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Validation in the SHRP Asphalt Research Program (October, 1991)

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VALIDATION IN THE SHRP ASPHALT RESEARCH PROGRAM (OCTOBER 1991)

INTRODUCTION

The successful development of performance-based specifications requires the validation of those properties identified as important determinants of pavement performance. We define validation as the verification of probable relationships between binder and asphalt-aggregate mix properties and pavement performance through the correlation of those properties with measured characteristics of in-service pavements.

SHRP views validation as a three stage process: the first two stages to be completed during its life and the final stage subsequent to March, 1993 as a part of the ongoing Long Term Pavement Performance (LTPP) program. The initial two-stage process is a coordinated effort between contracts A-003A and A-005 as illustrated in Figure 1.

FIRST-STAGE VALIDATION (A-002A/A-003A)

The first stage validation will confirm that variation of asphalt binder properties identified as probable, significant determinants of pavement performance yield physically reasonable, meaningful changes in relevant performance characteristics of asphalt-aggregate mixes. SHRP Contract A-003A is accomplishing this stage

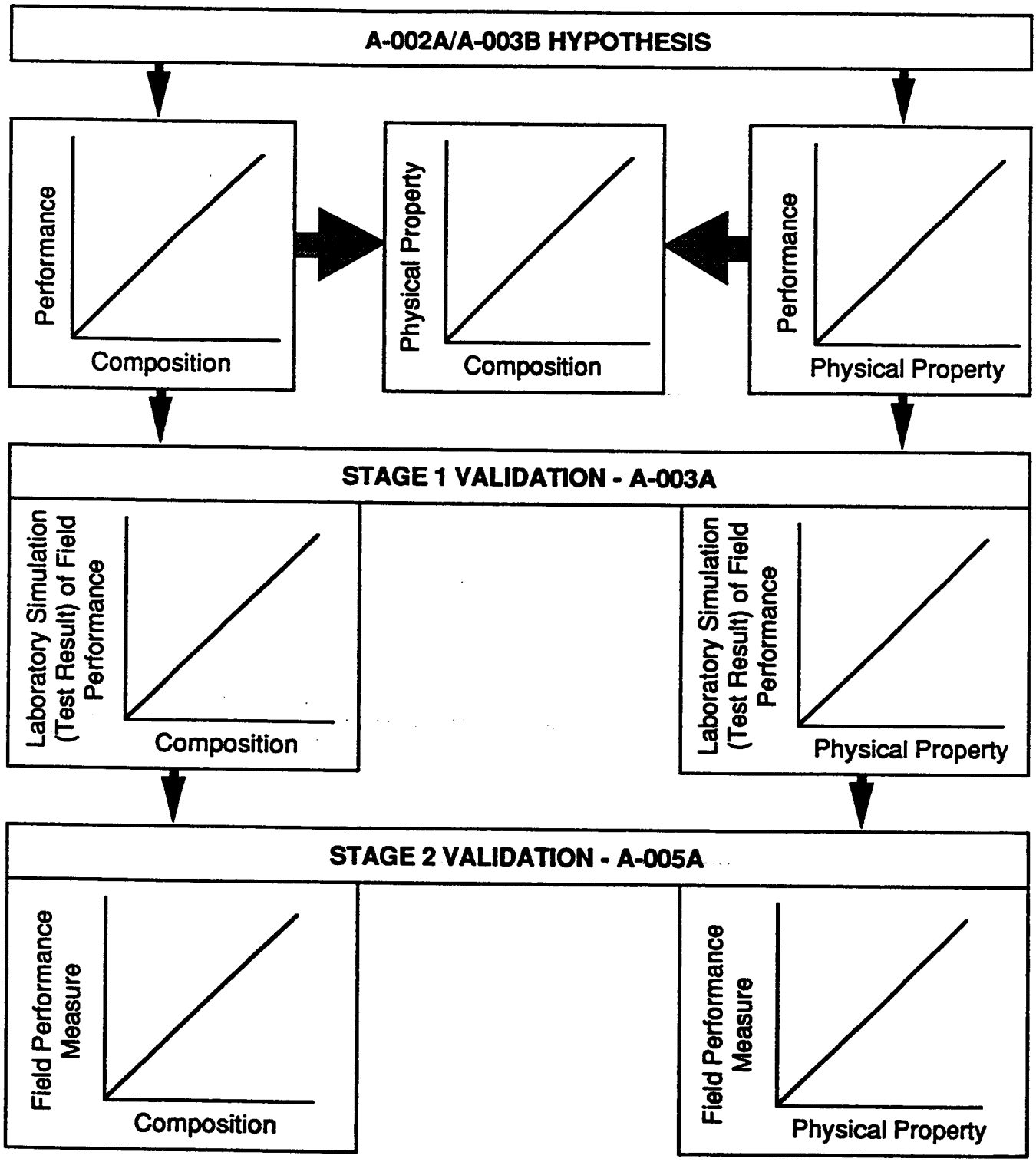


Figure 1. The two-step validation process using accelerated laboratory test (Torture Tests) and field performance data.

mainly by the use of highly simulative laboratory tests ("torture tests") such as wheel tracking, thermal stress restrained specimen, and flexural beam tests; specifically designed accelerated laboratory tests and existing accelerated load facilities also play a minor role.

SECOND-STAGE VALIDATION (A-005)

The second stage validation will establish the degree of correlation between field pavement performance and:

1) those asphalt binder properties shown to significantly affect the performance-related characteristics of asphalt-aggregate mixes;

2) performance-related material properties of asphalt-aggregate mixtures.

Furthermore, the second stage validation will provide the experimental results needed to set specification limits for the relevant binder and mixture properties selected to control pavement performance and to choose among laboratory test methods proposed to measure these properties. The second stage validation is being performed by SHRP Contract A-005 and relies heavily on sampling and testing the LTPP General Pavement Studies (GPS) sections. The GPS sections are in-service pavements that were constructed in the late

1970s or early 1980s.

Figure 2 illustrates the two approaches to the second stage validation.

The Direct Correlation Method

Ideally, the A-005 field (second-stage) validation process will establish specification properties, specification limits and test method selection by the following **direct correlation** method (Figure 3):

1) identification of field sections with a broad range of compositional and physical properties which exhibit distresses (permanent deformation, thermal and fatigue cracking) and/or distress related factors (moisture damage/adhesion, and aging);

2) measurement of selected binder and mix properties and their comparison to observed pavement distress; and

3) determination of correlation between binder and mix properties, and pavement distress to assess extent of validation.

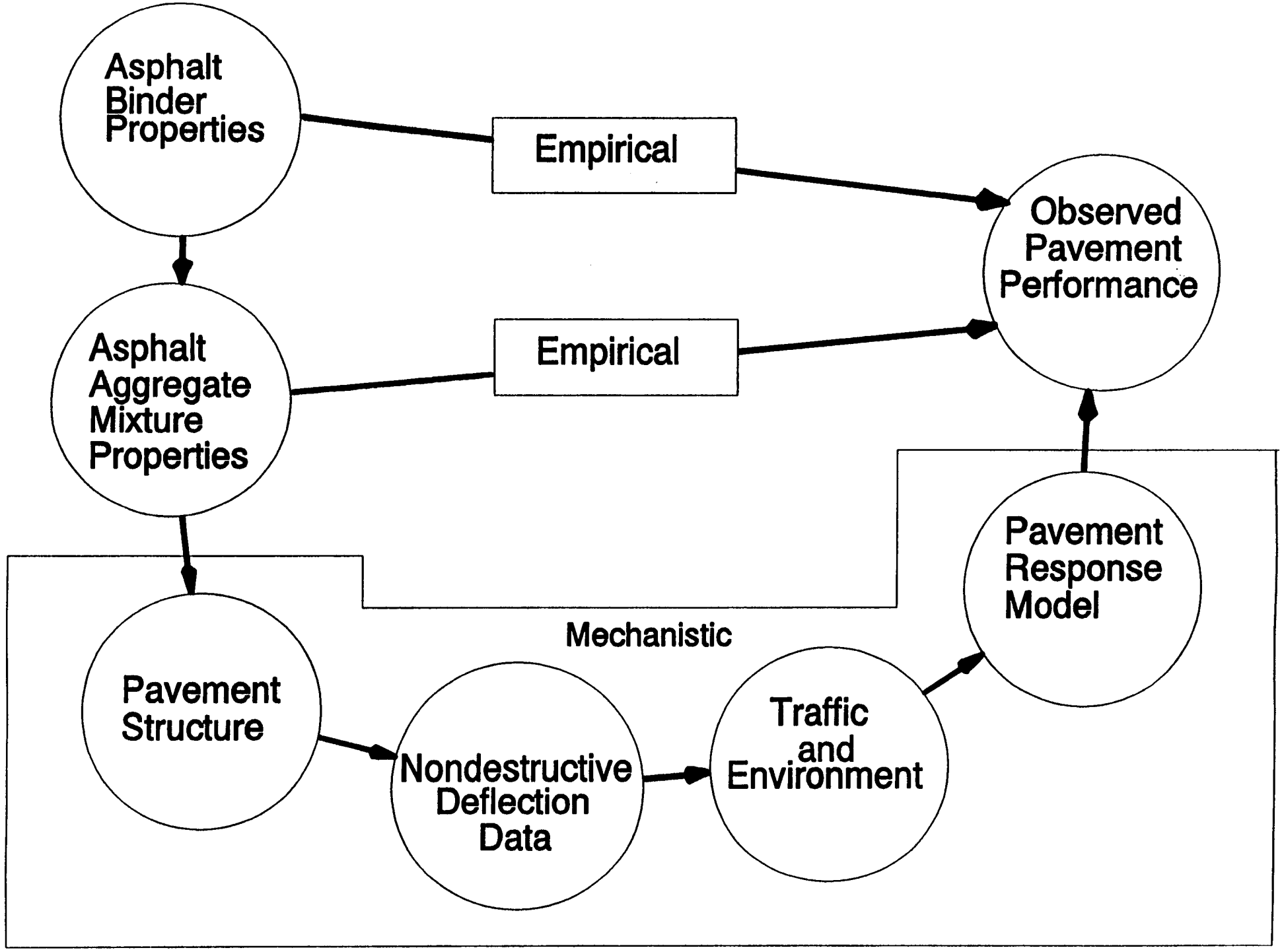
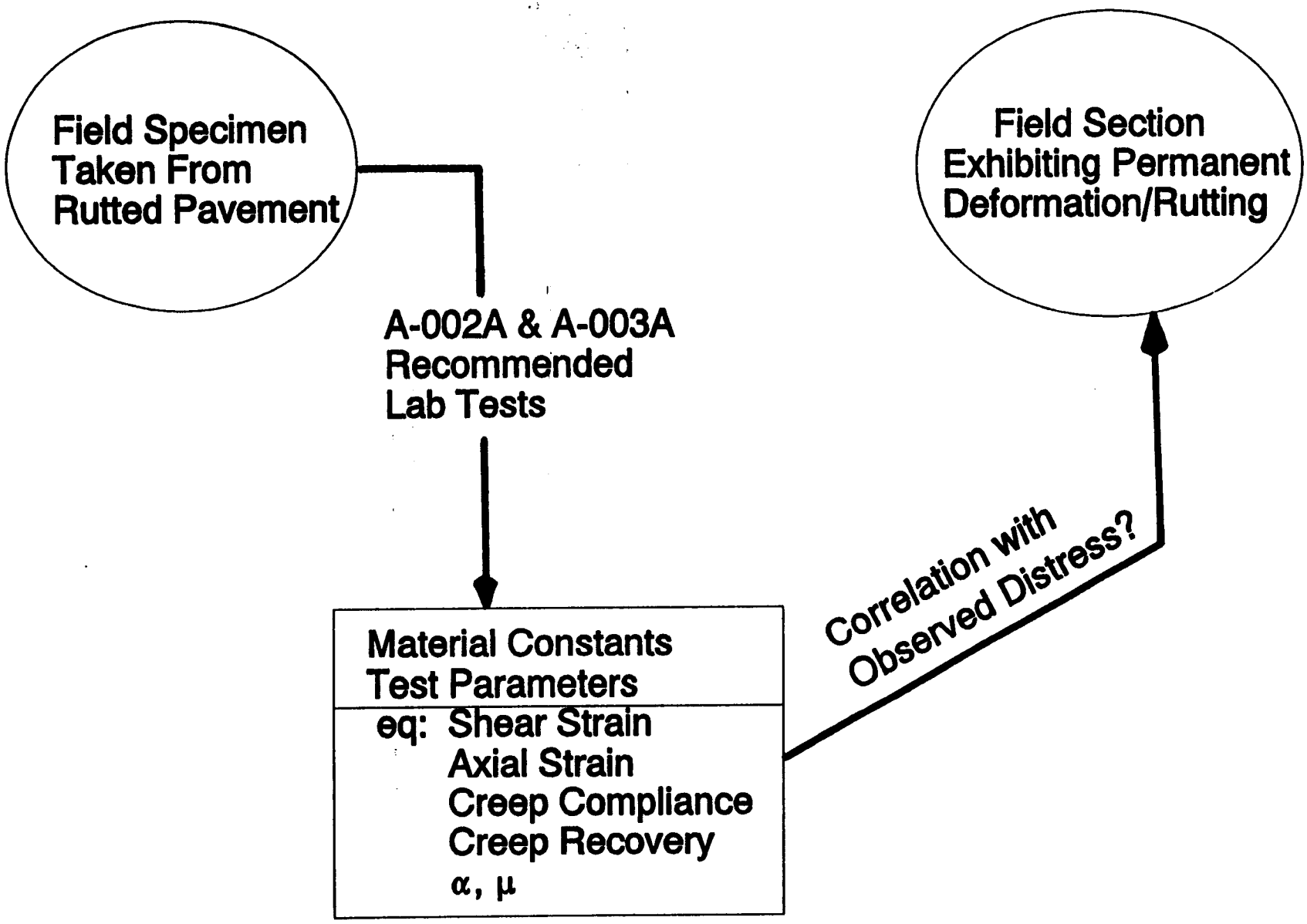


Figure 2. Flow Chart Illustrating the Two-Step Validation Process.

Figure 3. DIRECT/EMPIRICAL VALIDATION (eq: Permanent Deformation)



The advantage of this direct correlation method is that it can clearly demonstrate that a asphalt binder or mixture property directly affects pavement performance or that a laboratory test method is a true measure of field performance. However, in the real world the likely success of this direct correlation method is problematical. This uncertainty arises from the uncontrolled nature of the field pavements used in the analysis.

In the identification of field pavements a number of factors have been considered: materials, construction, traffic, environment, pavement condition, and availability of nondestructive test data. The LTPP GPS and NCHRP 9-6(1) AAMAS sites have provided the preponderance of data, although other potential sources of data including State Highway Agency controlled test sections and test tracks, and the FHWA's ALF (accelerated loading facility) at the Turner-Fairbank Highway Research Center have also been included where appropriate. The wide geographic distribution of test pavements yields a data base that encompasses the full range of environmental conditions and all the distresses at varying levels of severity. It is hypothesized that varying levels of distress within a geographic regions also ensures, to a large extent, a broad range of binders.

This use of GPS field pavements in the validation process, although eminently practical and dictated by the constraints of available resources and program deadlines, leaves open the possibility that

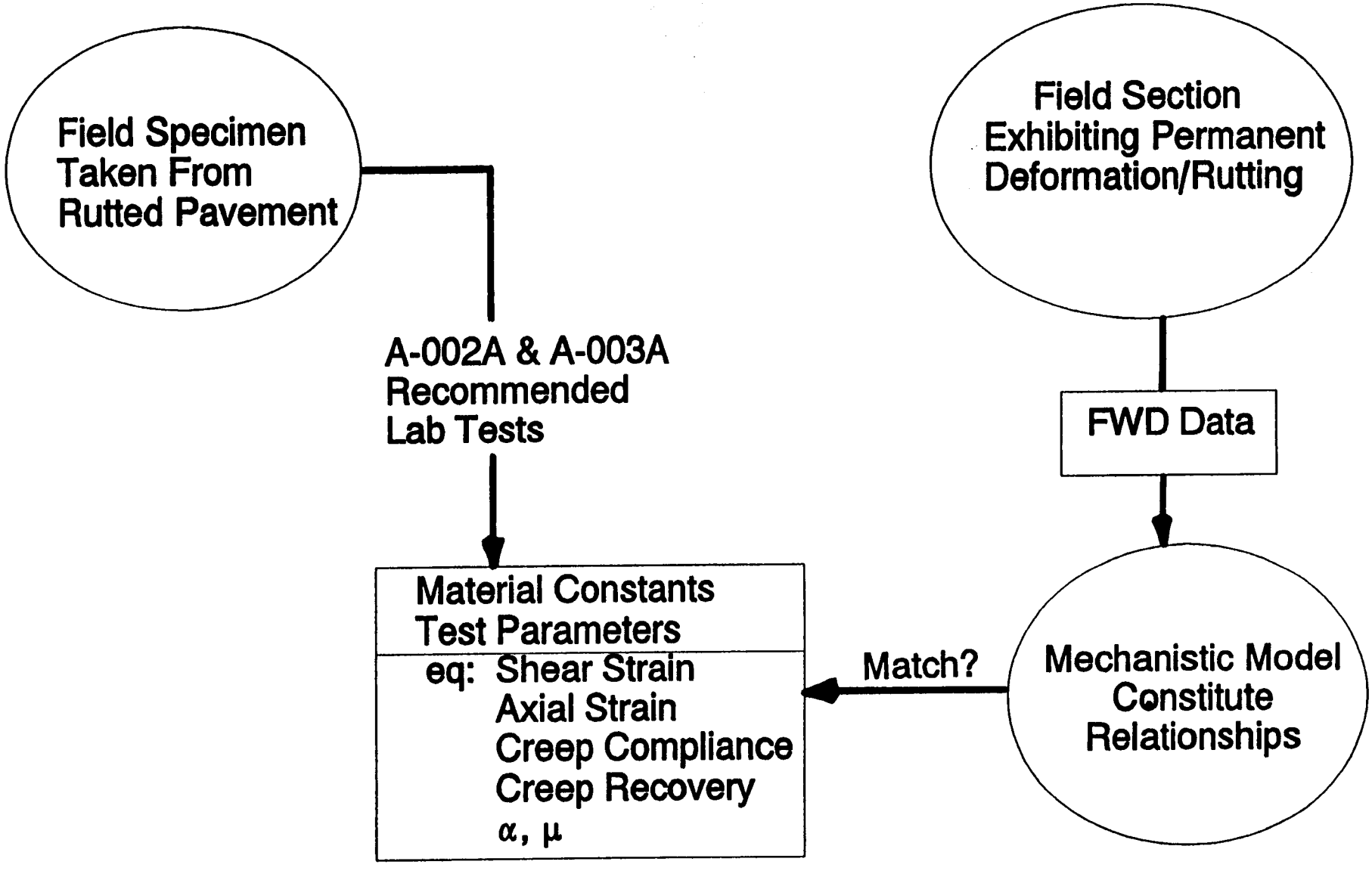
the precision of the analysis will be poor due to the lack of experimental control of key variables that affect pavement performance, e.g., traffic, climate, structure, subgrade, and construction and maintenance. Numerous constraints were imposed in the selection of GPS tests sections in the second stage validation process, but important factors such as age of the test section and drainage features could not be systematically controlled.

In these circumstances the absence of a direct correlation between a material property and field performance cannot be accepted as proof that no such correlation exists. An example may help to clarify this statement.

Figure 4 shows the direct approach to validation for the permanent deformation/rutting distress. Field specimens taken from rutted pavements are subjected to a series of laboratory binder and mix tests to determine the presence and range of specific chemical/compositional and physical properties which have been identified by the A-002A and A-003A contractors as related to permanent deformation. Significant (in the statistical sense) correlation between a laboratory-measured material property and the observed distress will strongly validate the property-distress relationship.

In an uncontrolled field experiment, the probability of finding a strong, direct correlation between a laboratory-measured parameter

Figure 4: INDIRECT/MECHANISTIC VALIDATION (eq: Permanent Deformation)



and observed pavement distress must be rated small. It is more likely that normalization of the pavement data to account for differences in traffic, pavement geometry and environmental conditions will be required. For example, the observed distress for two sections may indicate identical rut depths at the surface, but deformation within each layer may vary due to different geometries of the subbase and/or subgrade compaction and drainage conditions. Differences in traffic and environmental conditions may further confound the situation.

Thus, if the laboratory measured parameter (e.g. shear modulus) does not correlate with the observed distress (measured rut depth) then either of the following may be concluded:

The lack of correlation <u>is</u> due to the fact that the selected material property is <u>not</u> related to performance.

The material property <u>may be</u> related to performance, but factors such as traffic, environment, pavement geometry, subbase/subgrade support, etc, are also affecting the performance, and hence, the observed distress, and these factors must be accounted for in the analysis along with the material property.

Therefore, to provide proof beyond a reasonable doubt that the selected material property is related to the observed distress or

performance, its effect must be isolated from all the other aforementioned variables which contribute to the overall performance of the pavement structure. **Unless the data are normalized to identify the relative contribution of the other variables the direct validation approach is, at best, possible; at worst, suspect.**

The Indirect/Mechanistic Method

To address this potential shortcoming of the direct validation method, the A-005 contractor is simultaneously proceeding with a more complex **indirect/mechanistic** method of field validation (Figure 2). In this method, material relationships are used in mechanistic models to predict distress, whereas the direct approach attempts a simple correlation between material properties and observed distress.

The indirect/mechanistic method of field validation is illustrated in Figure 4 for permanent deformation/rutting distress. Falling weight deflectometer data (FWD) (e.g.: displacement, deflection basin, modulus) from each field pavement are used in conjunction with mechanistic models and constitutive relationships to generate values for the material properties/test parameters which characterize the permanent deformation potential.

Then, as in the direct validation approach, field specimens taken

from rutted pavements are subjected to a series of laboratory binder and mix tests to determine the presence of specific chemical/compositional and physical properties which have been identified by the A-002A and A-003A contractors as related to permanent deformation. With the indirect/mechanistic approach, generation of the material properties is the result of an iterative solution, thus requiring initial estimates of the parameters. If the laboratory determined material properties do not match those generated by the mechanistic models, the model coefficients may be adjusted iteratively until the predicted properties match the measured properties within acceptable limits.

The obvious advantage of this method compared to the direct approach is that it provides a mechanism to normalize and calibrate performance data from real-world, uncontrolled field pavements and to isolate the effect of material properties on performance from those of other internal and external factors. Moreover, the indirect method in theory permits a reasonable extrapolation of the performance predictive capabilities of the mechanistic models beyond the limits of the experimental data upon which it was based.

However, the indirect/mechanistic method has two significant disadvantages. First, those same mechanistic models that allow normalization and isolation of material property effects must be verified as a first step in the property-performance validation process. This, in effect, requires a doubling of the field

pavements included in the experiment design for validation. Second, the use of mechanistic models makes it more difficult to persuade non-specialists that the validation has been successfully accomplished since the one-to-one linkage between material property or test method and field performance obtained in the indirect method is obscured.

Summary of the Direct and Indirect/Mechanistic Methods

In summary, both the *direct* and *indirect/mechanistic* approaches to validation of binder and mix properties with GPS and other uncontrolled field performance data have drawbacks. The *direct* approach may suffice for the validation of A-002A and A-003A hypotheses, but the empirical/phenomenological relationships generated by the direct correlation of material properties or test parameters with observed distress will not necessarily provide all the fundamental engineering properties needed for structural design or performance prediction models. Also, such empirical relationships do not provide any explanation of the underlying physical principles involved in the material behavior, nor are they valid beyond the inference space from which they were constructed.

The *indirect* approach is an iterative solution that uses field data and mechanistic models to predict material properties/test parameters and explains the material behavior with constitutive relationships. However, it requires that the mechanistic models

also be validated, increasing the complexity of the process, and clarity of the approach to non-specialists and the highway community at large is problematical.

THIRD-STAGE VALIDATION (LTPP SPS-9)

The second-stage validation, involving the application of the direct and indirect approaches in parallel, offers the most effective use of the limited time and resources available to SHRP for the development of practical performance-based asphalt binder and mixture specifications.

Post-SHRP, third-stage validation will offer the opportunity for refinement of those specifications through the LTPP Specific Pavement Study (SPS) 9, Validation of Performance-Based Specifications and Mix Design and Analysis System. The SPS-9 experiment design considers in a statistically controlled manner the interaction of material properties, traffic, structural design and environmental factors to provide an accurate estimate of the relative influence of key factors on pavement performance.

If fully built out, SPS-9 will include 102 field pavements distributed among as many as 48 discrete climatic zones in the United States and Canada. Pavements will be constructed with both SHRP-defined and conventional material specifications and design methods. Pavement performance will be monitored and compared over

a period of 10 years or more.

As experimental data are obtained, further refinement of the specifications and design method will be made to improve their performance prediction capabilities. The controlled nature of the SPS-9 experiment will enable the various influences and interactions of materials, mixture design, pavement structure, climate, traffic and other factors on performance to be sorted out and weighted in a more straightforward, precise manner than is possible in the second-stage validation process using GPS pavement data.

SPECIFIC VALIDATION ACTIVITIES BY SHRP CONTRACT

Each main contract in the SHRP asphalt research program involves some validation activities. The primary objective of the A-003A and A-005 contracts is to validate that the asphalt binder and mixture specification properties and test methods are reasonably accurate measures of field performance. The A-002A and A-004 contracts have the responsibility of identifying chemical and physical properties of asphalt binders that are probable determinants of performance, and validating the correlation between the composition of asphalt binders and its rheological behavior. Finally, the A-001 contract is responsible for the development of the specifications and mix design and analysis system, including final selection of validated specification properties and supporting test and compaction

methods.

The following outlines the validation activities in progress in each major contract. Detailed experiment designs are contained in the appendices.

A-001

COMPACTION

Objective

- define protocol
  1) compare US mixes to French (2 x 2 partial factorial)
  2) variation on French protocol -- rotational speed (2 x 2 full factorial)

- validate gyratory compaction method
  use 4 x 8 ½ factorial
  evaluate compacted specimens with candidate tests
  compare to evaluation of rolling wheel compacted specimens

REPEATED LOAD AXIAL COMPRESSION TEST

Objective

- evaluate feasibility
  1) 4 x 8 ½ factorial of gyratory compacted specimens
  2) send gyratory compacted specimens to A-003A

A-003A

Objective

- validate ALTs

- validate candidate ALTs
  1) repeated load axial compression with both rolling wheel and gyratory compacted specimens
  2) simple shear with both rolling wheel and gyratory compacted specimens
  3) stiffness -- frequency sweep using gyratory compacted specimens with dissipated energy concepts

(same test matrix as used for fatigue
4) indirect tensile creep (same matrix as used for TSRST)
5) thermal stress restrained specimen test (TSRST)

A-005

Objective

- validate material properties by conducting candidate tests on field cores
  1) simple shear @ UCB
  2) repeated load axial compression @ TTI
  3) frequency sweep @ TTI
  4) indirect tensile test @ TTI/PTI
  5) TSRST (if necessary)

- direct correlation, viz, observed rut depth to material property generated by candidate test(s)
  (normalized for traffic, environment)

- indirect correlation
  1) models based on A-003A tests
  2) models based on A-005 tests
  3) models based on candidate tests

APPENDIX A

A-001 Validation Activities

A-001 VALIDATION ACTIVITIES

COMPACTION

The gyratory compaction protocol selected for the SHRP mixture design and analysis system matches the protocol as specified by the French LCPC Gyratory Press. Selection of this protocol was made to take advantage of the developmental experimentation done earlier by the French. The approach basically is to provide a modified gyratory using the following set of parameters:

- Angle of compaction -- 1°
- Vertical pressure -- 0.6 megapascals (87 psi)
- Speed of rotation -- 6 gyrations per minute

OBJECTIVE

The objective of this validation scheme is twofold:

- Compare a modified gyratory to the French compactor
- Validate that North American and French mixes compact similarly

VALIDATION PROCEDURES

The experiment will consist of compaction of various asphalt-aggregate mixtures. The number of controlled variables and levels of each is shown in Figure 5. A brief description of each variable and level follows.

Controlled Variable	Number of Levels
Compactors	2
Aggregates	2
Asphalts	2
AC Contents	3
Replicates	3

Figure 5. CONTROLLED VARIABLES IN COMPACTOR COMPARISON EXPERIMENT

Compactors

French Gyratory. This compactor is the gyratory compactor as developed by the LCPC in France. Arrangements must be made to compact specimens on a machine which is owned by the Ministre de Transport de Quebec. Alternately, arrangements will be required to compact specimens in France.

Modified Gyratory. The modified gyratory, which will be used in this experiment, is available at the Asphalt Institute. Modifications have been made to a six inch gyratory compactor. Specific modifications include a frequency controller which allows selection of gyration speed and a change in angle of gyration to one degree.

Aggregates

Two aggregates are proposed for the validation experiment.

Texas Chert Aggregate RL from the Materials Reference Library.

Watsonville Granite Aggregate RB from the Materials Reference Library.

Asphalt Cements

Two asphalt cements are proposed for the validation experiment.

AC 30 Asphalt Cement Asphalt cement AAK-1 from the Materials Reference Library.

AR 4000 Asphalt Cement Asphalt cement AAG-1 from the Materials Reference Library.

Asphalt Contents

Three asphalt contents are proposed for this experiment.

Optimum Optimum asphalt contents have been defined from a Hveem mix design for each of the combinations of Aggregates RL and RB with asphalt cements AAK-1 and AAG-1.

Optimum Plus Optimum asphalt content plus one percent.

Optimum Minus Optimum asphalt content minus one percent.

Replicates

Three replicate specimens are to be made for each combination of machine, aggregate, asphalt binder and asphalt content.

Factorial

A complete factorial with all cells of the experiment is shown in Figure 6. All of the cells are to be filled for the

Modified Gyratory. For the French Gyratory Compactor, specimens will be prepared for both aggregates at the design asphalt content. For one of the aggregates, RL, specimens will be prepared at all three asphalt contents.

The total number of specimens to be prepared is 48.

Figure 6. CELLS OF EXPERIMENT TO BE FILLED

		French Gyratory			Modified Gyratory		
		Opt-	Opt	Opt+	Opt-	Opt	Opt+
Aggregate RL	AC AAK-1	3	3	3	3	3	3
	AC AAG-1				3	3	3
Aggregate RG	AC AAK-1		3		3	3	3
	AC-AAG-1				3	3	3

NOTE: Number in cell represents number of specimens to be made.

REPEATED LOAD AXIAL COMPRESSION TEST

Simple test methods are necessary for the purposes of mix design, quality control and performance-based specifications. The repeated load axial compression test is considered by some European researchers as simulating in situ conditions more closely than static uniaxial creep tests. A-001 will determine the feasibility of this test in support of the performance-based mixture specification.

The repeated load axial compression test is carried out by pneumatically operated equipment. The specimen is subjected to repeated applications of the axial stress. The wave form is virtually square. The test may be conducted on laboratory compacted specimens or field cored specimens. The specimens have a height of 100mm and a diameter of 150mm. The ends of the specimens are trimmed to produce smooth surfaces for testing. To ensure negligible lateral constraint, silicon grease and graphite are applied to the ends of the specimen prior to testing. Tests will be conducted for a time period of one hour and the pattern of loading will be 0.2 seconds at 200 kpa load followed by a 1.8 second rest period. Both the loading port and the relaxation port of the deformation signal will be measured for data storage and subsequent analysis.

OBJECTIVE

- To evaluate the feasibility of the repeated load axial compression test for determining visco-elastic properties for use in fatigue and permanent deformation prediction.
- To validate the use of the repeated load axial compression test as a performance-based mixture specification test.

VALIDATION PROCEDURES

Asphalt Institute

The experiment will consist of a 4 x 10 factorial which is replicated. Four MRL aggregates and eight MRL core asphalts will be used in the experiment. In addition, two MRL asphalts will be modified to exhibit "good" and poor performance characteristics. The mix design will be the same used by A-003A for the accelerated laboratory test validation.

The Asphalt Institute will compact specimens using the modified gyratory compactor. Repeated load axial compression tests, each at three different temperatures (20, 40 and 60C), will be conducted by the Asphalt Institute. A total of 240 tests will be conducted. Figure 7 illustrates the factorial.

University of California at Berkeley (UCB)

The Asphalt Institute will compact specimens by the modified gyratory compactor and send to UCB. Specimens will be prepared for both the repeated load axial compression test and the cyclic shear test. The factorial design is a 2 x 6. Two MRL aggregates and four MRL core asphalts will be employed. In addition, two MRL asphalts will be modified. UCB will also compact specimens of the same asphalts and aggregate with the rolling wheel compactor.

UCB will conduct the repeated load axial compression test at three different temperatures on the modified gyratory and rolling

	Temp	AGGREGATE 1	2	3	4
1	T1 T2 T3				
2	T1 T2 T3				
3	T1 T2 T3				
4	T1 T2 T3				
5	T1 T2 T3				
6	T1 T2 T3				
7	T1 T2 T3				
8	T1 T2 T3				
Mod. AC	T1 T2 T3				
Mod. AC	T1 T2 T3				

2 specimens/cell

Figure 7. Experiment Design for Validation of the Repeated Load Axial Compression Test Conducted at the Asphalt Institute.

wheel compacted specimens. A total of 144 tests will be conducted. The cyclic shear test will be conducted by UCB on a duplicate set (24) of modified gyratory compacted specimens. Figure 8 illustrates the factorial design.

SWK Pavement Engineers

The Asphalt Institute will compact specimens by the modified gyratory compactor and ship to SWK in Nottingham, United Kingdom. Two MRL aggregates and four MRL core asphalts will be used in the experiment. In addition, two MRL asphalts will be modified. The factorial is similar to that discussed for UCB's evaluation except no rolling wheel compaction is included. SWK will perform repeated load axial compression tests at three different temperatures. A total of 72 specimens will be tested. Figure 9 shows the factorial.

In addition, SWK will perform repeated load axial compression tests for a 2 x 2 factorial under the A-003A project on cores taken from the Nottingham test track facility for evaluation to the laboratory compacted specimens.

Asphalt	Temp	Modified Gyratory Aggregate 1	Modified Gyratory Aggregate 2	Rolling Wheel Aggregate 1	Rolling Wheel Aggregate 2
1	1 2 3				
2	1 2 3				
3	1 2 3				
4	1 2 3				
Mod. AC	1 2 3				
Mod. AC	1 2 3				

2 specimens per cell

Figure 8. Experiment Design for Validation of the Repeated Load Axial Compression Test Conducted at the University of California at Berkeley.

Asphalt	Temp	Aggregate 1	Aggregate 2
1	1 2 3		
2	1 2 3		
3	1 2 3		
4	1 2 3		
Mod. AC	1 2 3		
Mod. AC	1 2 3		

2 specimens per cell

Figure 9. Experiment Design for Validation of the Repeated Load Axial Compression Test Conducted at SWK Pavement Engineers.

APPENDIX B

A-003A Validation Activities

A-003A VALIDATION ACTIVITIES

A-003A is actively involved with the first stage validation to confirm that variation of asphalt binder properties identified as probable, significant determinants of pavement performance yield physically reasonable, meaningful changes in relevant performance characteristics of asphalt-aggregate mixes. This is being accomplished by the use of highly simulative laboratory tests, specifically designed accelerated laboratory tests and existing accelerated load facilities.

OBJECTIVE

- To validate results from A-002A relating asphalt properties to performance.
- To validate results from A-003A accelerated laboratory tests relating mixture properties to performance.

VALIDATION PROCEDURES

1. **Validation of A-002A Test Results**

Specific testing has been scheduled for the University of Nottingham (UN), Oregon State University (OSU), CRREL and the University of California (UCB). Some of the A-002A validation activities will also be used for validation of A-003A accelerated load tests (ALT). Criteria for analysis of results should include, as a minimum, the ability to evaluate main effects (asphalt properties, aggregate properties) and two factor interactions (asphalt/aggregate, asphalt/voids, asphalt/asphalt

content, etc.).

Fatigue. (A) UN has scheduled 6 slab tests in their wheel track device for fatigue. This is the maximum within the time available at Nottingham. Due to the limited number of tests that are possible, it is not feasible to develop a rigorous experiment design for 16 asphalts. It is therefore recommended that A-002A select 6 asphalts considered to have widely different properties in fatigue for inclusion in this activity. The asphalts will be ranked according to their performance.

(B) The beam fatigue test is considered a failure (torture) test and can be used for validation of A-002A results and is included in Figure 1 for this purpose. The experiment design for beam fatigue testing is now being planned in two phases. Phase 1 will include only short term aged specimens without any special water conditioning. The results of Phase 1, with 2 aggregates and 16 asphalts, will provide sufficient information to rank the 16 asphalts to be included in this testing program. The results of Phase 2 will provide additional information to compare results of conditioned vs. unconditioned asphalt mixtures and to provide additional information relative to the influence of aggregates on performance of mixtures. By

taking advantage of Phase 1 test results, it is anticipated that the Phase 2 experiment will involve a reduced set of asphalts, selected from the original 16. In order to expand information relative to aggregates, two additional aggregates will be included in Phase 2.

The specific experiment design for Phase 1 is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of asphalt contents..... 1 (design)

Number of air voids..... 2 (4 ± 1%, 7 ± 1%)

Test conditions:

Temperature levels..... 1 (20C)

Stress levels..... 2

Aging (short term)..... 1

Moisture conditioning (none). 1

A full factorial test program is planned for Phase 1 requiring 256 tests, including two replicates. Aggregates for Phase 1 will be the RH and RD.

A tentative experiment design for Phase 2 is summarized as follows:

Number of asphalts.....4/8

Number of aggregates..... 4

Number of asphalt contents..... 1

Number of air voids..... 2

Test conditions:

Temperature levels..... 1

Stress levels..... 2

Aging (short term)..... 1

Moisture conditioning..... 1 (with water)

A full factorial test program is planned for Phase 2.

The following 4 aggregates are being considered for inclusion in the Phase 2 fatigue test program as described above: RH, RD, RC and RJ.

Rutting/Water Sensitivity. Two activities are scheduled to validate A-002A results at UN as follows: (1) 64 wheel track tests, to validate rutting, made on unconditioned 8 inch diameter specimens using a hard surfaced tire with 106 psi contact pressure, and (2) 40 wheel tracking tests on water conditioned specimens, to validate water sensitivity, using a hard surfaced tire with 29 psi contact pressure. The set of 40 tests is designed to identify water sensitivity of the asphaltic mixture using rutting as the objective function. The

specimen used in the water conditioning test is 305mm x 92mm in area and 25mm in depth and will be fabricated at OSU using a rolling wheel compactor. Each set of tests will include 16 asphalts and 2 aggregates.

This test program will provide information to rank the relative performance of the 16 asphalts incorporated in the test plan with and without water conditioning.

The specific experiment design for the 64 wheel tracking tests without water conditioning is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of air voids..... 2 low @ 4 ± 1%
high @ 7 ± 1%

Number of asphalt contents..... 1 (design)

Test conditions:

Temperature levels..... 1

Water conditioning (none).... 1

Total number of tests.....64

A full factorial test program is planned. It is not considered necessary to include any replicate tests with this number of degrees of freedom.

The specific experiment design for the 40 wheel track test with water conditioning is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of air voids..... 1 (high)

Number of asphalt contents..... 1 (design)

Number of replicates..... 8*

A full factorial test program is planned.

* Experiment design to be divided into 8 blocks with 4 cells in each block and 1 replicate in each block.

Total number of tests.....40

For these wheel track testing programs at UN, it is recommended that the RH and the RJ be used for the two aggregates. The RH can be considered as the control aggregate to be used in the fatigue wheel track tests and the RJ selection based on water sensitivity.

The UCB wheel track testing device will provide additional test data for validation of A-002A and A-003A findings relative to rutting and will provide a basis for comparing results obtained from the UN tests.

Thermal Cracking. The OSU thermal restrained specimen test (TRST) will be the methodology used to validate A-002A results for thermal cracking. The experiment design for the TRST program will include 16 asphalts and 2 aggregates. The recommended aggregates are the RH and RC.

The specific experiment design to be used with this activity is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of asphalt contents..... 1

Number of air voids..... 2

Test conditions:

Aging (short and long only).. 2

A full factorial testing program is planned for this activity. A one-quarter replication for short and long term aging conditions will be included in the test program. No water conditioning is considered necessary.

In order to accommodate the schedule, specimens will be prepared using a kneading compactor. A total of 160 tests will be required.

Water Sensitivity. The wheel tracking test included in the rutting program at UN will provide primary validation for the asphalt findings of A-002A as well as data for the mixture properties. The LCPC wheel tracking device at OSU will be used to compare results with those obtained by UN. The OSU program will duplicate the test plan at UN for the water sensitivity wheel track tests. Once the ALT tests are validated, they can also be used to estimate the rank order for the asphalts relative to water sensitivity. The ALT experiment design for water sensitivity is summarized in the section on validation of A-003A findings.

Aging. The low pressure oxygen/air triaxial test will be used for ranking the long term aging properties of 8 asphalts in combination with 4 aggregates. Loose samples of asphaltic mixtures in a forced draft oven at 135C for 4 to 6 hours will be used to simulate short term aging. Long term aging will most likely include pressure oxidation at two temperatures, i.e., 60C and one higher temperature, approaching 85C.

The specific experiment design for aging is summarized as follows:

Number of asphalts..... 8*

Number of aggregates..... 4

Number of asphalt contents..... 1 (design)

Number of air voids..... 1 (7 ± 1%)

Test conditions:

Aging conditions..... 3

(none/mixing, short term, long term)

Frequency..... From 0.01 Hz

Total number of specimens..... 96

A fractional, either one-quarter or one-half, replication will be included, depending on time requirements. The total number of tests will range from 120 to 144. The 4 aggregates for the aging program will be the RH, RC, RJ and RD. The primary objective will be to rank asphalts in accordance with the frequency sweep axial stiffness measurements associated with the aging process. These results will be of assistance in selecting asphalt-aggregate combinations to be used in Phase 2 of the fatigue testing program and Phases 2 and 3 of the A-003A validation plan for permanent deformation.

2. Validation of the Accelerated Load/Laboratory Tests (ALTs)

The working hypothesis for the validation is based on the ability of A-003A to develop prediction models from accelerated laboratory tests for each of the distress types and conditioning

procedures included in the A-003A project. Thus, from the laboratory tests, estimates will be made as to: (1) the influence of asphalt properties on mixture properties and predictions of performance, and (2) the relationship between mixture properties and performance.

The A-003A test plan is divided into two components: (1) an expanded ALT test plan to develop a set of hypotheses relative to the relationship of specific mixture properties and performance, and (2) validation of those findings in either a wheel tracking device, full scale test tracks or in-situ pavements.

Fatigue. The ALT test plan for A-003A, in 2 phases, was described in the A-002A validation experiment design. The validation of the A-003A findings will include comparisons of performance from the following tests:

Nantes (France).....does not incorporate MRL materials
(4 asphalts, 1 aggregate)

ALF (United States)..does not incorporate MRL materials
(1 asphalt, 1 aggregate)

UCB wheel track device...does incorporate MRL materials
(See Figure 1 for schedule)

UN slab tests - see A-002A validation

Rutting. The validation program for rutting is divided into three parts: (1) development of an accelerated load test, (2) development of a permanent deformation

law, and (3) validation of a deformation law based on test track results, or full scale tests.

Tentatively, the ALT test selected to relate rutting to material properties is a repeated load direct shear (cyclic shear) method used to calculate a dynamic shear modulus and such other properties as may be necessary for the prediction model. Asphalts can be ranked quantitatively according to results of the validated ALT tests; however, the preferred procedure will be to compare asphalts, and asphalt properties, on the basis of the predictive models for permanent deformation.

The experiment is divided into three phases. The specific experiment design for Phase 1 is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of asphalt contents..... 1

Number of air voids..... 2

Test conditions:

Moisture conditioning (none). 1

Temperature levels..... 1 (40C)

A full factorial test program is planned for Phase 1.

The aggregates for Phase 1 will be the RH and the RD.

The specific experiment for Phase 2 will be a replicate of Phase 1 except that samples will be exposed to water conditioning.

The objective of Phase 3 will be to provide information as to the influence of asphalt content on rutting and to expand the data to include two additional aggregates, specifically the RC and RJ.

The specific experiment design for Phase 3 is summarized as follows:

Number of asphalts..... 4
(Based on results from Phase 1)
Number of aggregates..... 2
Number of asphalt contents..... 2
Number of air voids..... 2

A full factorial is planned for this phase.

With regard to validation plans at UN, arrangements have been made to include 4 permanent deformation tests with their large pavement test facility to help validate A-003A rut depth prediction models. The materials will not be in the MRL, but will be available

to A-003A for testing at UCB. One of the 4 tests will include a modified binder.

A series of full size and in-service pavements will also be included in the A-003A validation program as follows:

In-service pavements.....no MRL materials

Selected LTPP sections.....no MRL materials

UN (see A-002A validation)...with MRL materials

ALF (U.S.).....includes materials routinely used by Virginia DOT but not currently in MRL. (Note: efforts are being made to include an asphalt meeting SHRP specifications for the rutting validation tests.)

UCB wheel track.....with MRL materials

Thermal. The ALT experiment design was summarized in the A-002A section of the report. The validation of the A-003A findings will include comparisons with the full size test facility at CRREL (FERF), as well as the various in-situ pavements.

Water Sensitivity. The ALT experiment design for water sensitivity is summarized as follows:

Number of asphalts..... 8 (core asphalts)

Number of aggregates..... 4

Number of asphalt contents..... 1

Number of air voids..... 1

Test conditions:

Levels of conditioning..... 3

* dry
* warm water soaking
* warm water soaking plus freeze-thaw

Test frequency..... 1

Specimens obtained by use of rolling wheel compactor.

A full factorial with one-quarter replication is planned for this activity.

The 4 aggregates will be the RH, RD, RC and RJ.

Validation of the ALT findings will, in part, be based on comparisons to results from the UN and LCPC test results included in the A-002A validation effort. In addition, a large number of field projects have been identified and are actively being investigated by the OSU staff. These in-service pavements will be used as case studies to help establish criteria for the interpretation of ALT results.

<u>Stiffness</u>. The ALT experiment design also includes a program to develop a test for stiffness modulus of

asphalt mixtures which will be sensitive to asphalt and mixture properties. The selected test, repeated load axial compression test or the cyclic shear test, will be considered for quality control during construction or possibly for initial mix design estimates.

The specific ALT experiment design is summarized as follows:

Number of asphalts.....16

Number of aggregates..... 2

Number of asphalt contents..... 2

Number of air voids..... 2

Test conditions:

Moisture conditioning..... 1

Aging..... 1

Temperature..... 3 (0C, 20C, 40C)

Frequency..... as needed for master curve

A full factorial of tests are planned for this program.

Specimens will be prepared with the rolling wheel compactor.

<u>Aging</u>. Various in-service pavements will be used to establish criteria for the aging ALT. Specific examples include:

Short term - Oregon DOT

Long term - Oregon DOT

AAMAS

LCPC

SPS (5, 6)

A-003A ALT

<u>UCB Wheel Track</u> - Current plans include a series of wheel track simulation tests on the UCB device. The objectives of the testing program will be to: (1) validate the prediction models for fatigue and permanent deformation, and (2) validate the findings of the ALT program. Once the ALT tests are validated, the laboratory test results can be used to evaluate, both qualitatively and quantitatively, the influence of asphalt binder on the performance of asphaltic mixtures.

Current plans also include a limited series of tests on large stone mixtures. The exact number and experiment design have not been established at this time.

3. Other Validation Activities

Repeated Load Axial Compression Test

The Asphalt Institute will compact specimens by the modified gyratory compactor and send to A-003A. Specimens will be prepared for both the repeated load axial compression test and the cyclic shear test. The factorial design is a 2 x 6. Two MRL aggregates and four MRL core asphalts will be employed. In addition, two MRL asphalts will be modified. A-003A will also compact specimens of the same asphalts and aggregate with the rolling wheel compactor.

A-003A will conduct the repeated load axial compression test at three different temperatures on the modified gyratory and rolling wheel compacted specimens. A total of 144 tests will be conducted. The cyclic shear test wil be conducted by UCB on a duplicate set (24) of modified gyratory compacted specimens.

Indirect Tensile Creep Test

A-003A will prepare specimens from the thermal restrained specimen test (TSRT) factorial and send these specimens to the A-005 contractor for comparison of the material properties derived from the indirect tensile creep test. A-005 will conduct 16.7 minute (1000 sec.) creep tests at four temperatures necessary to define the entire master stiffness curve (-10°C to 30°C).

Modified Mixtures

A certain level of testing of modified mixtures will be done by A-003A. The A-004 contractor will prepare modified mixture specimens and ship to A-003A. Testing will be conducted by A-003A in accordance with specified candidate ALTs. The specific details of the specimen preparation protocol, experiment design and testing are presently under development.

APPENDIX C

A-005 Validation Activities

A-005 VALIDATION ACTIVITIES

In A-005's original Workplan, all activities were directed towards accomplishing four objectives. The two objectives related to validation are:

Objective 1 - Using field performance data, establish criteria for asphalt binder and mixture specifications.

Objective 2 - Develop field performance models for asphalt binders and asphalt-aggregate mixtures.

To establish these 2 objectives, A-005 activities can be divided into three separate validation areas. These are:

* Selection of "real" pavement sites for measuring pavement distress and material properties or data collection. The experimental plan for collecting this information is discussed in a latter section.

* Establish the degree of correlation between the asphalt binder and mixture properties (used in the initial binder and mix specification) and pavement performance or data analysis.

* Calibrate the limits for the material properties used in the specification to control pavement distress or

model calibration.

All of these activities are confined in the Stage 2 validation area, as previously discussed. This validation effort will be accomplished in a two-step process, as shown on Figure 2. These two steps are listed below.

* Step 1 is the direct/empirical approach. On the surface, this is the straightforward simple approach. **BUT**, it is the one with the highest risk of failure to validate the material properties and the specification criteria and limits.

* Step 2 is the mechanistic approach. This approach is the more complicated one, but is theoretically more reliable or less risky. More importantly, it can also be used to establish the criteria for setting the specification limits.

Both of these steps are discussed below as they pertain to A-005, and are shown in flow chart form in Figures 10 and 11 for the binder and mixture tests, respectively.

EXPERIMENTAL PLAN

The A-005 experimental plan for the validation effort is shown in Figure 12. The experiment is divided into two parts: one for the load related sites and one for the non-load related sites. These were separated so that the total number of cores

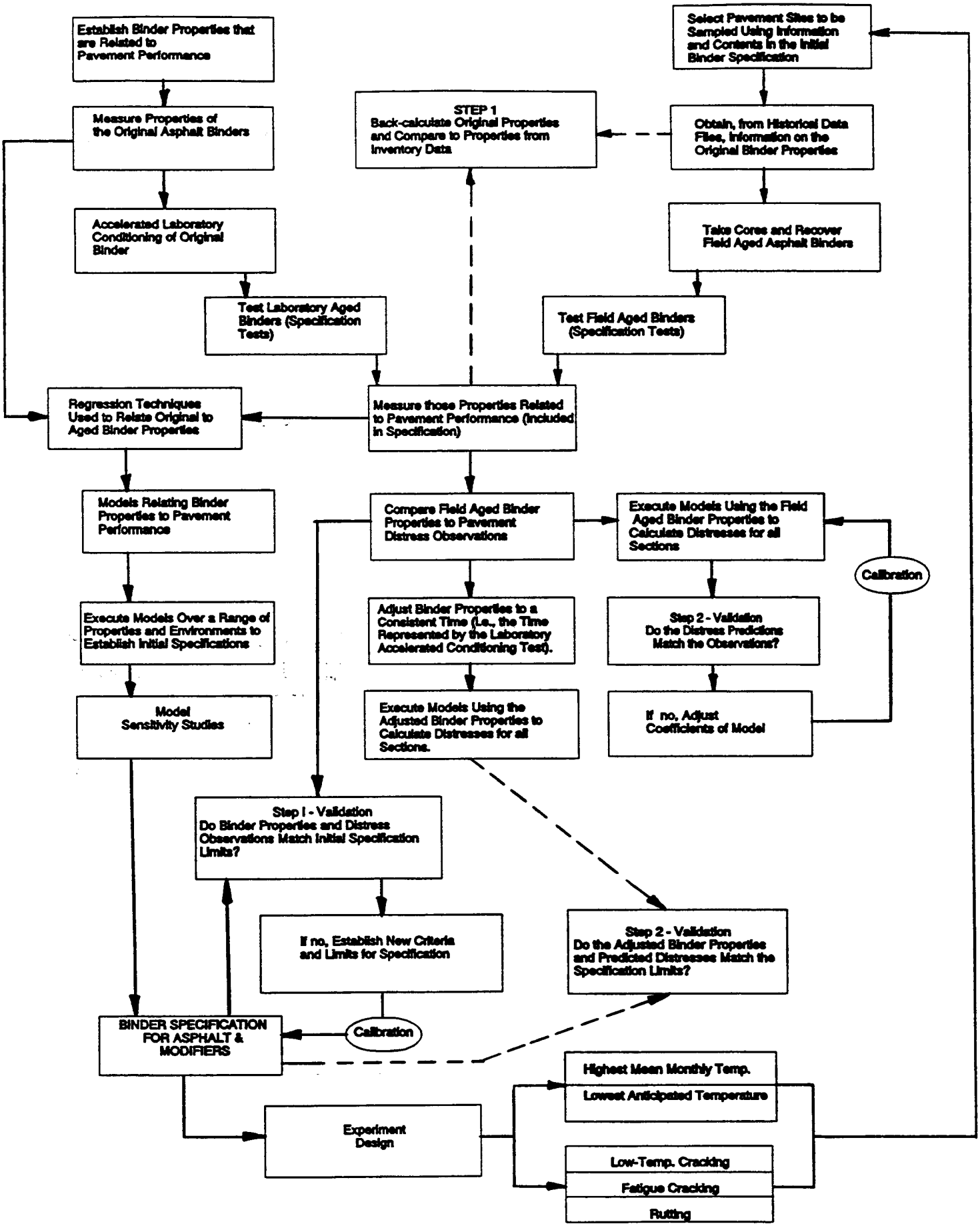


Figure 10. Flow Chart Illustrating the Different Steps Included in the Empirical and Mechanistic Validation Procedure of the Binder Specification.

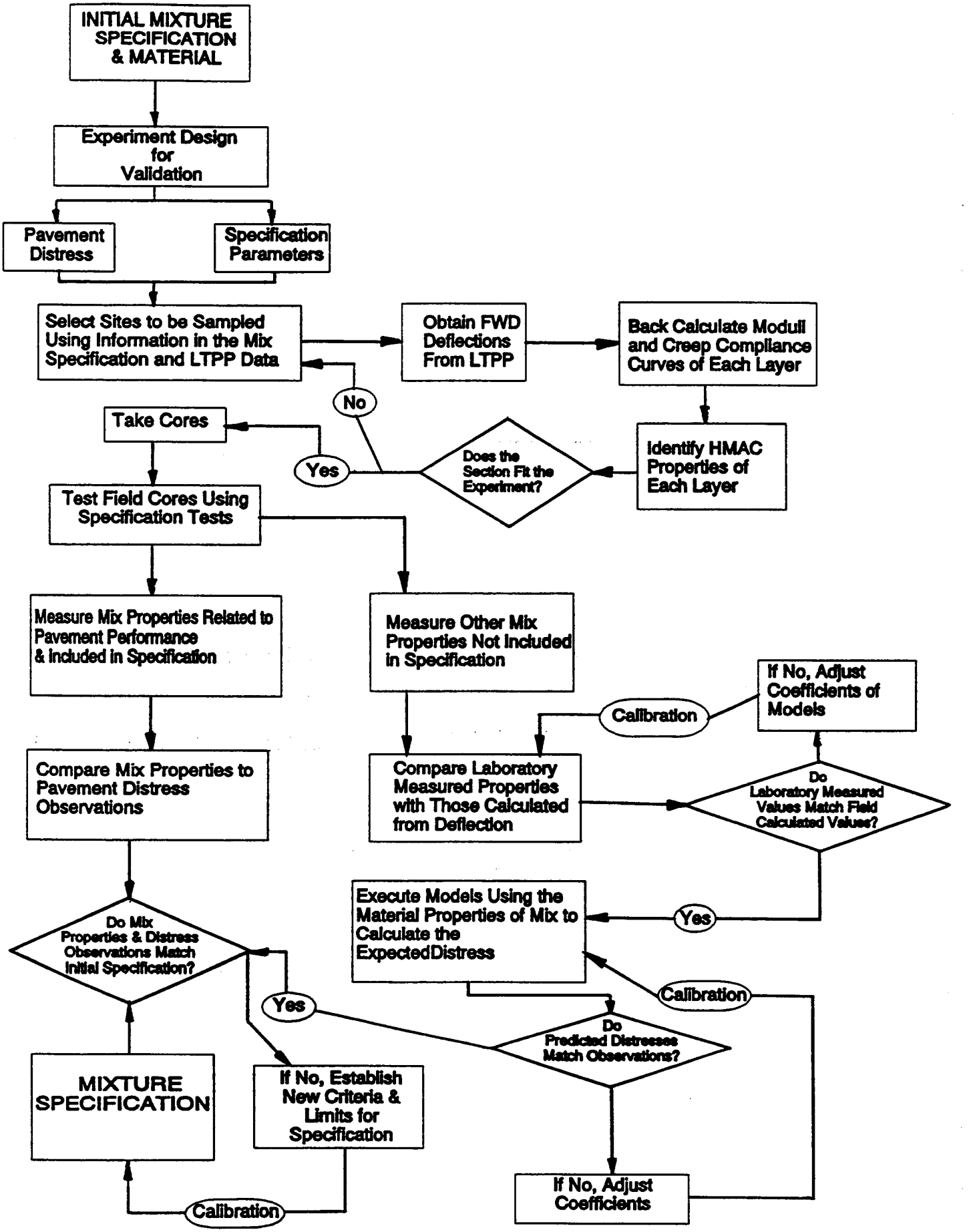


Figure 11. Flow-Chart Illustrating the Different Steps Included in the Empirical and Mechanistic Validation Mixture Procedures for the Mixture Specification

SHRP A-005 MODIFIED EXPERIMENTAL DESIGN

Load Related Experiment 12a.

MOISTURE / TEMPERATURE / FATIGUE CRK RATE / PERM DEFOR RATE		WET		DRY	
		FREEZE	NO-FREEZE	FREEZE	NO-FREEZE
H	H	2C 2V [10]	2C 2V [10]	2C 2V [10]	2C 2V [10]
	L	2C 2V [10]	2C 2V [10]	2C 2V [10]	2C 2V [10]
L	L	2C 2V [10]	2C 2V [10]	2C 2V [10]	2C 2V [10]

2 Sites for Verification

2 Sites for Calibration

Non-Load Related Experiment 12b.

MOISTURE / TEMPERATURE / THERMAL CRK RATE	WET		DRY	
	HARD FREEZE	FREEZE-THAW	HARD FREEZE	FREEZE-THAW
H	2C 1V [1]	2C 1V [10]	2C 1V [10]	2C 1V [10]
L	2C 1V [10]	2C 1V [10]	2C 1V [10]	2C 1V [10]

1 Site for Verification

2 Sites for Calibration

Figure 12. A-005 Factorials for the Load and Non-Load Related Experiments

from any one site would be less than 50, and to keep the inter-relationship between distresses out of the experiment, if at all possible.

The plan includes 48 GPS sites for the load related experiment, and 24 sites for the non-related experiment. Thirty-six to forty-six cores are being recovered from each of these sites. Test specimens will be extracted from these cores for various tests. The tests planned to be performed on material recovered at each site are listed below, along with the organization responsible for conducting the tests:

Load Related Experiment (Figure 12.a)

* Cyclic Axially Loaded Shear - UCB
* Repeated Load Axial Compression Test - TTI
* Repeated Load Axial Tension Test - TTI
* Frequency Sweeps using Tensile Loading - TTI
* Direct Tensile Strength Test - TTI
* Volumetric Tests - TTI
* Repeated Load Axial Compression Test

Non-Load Related Experiment (Figure 12.b)

* Dynamic Rheometer Test - PTI
* Bending Beam Test - PTI
* Direct Tensile Test - PTI
* Indirect Tensile Creep Test - PTI
* TSRST (if applicable to field cores) - TTI

* Volumetric Tests - TTI

(Note: UCB = University of California at Berkeley; TTI = Texas Transportation Institute; PTI = Pennsylvania Transportation Institute)

STEP 1 - DIRECT/EMPIRICAL APPROACH

The direct/empirical approach is similar to what LTPP is doing, with the exception that LTPP has over 800 GPS sites plus numerous SPS sites across the U.S. LTPP (for the most part) is only performing physical tests (i.e., gradations, moisture contents, Atterberg limits, moisture-density relationships, etc.). Only one surrogate test is being used to measure a mechanical property (resilient modulus). In order for the asphalt program to be successful, fundamental material properties of the binder and mix (chemical and mechanical) must be determined. These fundamental properties include a barrage of tests on the binder and mixture. Those included in the validation study are listed below:

Binder Tests - Dynamic Rheometer Test
- Bending Beam Test
- Direct Tensile Test

Mixture Tests - Cyclic Axially Loaded Shear Test
- Repeated Load Axial Compression Test

- Indirect Tensile Creep Test
- Repeated Load Axial Tension Test
- Direct Tensile Strength Test
- Frequency Sweeps using Tensile Loading
- TSRST (if applicable to field cores)

The test outputs and material properties calculated from these tests will be correlated to the distress observations made at each of the validation sites. Thus, data set A (material properties) are being correlated with data set B (distress observations).

To do this, the experiment design should be controlled (same supporting conditions, traffic levels, pavement geometry, etc.) to validate the asphalt concrete material properties and, more importantly, establish criteria for developing the specifications. Unfortunately, the LTPP GPS sites are uncontrolled. Sites were selected for the validation by considering varying levels of distress, different types of distress, and those factors related to each distress, in addition to binder and mix properties. Thus, the experiment or site selection was controlled to the same degree.

Why is Step 1, the direct/empirical approach, so risky? Stated simply, because the pavement is a structure or system composed of different materials, and the distresses measured at the surface are dependent (to different degrees) on traffic, environment, layer thicknesses, selected material properties of

each layer in the pavement structure (base, subbase and subgrade). Any analysis of these two sets of data will be confounded by inflated variabilities, because we are not directly considering all of the important parameters.

For example, GPS Sites 123995, 281001, 351022, and 40164 have the pavement structures and materials, as listed in Figure 13. These are actual sites included in the validation effort. Are the differences in cracking and rutting caused by different mix properties, different traffic levels, different layer thicknesses, different supporting conditions, different climatic conditions, or a combination of all of the above?

The A-005 contractor has recognized these risks and considered them in the development of the validation plan. The plan uses the inventory and field data collected by the Regional Coordination Offices for selecting those sites with the most beneficial information for validation purposes.

The most important pieces of information are the layer geometry and FWD deflections. The entire time-deflection-load histories were recorded during testing, not just peak load and deflection. This information and data will be used to back calculate layer moduli (from the peak deflections) and compliance curves (from the time dependent data) for each structural layer in the pavement, including the subgrade. These values and relationships were used for selecting those sites with significant differences in asphalt concrete mix properties, as well as differences in surface distress observations. Of course,

GPS Site 404164
Fatigue Cracks = 0
Rutting = 0.6 inches

1.5" HMAC AC = 5.2% Air Voids = 2.0%
3.1" HMAC AC = 4.3% Air Voids = 2.0%
7.6" Sand Asphalt
Silty Clay Subgrade

GPS Site 281001
Fatigue Cracks = 4,000 $ft.^2$
Rutting = <0.1 inches

1.0" HMAC
2.7" Sand Asphalt AC = 5.8% Air Voids = 2.7%
6.0" HMAC AC = 5.1% Air Voids = 4.9%
Sand-Soil Subbase
Clay Subgrade

GPS Site 351022
Fatigue Cracks = 0
Rutting = <0.1 Inches

0.8" PFC
5.5" HMAC AC = 5.6% Air Voids = 3.8%
Crushed Stone Base
Silty Sand Subgrade

GPS Site 123995
Fatigue Cracks = 4,000 $ft.^2$
Rutting = <0.1 inches

1.1" PFC
3.9" HMAC AC = 5.6% Air Voids = 6.4%
Crushed Stone Base
Silty Sand Subgrade

Figure 13. Example of Four GPS Sites Included in the A-005 Validation Effort

specimens from the asphalt concrete cores recovered from each GPS site will be tested and evaluated in the laboratory. This laboratory data will be used in the correlation.

If Step 1 is successful, no additional validation work will be necessary. But if Step 1 is unsuccessful, because of the reasons noted above: What is the plan of action? The plan is to implement Step 2.

STEP 2 - MECHANISTIC APPROACH

The mechanistic approach is to perform those same tests, as listed under Step 1; however, data set A is not directly correlated to data set B. Data set A, the material properties, are used to predict pavement distress (fatigue cracking, thermal cracking and rutting) for each site using a pavement response model. This allows the evaluation technique to consider traffic, environment and structure. A-005's current plan is to use approximately one-half of the sites for model calibration and the other one-half for validation. Figures 10 and 11 illustrate the different calibration steps in the overall validation process.

These predictions of distress become data set C, which are directly compared to data set B (distress observations). This normalizes the varying effects of traffic, support conditions, environment and pavement geometry at the different GPS sites. In this manner, the differences between asphalt concrete mix properties at each of the sites can be evaluated as to their effects on pavement distress. Once the sensitivity of the

distress to the material property is established, the criteria and limits included in the specification can be validated. The probability of success using this approach is very high and requires much fewer sites for the validation effort.

For the mixtures included in the load related experiment, fundamental material properties from each of the sites will be calculated and compared. These material properties will also be used to predict pavement distress observed at each site to determine the error associated with each test. This information will be used to determine if a simpler or more economical test can be used in place of the accelerated test without a significant loss of accuracy.

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