 hours. Furthermore, considerations should be given to the impact of the number of replicate test specimens needed to generate valid results on specimen conditioning and testing time.

- ***Training needs and applicability***. Assessed based on the level of training needed for equipment operation and data analysis, the suitability of the test for both laboratory-molded specimens and field cores, as well as the ability of the test to be used in a mobile laboratory for field acceptance and/or quality control (for remote projects, mobile plant quality control testing, etc.). For instance, training has three levels depending on the extent of training needed for engineers and technicians on the test procedure and analysis of test results: Level A indicates similar or minimal increase in current training practices and activities, Level B indicates additional 3-5 days of training activities, and Level C indicates over 6 days of additional training activities. Data analysis is considered using three levels depending on the complexity of interpretation of results for use in specifications, assuming software exists to obtain test results from raw measurements: Level A for simple, Level B for fair, and Level C for complex. The suitability of the test for both laboratory-molded specimens and field cores, and the ability of the test to be used in a mobile laboratory for field acceptance and/or construction quality control each have two levels for this example: Level A for yes and Level C for no.

- ***Equipment Cost***. Assessed based on the level of financial investment for acquiring new or modifying existing equipment for sample preparation and testing. For this example, new equipment has three levels depending on the cost of new testing apparatus, environmental chamber, compactor, coring drill machine, and saws for cutting, trimming and notching: Level A for cost less than or equal to $40,000, Level B for cost between $40,000 and $100,000, and Level C for cost greater than $100,000. Existing equipment has three suggested levels depending on the cost for modifying or expanding the capability of existing equipment (e.g. cost for acquiring a new jig/fixture, different size core bit): Level A for cost less than or equal to $15,000, Level B for cost between $15,000 and $40,000, and Level C for cost greater than $40,000. Additional costs that can be considered are equipment maintenance, calibration, services, and mobilization costs.

- ***Repeatability***. Assessed based on the level of coefficient of variation (COV) associated with repeated measurements on replicate test specimens in a single laboratory. For instance, repeatability has three suggested levels depending on the typical COV: Level A for COV less than or equal to 10%, Level B for COV between 10 and 25%, and Level C for COV greater than 25%. More than one replicate test specimen should be used to establish the COV for test selection purposes. In acceptance, repeatability (within laboratory) and reproducibility (between laboratories) of the test results, including number of replicate test specimens and the COV of the test, should be considered in establishing specification acceptance criteria.

- ***Material sensitivity***. Assessed based on the status of existing national and local sensitivity analysis studies, as well as the sensitivity significance level of the index parameter to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), air voids, and aging. For example, three levels are used, depending on the number of national and local studies conducted: Level A indicates one or more sensitivity analysis studies have been conducted using available (local) materials, Level B indicates that some national or regional studies have been conducted but did not use local materials, and Level C indicates no or very limited national studies have been conducted. There are three levels that can be used for the sensitivity significance level depending on the ability of the test to properly capture changes in these variables: Level A indicates the test index parameter is sensitive to relatively small changes in the considered variable, Level B indicates the test index parameter is sensitive to relatively large but acceptable changes in the considered variable, and Level C indicates the test index parameter is not sensitive to acceptable changes in the considered variable. It should be noted that the trends for the index parameter should be rational and in line with engineering intuition; for example, a decrease in flow number with the increase in specimen air voids level is expected. Analysis of variance can be used to check for the variable significance. The Fisher's least significant difference test can then be used to determine which variable levels result in significant differences. For example, an analysis of variance can show that for a specific asphalt mixture flow number is significantly sensitive to changes in asphalt binder content. However, the Fisher's least significant difference test can show that the flow number of an asphalt mixture is not sensitive to a 0.2% increase in asphalt binder content, but is rather sensitive to a 0.4% increase in asphalt binder content.

- ***Field validation***. Assessed based on the status of existing national and local efforts conducted for the correlation and validation of the test index parameter with measured field performance data, as well as the added benefits of performance test results for use in mechanistic analyses; thus strengthening field validation efforts. In this example, three levels are used depending on the number of national and local studies conducted to relate laboratory results to field performance: Level A indicates one or more studies have been conducted using available (local) materials, Level B indicates that some national or regional research has been conducted but did not use local materials, and Level C indicates no or very limited national research has been conducted. There are two levels for the performance test results: Level A indicates the ability of the performance test to result in a mechanistic-oriented parameter or a laboratory performance model that can be used in mechanistic analyses, and Level C indicates that the performance test can only result in an index parameter.

It should be noted that an SHA or a contractor might consider having different thresholds or definitions than those presented in this informational brief for the hierarchical levels, and/or further refining the current levels to include additional sublevels. An SHA or a contractor might also elect to establish different statistical weights to increase or decrease the significance of each of the evaluation factors; all depending on the entity specific needs, capabilities, resources, etc.

SAMPLE EVALUATION OF PERFORMANCE TEST CHARACTERISTICS

The sample evaluation factors and associated hierarchical levels summarized in table 4 provide SHAs and contractors with an example for an overall framework for assessing and selecting performance tests for inclusion in an index-based PEMD process. Accordingly, figure 3 through figure 5 show an illustrative example for the characteristics of some selected performance tests in relation to the evaluation factors summarized in table 4. As noted, Level A, Level B, and Level C indicate the most desirable, intermediate, and least desirable levels, respectively.

Some assumptions were made when generating the specific examples shown in figure 3 through figure 5. It should be noted that the assessment of any performance test is likely to differ between SHAs and contractors based on their own specific needs, capabilities, expertise, etc. Thus, it is important to recognize that the summaries of performance test characteristics presented in figure 3 through figure 5 are for illustration purposes and should not be generalized. The assumptions used in this example were:

- Sample preparation is based on a single replicate test specimen. Essentially, more than one replicate is needed to generate valid performance test results. The number of replicate test specimens is generally test specific; thus, influencing the estimated level of effort needed for sample preparation and instrumentation.

- Specimen conditioning and testing is evaluated based on respective durations for a single specimen using a single test equipment.

- Engineers and technicians are familiar with relevant equipment but not necessarily with the standard test methods and associated data analyses.

- Equipment cost is evaluated based on the estimated purchase of new equipment only (i.e., new testing apparatus, environmental chamber, compactor, coring drill machine, and/or saws for cutting, trimming and notching). Modification of an existing equipment was not considered in this example.

- Material sensitivity was not considered in this example since it involves a literature search of sensitivity analysis studies as well as statistical analysis of test results for determining significance of factors for particular mixtures. However, when assessing material sensitivity, it would be useful for an SHA to prepare specimens at the extremes (allowable limits) of its current specification acceptance criteria. For example, accompany specimens prepared at JMF target values with JMF target values plus and minus the allowable tolerances, per factor/parameter. This would also provide an indication of the impact performance test implementation has on current asphalt mixture properties

- Studies using available (local) materials for all selected performance tests in this example have been conducted to relate laboratory results to field performance for the development of performance tests criteria.

SUMMARY

The need for the incorporation of asphalt mixture performance testing for design and construction QA to improve performance of all asphalt mixtures has been recognized by FHWA, SHAs, and asphalt paving industry. There has been an increase in alternative project delivery methods for highway construction projects, different mixture types and composition, asphalt additives and modifiers, as well as recycled materials in use today (and likely in the future). Thus, there is a widespread recognition and desire need to use performance testing to complement volumetric properties and help ensure satisfactory asphalt pavement performance. To more accurately capture the effects of these changes, efforts to develop index-based and predictive PEMD processes for asphalt mixture design and acceptance are underway at several agencies. This informational brief provides examples of asphalt mixture performance tests that can be used in an index-based PEMD process for stability/rutting, durability/cracking, and moisture damage/stripping, while also identifying test procedures appropriate for predictive PEMD processes.

An index-based PEMD process relies on index parameters determined using performance tests on appropriately conditioned specimens to address multiple modes of distress. The index parameters should be correlated to field pavement performance using available (local) materials before they can be used by an agency in an index-based PEMD as go/no-go (pass/fail) design and acceptance criteria. On the other hand, a predictive PEMD process relies on mechanistic-oriented parameters that are combined with mechanistic models in order to evaluate asphalt mixture resistance to individual distresses. Thus, allowing for the prediction of pavement performance under given traffic and climate conditions. The predictive PEMD performance tests that an agency adopts and incorporates into its QA Program could be further utilized as performance model inputs within a PRS as the basis for acceptance and price adjustment

A five-step procedure guideline is presented in this document for the selection and incorporation of performance tests in an index-based PEMD process for asphalt mixture design and acceptance. Seven evaluation factors and associated hierarchical levels are identified and presented as part of an approach for assessing the overall appropriateness of specific performance tests for use in an index-based PEMD process. The approach is demonstrated on selected performance tests using illustrative examples and following certain assumptions. SHAs and contractors can make use of the suggested five-step procedure guideline presented in this informational brief for their own selection of performance tests, depending on their specific needs, goals, capabilities, and resources, as part of an index-based PEMD process.

Test Name	Sample Preparation	Specimen Conditioning and Testing	Training Needs and Applicability	New Equipment Cost	Repeatability	Field Validation
Asphalt Pavement Analyzer (APA)	A	B	A	B	B	B
Dynamic Modulus (Small Specimen)	B	B	B	C	B	A
Flow Number	B	B	A	C	C	A
Hamburg Wheel-Tracking Test (HWTT)	A	C	A	B	B	B
Hveem Stability	A	B	A	B	A	B
Stress Sweep Rutting	B	B	A	C	– Not Available	A

Legend: Level A; Level B; Level C; Arrow points to the estimated tally of the performance test; – indicates not applicable.

Notes: Assessment is for illustration purposes and is based on certain assumptions that are likely to vary based on the entity specific needs, capabilities, expertise, etc.
Sample Preparation is based on a single replicate test specimen.
Specimen Conditioning and Testing is evaluated based on respective durations for a single specimen using a single test equipment.
New Equipment Cost includes approximate costs for testing apparatus, environmental chamber, compactor, coring drill machine, and saws for cutting, trimming and notching.
Level A indicates the most desirable level, for example, slightest specimen conditioning and testing time, lowest cost, etc.
Level B indicates an intermediate level, for example, medium duration for specimen conditioning and testing, moderate cost, etc.
Level C indicates the least desirable level, thus, most training needs, lowest repeatability, etc.

Figure 3. Chart. Sample characteristics of stability/rutting performance tests (based on certain assumptions).

Test Name	Sample Preparation	Specimen Conditioning and Testing	Training Needs and Applicability	New Equipment Cost	Repeatability	Field Validation
Direct Tension Cyclic Fatigue (Small Specimen)	B/C	B	A	C	– Not Available	A
Disc-Shaped Compact Tension (DCT)	C	B	A/B	C	B	B
Dynamic Modulus (Small Specimen)	B	B	B	C	B	A
Flexural Bending Beam Fatigue	C	C	B	C	C	A
Illinois Flexibility Index	B	A	A	B	B	B
Indirect Tensile Cracking	A	A	A	B	B	B
Overlay Test	B/C	B	A	B	C	B
Semi-Circular Bend (SCB)—AASHTO TP105	B/C	B	A	B	B	B

Legend: Level A; Level B; Level C; Arrow points to the estimated tally of the performance test; – indicates not applicable.

Notes: Assessment is for illustration purposes and is based on certain assumptions that are likely to vary based on the entity specific needs, capabilities, expertise, etc.
Sample Preparation is based on a single replicate test specimen.
Specimen Conditioning and Testing is evaluated based on respective durations for a single specimen using a single test equipment.
New Equipment Cost includes approximate costs for testing apparatus, environmental chamber, compactor, coring drill machine, and saws for cutting, trimming and notching.
Level A indicates the most desirable level, for example, slightest specimen conditioning and testing time, lowest cost, etc.
Level B indicates an intermediate level, for example, medium duration for specimen conditioning and testing, moderate cost, etc.
Level C indicates the least desirable level, thus, most training needs, lowest repeatability, etc.

Figure 4. Chart. Sample characteristics of durability/cracking performance tests (based on certain assumptions).

Test Name	Sample Preparation	Specimen Conditioning and Testing	Training Needs and Applicability	New Equipment Cost	Repeatability	Field Validation
Hamburg Wheel-Tracking Test (HWTT)	A	C	A	B	B	B
Indirect Tensile Strength Ratio	A	C	A	B	B	B

Legend: Level A; Level B; Level C; Arrow points to the estimated tally of the performance test.

Notes: Assessment is for illustration purposes and is based on certain assumptions that are likely to vary based on the entity specific needs, capabilities, expertise, etc.
Sample Preparation is based on a single replicate test specimen.
Specimen Conditioning and Testing is evaluated based on respective durations for a single specimen using a single test equipment.
New Equipment Cost includes approximate costs for testing apparatus, environmental chamber, compactor, coring drill machine, and saws for cutting, trimming and notching.
Level A indicates the most desirable level, for example, slightest specimen conditioning and testing time, lowest cost, etc.
Level B indicates an intermediate level, for example, medium duration for specimen conditioning and testing, moderate cost, etc.
Level C indicates the least desirable level, thus, most training needs, lowest repeatability, etc.

Figure 5. Chart. Sample characteristics of moisture damage/stripping performance tests (based on certain assumptions).

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