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Asphalt Pavement Analyzer (APA) Evaluation

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16. Abstract (Limit: 200 words)

Rutting in an HMA or overlay pavement can occur in any or a combination of the layers. The rutting module of MnPAVE currently relates the development to the vertical strain on the subgrade. Rutting can also occur primarily in the HMA layer(s) due to low shear strength of the mix.

The literature search has shown that a number of devices have been used to directly determine the susceptibility of a given mix to rutting. Of these, the Asphalt Pavement Analyzer (APA) is the most accepted.

Based on the literature search and questionnaire it is recommended that the Minnesota DOT should purchase an Asphalt Pavement Analyzer (APA) because:

- It provides a measure of rutting susceptibility of a given HMA
- The device has been used by over 60 agencies and contractors.
- The users group will provide a forum for support and discussion of how best to setup evaluations and use information for correlation with other parameters and possible use in performance based specifications.
- Procedures for conducting the test are available in ASTM and AASHTO formats.
- Preliminary criteria are available from previous studies.
- The APA is reasonably reliable and repeatable.

Performance evaluations both in the field and with the APA should make it possible to determine which variables do and do not have a significant effect on the rutting performance of Minnesota HMA mixtures.

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ASPHALT PAVEMENT ANALYZER (APA) EVALUATION

Final Report

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Executive Summary

The purpose of this report was to research the use of the Asphalt Pavement Analyzer (APA) as a tool for evaluating the rutting susceptibility of Minnesota Hot Mix Asphalt (HMA). The Minnesota Department of Transportation (Mn/DOT) is considering the purchase of an APA.

Rutting in an HMA or overlay pavement can occur in any or a combination of the layers. The rutting module of MnPAVE currently relates the development of rut depth to the vertical strain on the subgrade. The subgrade strain can be reduced by increasing the thickness or stiffness of the pavement layers which then reduces the predicted development of rutting.

Rutting can also occur primarily in the HMA layer(s) due to low shear strength of the HMA mix. Superpave mix design has attempted to increase the shear strength by requiring coarse aggregate with some fractured faces and manufactured sand with angularity measured by the Fine Aggregate Angularity (FAA) test. Volumetrics of the HMA such as total voids (V_t), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), etc have also been specified to help insure a stable and durable mixtures.

The literature search has shown that a number of devices have been used to more directly determine the susceptibility of a given mix to rutting; the

1. Asphalt Pavement Analyzer (APA)
2. Hamburg Wheel Tracking Device (HWTD)
3. French Pavement Rut Tester (FPRT), and
4. PURwheel

Of these, the APA is the most accepted. It can be used with beam or cylindrical specimens tested under controlled temperature and/or dry or soaked conditions. The results from any of these tests can only be used as an index of rutting susceptibility because the mechanistics of the test procedures can not be easily defined.

A questionnaire was developed and sent to the members of the APA Users Group. The 25 responses indicated that most of the users are satisfied with the results and reliability of the APA. They indicated that 150-mm (6-in.) cylindrical specimens compacted in the Superpave Gyratory Compactor (SGC) were used for rut susceptibility evaluations. Tests were conducted dry and very few used the flexural beam mode and none tested for friction.

Based on the literature search and questionnaire responses the following recommendations are made:

2. Mn/DOT should purchase an APA because:
   - It provides a measure of rutting susceptibility of a given HMA
   - The APA has been used by over 60 agencies and contractors with good success

- The users group will provide a forum for support and discussion of how best to setup evaluations and use information for correlation with other parameters and possible use in performance based specifications.
- Procedures for conducting the test are available in American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Official (AASHTO) formats.
- Preliminary criteria have been established from previous studies.
- Responses to the questionnaire used for this study indicate that the APA can be used as a good empirical tool for measuring rutting susceptibility and the test results are reasonably repeatable and reliable.

3. Evaluation of Minnesota HMA mixtures should be conducted:
    - Using the APA with 150-mm (6-in.) cylindrical specimens compacted in the SGC.
    - Using APA criteria cuttently developed by a number of agencies. A typical criterion is a maximum of 7 mm (0.28 mm) rut depth at 8000 cycles. The number of cycles should be varied depending on the design traffic for the HMA being evaluated.
    - Defining "Rutting Equivalent Standard Axle Loads (ESALs)" for various locations around Minnesota. MnPAVE software can be used to predict temperatures in the HMA. Currently, "Rutting ESALs" are defined using the number of days the air temperature is above 10C (50F) (10).
    - Setting up an experiment using HMA mixes from around Minnesota to evaluate the effect of selected parameters on rut susceptibility. The effect of air voids, asphalt content, Performance Grade (PG) of the asphalt, etc should be used. Ten variables are listed in Section5.1.2.2. The parameters should be studied in a controlled laboratory setting. HMA mixtures with good, fair and poor field rutting performance should be studied. APA failure criteria can then be established.
    - Developing and conducting a factorial experiment to establish the effect of air voids, VMA, asphalt content, film thickness and other volumetric parameters to establish their effect on rutting performance.
    - Conducting dynamic modulus tests on the HMA mixtures studied above so that rutting performance can be predicting using a mechanistic design procedure such as MnPAVE or AASHTO 2002.
    - Conducting field and laboratory testing to determine to determine which variables which correlate with field and APA performance. A list of variables is presented in Chapter 5.

    The performance evaluations both in the field and with the APA should make it possible to determine which variables do and do not have a significant effect on the rutting performance of Minnesota HMA mixtures.

4. Develop a relationship between APA rut depth performance and dynamic modulus for the mixes. The APA and dynamic modulus testing should be conducted at the same temperatures.
5. Develop a comprehensive database for Minnesota HMA mixes. Parameters suggested for the database are presented in Section 5.2. The database will make it possible to track good and poor field performance and evaluate which parameters correlate best with rutting performance.

In the next year Fine Aggregate Angularity (FAA), the percentage and type of recycled asphalt pavement (RAP) and other parameters will be studied. The APA can be a good evaluation tool for studying the effect of these parameters.

CHAPTER 1.
INTRODUCTION AND BACKGROUND

1.1 Introduction

Rutting, in hot mix asphalt (HMA) pavements has been a major problem for many years but now especially with greater wheel loads and higher tire pressures. Permanent deformation or rutting occurs as longitudinal depressions in wheel path. This type of distress may occur due to repeated application of high stresses on the subgrade or by inadequate shear strength of the Hot Mix Asphalt (HMA). Rutting may be caused by inadequate structure which results from pavement layers which are too thin or weakened subgrade due to moisture or poor compaction. Rutting can also occur due to low shear strength in the HMA, which results in accumulation of unrecoverable strain resulting from applied wheel loads. This results in a combination of consolidation and/or lateral movement of the HMA under traffic. Shear failure (lateral movement) in a HMA pavement generally occurs in the top 100 mm (4 in.)*(*1). Rutting decreases the useful life of a pavement and creates a safety hazard. Higher traffic volumes and the increased use of radial tires (higher inflation pressures) have increased the potential for rutting.

For state and local transportation agencies identifying HMAs that may be prone to rutting is of great use for design and Quality Control / Quality Assurance (QC/QA) purposes. Some transportation agencies and contractors have begun using the Asphalt Pavement Analyzer (APA) to identify HMAs that may be prone to rutting as a supplement to their mix design procedure. The APA allows for an accelerated evaluation of rutting potential after volumetric design. A typical testing time for a complete rutting evaluation is 135 minutes (8000 cycles). Permanent deformation (rutting) susceptibility of mixes is assessed by placing a beam or cylindrical samples under repetitive wheel loads and measuring the permanent deformation. The APA features an automated data acquisition system, which obtains rutting measurements and displays these measurements in a numeric and/or graphical format. Five measurements can be taken during a single pass.

The APA features controllable wheel load and contact pressure that are representative of actual field conditions. Each sample can be subjected to a different load level up to 113 kg (250 lb) resulting in contact pressures of 1378 kPa (200 psi). Three beam samples or six cylindrical (gyratory, vibratory, Marshall samples, roadway cores) samples in three sample molds can be tested under controllable temperature and in dry or submerged environments. The most common method of compacting beam specimens is by the Asphalt Vibratory Compactor. The most common compactor for cylindrical specimens is the Superpave Gyratory Compactor (SGC). Beams are compacted to 7 percent air voids, while cylindrical samples are compacted to 4, 7 percent or other air void contents. Tests can also be performed on cores or slabs taken from an in-service pavement.

The APA can also be used to test asphalt concrete beam samples for fatigue. Fatigue cracking resistance of asphalt concrete can be determined by subjecting beam samples to a repeated wheel load of controllable magnitude and contact pressure in a low temperature environment. The automated data acquisition system includes a computer, monitor and software for measuring rutting and fatigue.

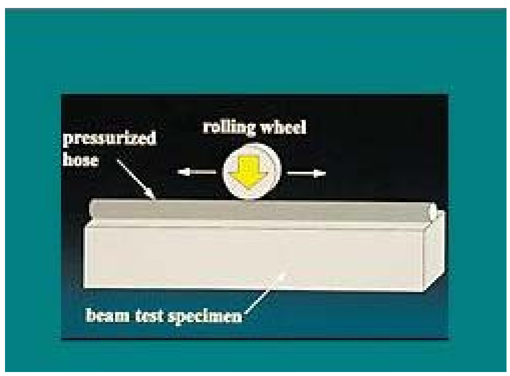

Figure 1.1. Asphalt Pavement Analyzer

The APA is manufactured by Pavement Technology Inc., (PTI) Covington, GA, is a multifunctional Loaded Wheel Tester (LWT) for lab use. It evaluates permanent deformation (rutting), fatigue cracking and moisture susceptibility of hot or cold mixes by subjecting mix samples, placed in a test chamber, to repetitive wheel loads (A wheel is loaded onto a pressurized linear hose and tracked back and forth over a testing sample to simulate a wheel load). After placing up to three rectangular or six cylindrical samples in the chamber, the operator adjusts the chamber temperature as needed from 5 to 70 C (41 to 160 F). The APA is designed to perform rut tests on three different samples simultaneously, either wet or dry. It is designed to simulate actual road conditions by rolling a concave metal wheel over a rubber hose pressurized at 689 to 827 kPa (100 to 120 psi) to generate the effect of various tire pressures. Since the three metal wheels sit on separate beams, each sample can be subjected to a different load level.

The APA is 0.9 m (2.9 ft) wide, 1.78 m (5.7 ft) high and 2.03 m (6.5 ft) long. It weighs 1357.4 kg (3000 lb). It features retractable legs with wheels to make it portable and is anchored while in use. Manual or automated modes can be used. The automated option allows the user to obtain measurements via personal computer. Appendix A is the recommended APA testing procedure in American Society for Testing and Materials (ASTM) format and Appendix B is the procedure in American Association of State Highway and Transportation Officials (AASHTO) format.

1.2 Use of Asphalt Pavement Analyzer (APA) Increases

Several state highway agencies now use the APA to screen mix designs in specific situations. Georgia and Utah require all mix designs to pass as part of a performance based specification. A handful of other states require the test only for mixes passing through the Superpave restricted zone or other similar situations. Most states, however, have yet to find the level of confidence needed to utilize the test to accept or reject mixtures. Several researchers also continue to experiment with other uses of the APA including moisture damage tests, fatigue tests, and a friction test.

With some modification in sample preparation and test temperature, the APA has the potential of being able to perform fatigue testing as well. More research is needed to develop an APA fatigue test method, but it may be possible to perform both rutting and fatigue testing using the same specimen. There is also interest in developing a moisture susceptibility test. Other Load Wheel Testers in use are the Georgia loaded wheel tester (base model for APA), French Pavement Rut Tester (FPRT), Hamburg Wheel-Tracking Device (HWTD) and PURWheel.

Appendix D is a list of APA owners who are part of the users group which works together to develop procedures for testing and evaluation of data for determining the acceptability of a given HMA.

1.3 Evaluation of the APA for use in Minnesota

For this project we have:

1. A literature search to review previous studies made to establish the usefulness of the APA and procedures used to setup evaluations and specifications including the APA test results.

2. The APA Users Group list has been obtained.

3. A questionnaire was developed and sent to the 65 contacts on the list.

4. A summary of the 25 replies is presented in Chapter 3.

5. The actual responses are summarized in Appendix E.

6. Guidelines for operation of the APA in Minnesota are presented in Chapter 4. The guidelines include the use of laboratory samples compacted with the Superpave Gyratory Compactor (SGC) using a 150-mm (6-in.) cylindrical specimen. A procedure for correlating APA rut depths to field rut depths is presented. Until specific criteria have been developed for Minnesota the commonly used criteria of 7 mm (0.28 in.) after 8000 cycles is recommended. The 8000 cycles represents about 1,000,000 "Rutting Equivalent Standard Axle Loads (ESALs)" which represents about 3,000,000 total ESALs in Minnesota. Rutting ESALs are defined and related to total ESALs in Chapter 4.

7. A proposed study of Minnesota HMAs is presented in Chapter 5 includes a list of parameters from laboratory and field prepared mixtures. A listing of parameters to use for rut depth evaluation is presented. Correlation of these variables with the APA rut depth results will help show which variables have a significant effect of rut depth development.

8. A summary of the APA testing and analysis procedures used by a number of researchers and DOTs is presented in Chapter 6. It includes:

   a. a recommendation to purchase an APA for the purpose of studying the effects of various parameters on the rut depth performance of Minnesota mixes.

   b. guidelines for running the APA test and what parameters to include in an evaluation of Minnesota mixtures,

   c. measurement of dynamic modulus of the Minnesota HMA mixtures evaluated with the APA. The rutting performance of the mixes could then be incorporated into the MnPAVE software. Currently, the rutting predictions by

MnPAVE represent subgrade rutting. The APA and dynamic modulus of the HMA will make it possible to predict shear resistance of the HMA. This information could be used to develop an additional MnPAVE module.

CHAPTER 2.
LITERATURE REVIEW

2.1 General

A literature review has been conducted to obtain information relevant to the use and effectiveness of the APA for HMA evaluation. The search included the suitability of the APA to predict rut depth performance of HMA mixes.

The literature search and review was directed at answering the following questions:

1. What can the APA do?
2. What are the conclusions and recommendations of researchers who have evaluated the effectiveness of the APA?
3. What are the potential variables that should be studied to evaluate the sensitivity of the APA results?

Using the information obtained from the review, an experimental plan has been developed and presented in Chapter 4.

2.2 Reviews

Summaries of the information found in ten of the references which report on the use of the APA and other similar devices follow.

Reference 1 presents a study by Collins, Johnson, Wu and Lai. The study looks at the deterioration of HMA due to the detrimental effects of moisture. Moisture produces a loss of strength caused by the weakening of the bond between the asphalt binder and the aggregate. A gradual loss of cohesive strength due to moisture conditions may cause an increase in permanent deformation. Permanent deformation can also be an indication of the effect of moisture (moisture susceptibility) on the HMA performance.

The APA has the capability of testing specimens in a temperature controlled water bath. The development of a moisture susceptibility test specification was completed through a joint effort between the Georgia Department of Transportation and Georgia Institute of Technology.

Each mixture was tested with and without 1 percent hydrated lime. Six, 150-mm (6-in.) diameter specimens were prepared for each of the following conditions: dry control, vacuum saturation conditioning, and freeze/thaw conditioning. In each of these three categories, four specimens were used for rut testing and two specimens were used for Tensile Strength Ratio (TSR) (AASHTO T283). There were also six, 100-mm (4-in.) specimens prepared for each mix. These were needed for TSR (Georgia Department of Transportation (GDT)-66 testing.

Rut testing was done using Georgia Method GDT-115 "Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester" with the exception of the test temperature being changed to 49C (120F).

APA cycles corresponding to the rut depth failure criteria show good correlation with GDT-66 for samples subjected to vacuum saturation and freeze-thaw. The GDT-66 (APA) was found to be more comparable with field performance than the AASHTO T-283 (with vacuum saturation and freeze/thaw) for the aggregate mixtures selected.

Reference 2 presents a National Center for Asphalt Technology (NCAT) study to evaluate the effect of restricted zone on performance of mixes measured with the APA. The test plan consisted of a comparative evaluation of three mix gradations: ARZ, TRZ, and BRZ (the gradations above, through, and below the restricted zone respectively). These gradations were tested for three types of aggregate (+granite, limestone, and crushed gravel) in two types of mix (wearing and binder) with two grades (PG 64-22 and PG 52-22) of asphalt binder. An intermediate traffic level (0.3 to 1 million ESALs) was considered, with N=7, N=76, and N=117 with the SGC. Results indicate that for crushed granite and limestone, (1) the TRZ gradation produces the best mix (in terms of rut depth performance), (2) the BRZ gradation produces the worst mix, and (3) the ARZ gradation produces a mix falling in between the first two. However, for the crushed gravel mixes, the results are significantly different as they are in the case of granite and limestone. The TRZ gradation exhibited slightly higher rutting potential compared with the BRZ gradation. A two-way analysis of variance (ANOVA) with aggregate type and gradation as factors and rut depth indicates a highly significant effect of the interaction between aggregate type and gradation. This finding suggests that the effect of restricted zone depends on the shape and texture of the aggregate.

The purpose of the study by Asphalt Pavement Associated Contractors (APAC) presented in **Reference 3** was to evaluate the factors that can contribute to the variability of the test results when using the APA. This type of study is used to refine the written procedure to eliminate unnecessary variability. The experimental design used was based on the guidelines in ASTM C1067 (Appendix A). Six factors were investigated: (1) air void content, (2) the test temperature, (3) preheating time, (4) wheel load, (5) hose pressure, and (6) compaction method. Analysis of the results showed that the allowable range of 1.0% air voids in the test specimens should be reduced, the test temperature must be accurately calibrated, and the method of compaction should be standardized. The current procedural ranges permitted for wheel load, hose pressure and preheat time did not significantly affect the test results. Additional information gathered from this study provides insight on the repeatability and reproducibility of the APA test and evaluation of possible outlier data.

The study presented in **Reference 4** was carried out at NCAT by Kandhal and Mallick to evaluate the potential of the APA to predict rutting of in-service pavements. Specifically, the objectives were to find the sensitivity to changes in aggregate type and gradation, performance grade (PG) of the asphalt binder, and evaluate the equipment by comparing the test results with the test results from the Superpave Shear Tester (SST). Mixes from poor, fair and good performing pavements were also tested with the APA to develop a rut depth criterion for evaluation of mixes.

Binder and surface course mixes were made with granite, limestone and gravel aggregates, with gradations above the maximum density line, through the Superpave restricted zone in close proximity of the maximum density line, and below the maximum density line. Results from tests with different aggregates, gradations, and binder types show that the APA is sensitive to these factors and, therefore, has a potential to predict relative rut performance of HMA mixtures. The APA had a fair correlation with the SST.

A study by Williams and Prowell reported in **Reference 5** shows a comparison of wheel tracking test results for the APA, the FPRT and the HWTD. Samples from WesTrack were tested with each of the devices. The data and analysis for this study showed that the three devices satisfactorily correlate with measured rut depth at Westrack. The correlations were 89.9, 83.4 and 90.4 percent for the APA, FPRT and

HWTD respectively. The variability in results for each of the devices increased for the poorer performing mixtures. The increased variability with increased rut depth development allows for a rational method to establish mixture design specifications. An appropriate test temperature reflecting in-service temperature at which the mixture is expected to perform must be established.

In **Reference 6** findings are summarized from a study to evaluate the suitability of the APA for assessing the rutting potential of asphalt mixes in Florida by Choubane, Page and Musseleman. The evaluation consisted of correlating the APA predicted rutting development with field measurements. Correlations were made with both beam and gyratory samples. The testing variability was also investigated. The APA test results were also compared with results from the Georgia loaded wheel tester.

The findings indicate that the APA may be an effective tool to rank HMAs in terms of their respective rut performance.

Average values within the ranges of 7 to 8 mm (0.28 to 0.31 in.) and of 8 to 9 mm (0.31 to 0.35 in.) may be used as performance limiting criteria at 8,000 cycles for beam and gyratory samples, respectively. The average values were determined using the results of three tests and three samples per test. However, for each mixture type, the APA testing variability was significant between tests and between the three testing locations within each test. Differences in rut measurements of up to 4.7 and 6.3 mm (0.18 to 0.25 in.) were recorded for beam and gyratory samples, respectively. Therefore, using the APA as a clear pass/fail criterion for performance prediction of asphalt mixtures may not be appropriate at this time.

These findings are based on data from three mixes. It is suggested that the APA testing variability (testing and testing locations within the device) be further assessed with a wider range of mixtures. The intent of such an assessment should not only be to correlate the APA results with field data but also to develop potential pass-or-fail limits and procedures.

Reference 7 reports on a study at the University of Kansas in which the APA was used to determine the moisture susceptibility of an HMA mixture.

AASHTO T-283 (KT-56) has been used by many agencies over the past decade to detect moisture susceptibility of asphalt mixtures. The level of the Tensile Strength Ratio (TSR) is used to indicate moisture susceptibility. Results from AASHTO T-283 have been inconsistent. The objective was to evaluate the effects of sample preconditioning on APA rut depths and to further evaluate the suitability of the APA for predicting moisture susceptibility of HMA mixtures.

Eight different mixtures from seven projects were evaluated with the APA. Cylindrical samples of the eight asphalt mix designs were made and compacted to 7 plus or minus 1% air voids with the SGC. The samples were tested up to 8000 cycles at 40C (104F) using four different preconditioning procedures: dry, soaked, saturated and saturated with a freeze cycle. All sites with TSR values below 80% had rut depths of at least 5.0 mm (0.2 in.) for the 40C (104F) soak conditioning. The results were compared with TSR values, methylene blue value and sand equivalent.

The APA evaluation able to identify every mix with a failing TSR. In addition, the APA identified one mix containing a large percentage of chert (an aggregate with a history of moisture susceptibility, as failing when the TSR indicated a passing result). Additionally, the results indicate that the harsher preconditioning of saturation and saturation with a freeze cycle did not result in poorer wet results (Using only dry and soaked conditioning appears to be adequate).

. The purpose of the project reported in **Reference 8** by Brown, Kandhal and Zhang at NCAT was to evaluate available information on permanent deformation, fatigue cracking, low temperature cracking, moisture susceptibility and friction properties. A summary is given of the advantages and disadvantages of many tests that are used to evaluate permanent deformation. Four devices were considered as primary “Simulative Tests”. These are the APA, HWTD, FPRT and the PURWheel. Table 2.2.1. is a summary of Table 1.of **Reference 8.**

Table 2.2.1. Advantages and Disadvantages of Four Rut Testing Devices (8)

Test Device	Sample	Advantages	Disadvantages
Asphalt Pavement Analyzer (APA)	Cylindrical or Beam	-simulates field traffic and temperature -simple to perform - 3 to 6 samples can be tested together -most widely used in USA -Guidelines and criteria available -Cylindrical specimens use SGC	-relatively expensive except for new table version
Hamburg Wheel Tracking Device (HWTD)	10.2in.x 12.6in. x 1.6in. beam	-widely used in Germany -capable of evaluating moisture susceptibility -2 samples tested at same time	-less potential to be accepted widely in USA
French Rutting Tester (FPRT)	7.1in.x 19.7in.x 0.8 to 3.9in.beam	-2 slabs can be tested at same time	-not widely available in USA
PURWheel	11.4 in. x 12.2 in. x 1.3 to 2.3 in. beam	-specimens can be from field or lab	-linear compactor needed -not widely available

Table 2. of Reference 8 lists the recommended tests and criteria for permanent deformation. The first choice was the APA with criteria of 8 mm (0.31 in.) @ 8,000 wheel load cycles at the high PG temperature to be used on the given project.

The second choice was the HWTD with criteria of 10 mm (0.39 in.) @20,000 wheel passes at 50C (122F).

The third choice was the FPRT. The criteria recommended are 10 mm (0.39 in.) @ 30,000 wheel load cycles at 60C (140F).

Reference 9 which reports on the first phase of National Cooperative Research Program (NCHRP) 9-17 reviews the characteristics and use of the HWTD (Germany), FPRT (France), Nottingham rutting tester (UK), Georgia loaded wheel tester (US), and the APA (US). The paper reviews the methods to develop criteria and test procedures for the last two devices. Four factors were included within the experimental plan. These are:

1. Specimen type: a. Beams compacted with an Asphalt Vibratory Compactor. and b. Cylinders compacted with the SGC.
2. Hose diameter: a. The standard hose diameter of 25 mm (1.0 in.) and b. 38 mm (1.5 in.).
3. Test Temperature: a. High temperature of standard PG grade based on climate and b. 6C (11F) higher than high temperature of standard PG grade.
4. Air void contents of. 4.0 and 7.0 percent average.

Materials were obtained from Westrack, MnROAD and the Federal Highway Administration (FHWA) Accelerated Loading Facility (ALF) at Turner-Fairbanks Highway Research Center (Virginia). A total of 160 factor-level combinations were used. Three replicates of each factor-level combinations were tested. Testing was conducted on mixes fabricated from original materials and subjected to short term aging per AASHTO TP-2-96. Plots were developed which reflected actual field rutting versus laboratory rut depth for a given factor-level combination.

The tentative findings from the first phase of NCHRP 9-17 are:

-Both gyratory and beam specimens are acceptable

-Four percent air voids in cylinders and 5 percent in beams gave the best results.

-25-mm (1-in.) standard, small hose gave acceptable results.
-PG high temperature gave better results compared to PG+6C.

It is planned to further validate these results using the NCAT Test Track.

Correlations were also made between the Repeated Shear Constant Height (RSCH), the Repeated Load Confined Creep (RLCC) test and the APA. The relationship between RSCH and critical APA rut shows a critical range would be 8.2 to 11.0 mm (0.32 to 0.43 in.). The temperature-effect model was used to convert Georgia's critical rut depth of 5 mm (0.21 in.) at a temperature of 50C (122F) after 8,000 cycles to a critical rut depth at a test temperature of 64C (147F) after 8,000 cycles. Based on these results a tentative value of 8.0 mm (0.31 in.) maximum rut depth can be recommended for the APA when tested at the high temperature of the standard PG grade for a given location. This criteria needs to be evaluated by specific agencies for their locations and typical mixtures.

References 10 and 11 present a study by Williams, Hill, et al at Michigan Technology College on the background, operation, and use of APA data to evaluate HMA mixtures in Michigan. The study reviews background information on the APA, specimen preparation, a suggested procedure for conducting the test, an empirical rut depth model relating APA performance to field performance using ten Michigan mixes, and an analysis to show how many rut depth ESALs are represented by one APA cycle. An empirical rut depth prediction model is developed for local conditions. A preliminary performance based specification with failure criteria is also suggested.

It is recommended that three samples compacted using the SGC compacted specimens or field cores be used for each evaluation. The average and standard deviation of the individual tests are used. It was found that the variability and measured rut depth both increased for poorer mixtures.

The APA rut depth measured at 8000 cycles was used for evaluation. The effect of asphalt content and air voids were studied. Asphalt content was varied by increasing the AC content by plus and minus 0.5%. Air void contents of 4, 8, and 12% were used. Tukey and Duncan's Multiple Range analysis was used to determine what variations were significant. Air voids had more effect on rut depth performance than did asphalt content.

Two regression models were used to predict rut depth performance. Ten mix properties were used for the advanced model and eight for the simplified model. The ten variables were:

1. Superpave design level, 2 Coarse or fine mix, 3.Was the PG grade "bumped"? 4. Fine Aggregate Angularity (FAA), 5. G*/sinδ, 6. Asphalt film thickness, 7. Fines to binder ration, 8. AC Content, 9 .Air voids and 10. VMA. The advanced model resulted in an R^2 of 0.806. The simplified model did not include film thickness and G*/sinδ were omitted. This regression equation resulted in an R^2 value of 0.727.

The most effective parameter was the "binder bump" which had the effect of reducing the rut depth by 2.26 mm (0.09 in.).

References 10 and 11 present very complete study of how the APA information can be correlated with field data and the analyses can be used to establish a performance specification using the APA. The information presented in this report is used to set up the recommended testing and evaluation program for Minnesota outlined in Chapter 3.

2.3 Summary of Literature Review

Based upon review of the APA related literature the following findings are stated:

1. Both cylindrical and beam specimens are acceptable to rank mixtures according to their rutting potential.

2. The APA results correlate reasonably well to actual field performance when the appropriate loading and environmental conditions of the location are considered.

3. The APA is sensitive to and differentiates reasonably between performance grades of asphalt binder.

4. The APA has the potential to be used as pass/fail criteria in the future. The APA does not conclusively predict the magnitude of the rutting for a particular pavement.

5. The capability of conducting APA tests in both air and in a submerged state will offer the user agency the most options of evaluating HMA mixes.

6. The APA distinguishes the low rutting susceptibility of the Stone Matrix Asphalt (SMA) mixes as compared to conventional HMA mixes. It also differentiates the high rutting susceptibility of the Large Stone Mix (LSM) as compared to conventional mixes.

The following is an example of typical test criteria for APA rut test (11).

Table 2.3.1 Typical Asphalt Pavement Analyzer Test Conditions and Mixture Design Specifications

Parameter	Specification
Test Temperature	98% Level of Reliability for
Pavement Environment Environmental Condition	Dry
Specimen Size, mm (in.)	150 (6), 75 (3)
Load, N (lb)	45 (100)
Hose Pressure, kPa, (psi)	689 (100)
Wheel Speed, m/sec (ft/sec)	0.6 (2.0)
Number of conditioning cycles	50
Number of test wheel cycles	8000
Air Voids, %	7 ± 1
Permanent Strain in Sample, mm (in.)	< 7 (0.28)

* see also Appendix B

2.4 Table Top Version

The MVT is a compact version of the APA which can be placed on a lab countertop. The MVT is used for rut-testing plant-produced mixes and is intended to be located in the asphalt mix plant quality control/quality assurance (QC/QA) testing laboratory. It is designed to test two SGC specimens, or one beam specimen, in an environmentally controlled chamber. The load is applied through a concave wheel fitted over a pneumatic hose. A control system takes deformation measurements, and plots these measurements in a numeric and graphic format.

The benefit of a mix verification tool is that the user can test plant-produced mix and compare it with the original mix design. If inconsistencies are evident, the designer can initiate an immediate investigation, make adjustments to the plant and minimize substandard mix before it is placed on the roadway. The MVT also provides quality assurance that the desired quality of HMA is placed on the roadway.

To conduct an HMA verification test with the MVT, the lab technician first takes a representative sample from the haul truck. The sample is compacted in the SGC with the design number of gyrations. Then the volumetrics of the mix (V_t, VMA, voids in fine aggregate) are determined. These specimens are then placed in the MVT molds, conditioned to the proper temperature and tested as in the APA.

CHAPTER 3.
MINNESOTA APA QUESTIONNAIRE

3.1 Questionnaire Development

A Questionnaire was developed by the staffs of the University of Minnesota and Mn/DOT. The questionnaire was designed to determine the experience with the device for various uses for HMA evaluation. The following information was requested: 1. Years owned, 2. Reason for testing, 3. Use in HMA design, 4. Use during HMA production, 5. Type of testing (rut depth, dry, moisture susceptibility, and/or flexural strength, stiffness, or fatigue and friction). 6. The performance of the machine and software. Finally, general comments regarding the suitability of the APA were requested.

Appendix C shows the questionnaire as sent.

3.2 Questionnaire Distribution

Pavement Technologies, Inc provided a Master APA Users List to the University staff. The list which is included as Appendix D, includes contacts for 65 companies and agencies which own APA rut testers. Twenty five responses were received.

3.3 Summary of Responses

Appendix E is a summary of the responses. It shows that one half of the machines are 5 or more years old. Most of the machines are used for research and general HMA evaluation and only five use it for QC/QA.

The respondents state that the APA is used for the following purposes:

1. Rut Depth (dry), 20
2. Moisture Susceptibility (9)
3. Flexural Strength, Stiffness, Fatigue (5)
4. Friction (0)

The majority of users rated the machine performance Excellent or Good for Durability, Repeatability, Calibration, Technical Support and Overall evaluation.

The Comments indicate that the APA has been a good tool for HMA evaluation; however, it is generally, too slow for QC/QA work. See Appendix E for specific comments. The individual respondents have not been identified.

CHAPTER 4.
GUIDELINES FOR OPERATION OF AN APA IN MINNESOTA

4.1 Operating Procedures

The APA can be operated in the rutting mode (dry), rutting mode (wet), or the flexural mode (1). Kandhal and Cooley (9) stated that HMAs can be adequately rated in the dry rutting for determining if it is susceptible to rutting.

The APA can evaluate either beam or cylindrical specimens. A special beam compactor system is available for compacting those materials. The Superpave Gyratory Compactor (SGC) can also be used to produce 150-mm (6-in.) diameter HMA specimens. It is recommended that the specimens be compacted using the SGC and that three samples be made for each mix produced.

Appendix A is the Standard Test Method for the APA testing in ASTM format and Appendix B is the Standard Test Method in AASHTO format. It recommended that the general methods be followed in Minnesota except for procedures for measuring specific gravities (bulk and maximum theoretical, etc.) when procedures developed at Mn/DOT for Minnesota materials are used. The availability of these procedures is one of the reasons we feel the APA is a good device to use for evaluation of Minnesota HMAs.

Table 1 in Reference 10 is a listing of specific test conditions used by agencies throughout the US. This shows that there is some uniformity in criteria; however, the use of the data for HMA evaluation has not been standardized. The laboratory criteria depend on the permissible rut depth in the field and correlation with the rut depth measured in the APA. Table 4.1.1 is a list of the APA Machine Settings and Test Methods recommended to start in the laboratory.

The SGC compacted specimens must be placed in the APA molds flush with top of the molds. This may require plaster of Paris to level and confine the specimens. As noted in Table 4.1.1. the specimens are temperature conditioned in the molds for 4 hours.

Table 4.1.1. APA Machine Settings and Test Methods

Parameter	Specification
Test Temperature	Upper Performance Grade of HMA Mixture being Tested
Environmental Condition	Dry
Specimen Size, mm (in.)	150 (6) diameter, 75 (3) height
Load, N (lb)	445 (100)
Hose Pressure, kPa (psi)	689 (100)
Wheel Speed, m/sec (ft/sec)	0.61
Number of Test Wheel Load Cycles	8000
Laboratory Compaction Device	Superpave Gyratory Compactor
Pretest Specimen Conditioning	4 hours @ test Temperature
Number of Seating Cycles	50

It is recommended that three (3) specimens of each mixture and condition be fabricated so that the average and standard deviation of the measured rut depths can be used for analysis. Michigan Technology University has devised a method by which rut depths of three specimens can be measured independently. The average and standard deviation are then calculated for each test setup. The recorded rut depths were for the HMA specimens located in the front of the molds (10).

4.2 APA Rut Depth data correlation with Field Measurements and Conditions and Development of APA Criteria for Minnesota

4.2.1. General

The rut depth measured with the APA cannot be directly correlated with field measured rut depths because it is not a mechanistically based measurement. The stress and strain conditions of the APA cannot be directly defined mechanistically; however, correlation models can be used to setup predictions of field rut depths. In this section parameters are recommended to determine correlations in an evaluation procedure for Minnesota HMA mixtures.

It is recommended that the following steps and procedures be developed to predict of critical field and then APA rut depths in Minnesota.

1. Establish a critical in-service rut depth criterion for field measurements in Minnesota. Typical values of 8 to 12 mm (0.31 to 0.47 in.) have been used by various agencies (11).
2. Identify 10 to12 projects throughout the state; some with and without rutting problems.
3. Obtain mix design and construction data for the identified projects.
4. Obtain original asphalt and aggregate materials from the projects.
5. Obtain cores from the projects.
6. Conduct APA tests on specimens using the three-specimen procedure recommended in Section 4.1.
7. Correlate laboratory average and variation in rut depths measured with the APA with rut depths measured in the field.

4.2.2. Critical Rut Depth in Minnesota

The Mn/DOT Bituminous and Pavement Management offices should confer to determine what a critical rut depth is for field measured values considering especially safety. A determination also needs to be made as to whether the surface rut depth is primarily in the HMA or is caused by rutting in the subgrade. Rutting caused by subgrade weakness or deformation of 12.5 mm (0.5 in.) is one of the criteria used for the Mn/PAVE thickness design (13).

Generally, a wider rut depth indicates rutting caused by a weak subgrade of insufficient pavement structure. It may be necessary to do a trench study to determine how much rutting occurs in each of the pavement layers.

4.2.3. Relationship between APA Test Performance and Field Performance

Williams and Hill (11) suggest a method for relating APA performance to in-service rutting. It involves first determining a failure rut depth in the field as defined in Section 4.2.2. Earlier work by Barksdale (14) has indicated that rut depths of 12.5 mm (0.5 in.) can hold enough water to cause a vehicle driving 80 kph (50 mph) to hydroplane. A 12.5- mm (0.5-in.) rut depth has been shown to be equivalent to a downward rut depth of 10 mm (0.39 in.) at Westrack. (15). Using this information on critical mixes from Westrack resulted in an APA critical rut depth of 7 mm (0.28 in.) at 8000 cycles.

Williams and Prowell (5) presented an analysis to relate APA rut depth to in-service rutting at Westrack. The testing was done at approximately the same average temperature at Westrack, 60C vs 57.7C (140F vs 136F). The Westrack ESALs were converted to in-service ESALs by adjusting for speed and wander. The resulting relationship indicates that one APA cycle is equivalent to 129.9 ESALs. This relationship assumes that the APA testing is done at approximately the high performance grade of the binder or approximately the highest pavement temperature the HMA mixture will be subjected to in-service (10).

For instance, if a mix is to be designed for 3,000,000 ESALs and all ESALs are rutting ESALs the APA testing should result in no more than 7 mm (0.28 in.) at 23,095 APA cycles.

Only a small amount of rutting occurs during much of the year in northern latitudes such as Minnesota and Michigan. Mahboub and Little (12) made the following assumptions when developing the "rutting ESAL" concept:

- Permanent deformation occurs daily over the time interval from 7:30AM to 5:30PM.
- Permanent deformation occurs only from the period of April to October, inclusive
- Measurable permanent deformation does not occur at air temperatures below 10C (50F).

A method for determining "Rutting ESALs" is presented in Table 5 of Reference 11. Williams and Hill have used this procedure to determine the APA rutting criteria to use for six regions in Michigan (11).

4.2.4. Identify Projects Throughout Minnesota

To determine appropriate APA criteria for Minnesota six to eight in-service projects for which rutting performance is available should be defined.

Projects should be selected from throughout the State. The temperature of the mixture is one of the most important factors with respect to rutting susceptibility. The temperature effects can be evaluated using the “rutting ESALs” concept summarized in Section 4.2.3. Alternately, the temperature of the HMA can be calculated using the algorithm available with the MnPAVE software (13). The 10C (50F) critical temperature can be used to evaluate the temperature rutting potential at a given pavement location.

4.2.5. Mixture Design Procedure

The HMA design procedure used for initial design should be determined. For the last five years the 2350 (Marshall) and 2360 (Superpave) mixtures have been used on all Mn/DOT and many city and county projects. Previously, 2331 or 2340 mixture design and specifications were used. It will be of interest to evaluate HMAs designed and constructed with each of the design criteria and specifications. To obtain significant rut depth history it will be necessary to use some projects designed and constructed with the earlier specifications.

4.2.6. Mix Design and As-Built Data

The original HMA design and as-built construction results need to be obtained. The materials and material proportions used for individual projects should be determined and documented. An HMA database will help organize the information and make it possible to correlate HMA design and as-built criteria to field performance.

4.2.7 Materials Acquisition

Materials from original construction should be obtained and tested to determine their original characteristics. In this way testing will simulate testing which would be done before design and construction.

a. For the asphalt determine the actual Dynamic Shear Rheometer DSR values especially at high temperatures

b. The aggregate type, gradation, angularity and other significant characteristics should be determined.

4.2.8. Field Cores

Cores from the projects should be obtained to determine the current material characteristics and volumetrics of the in-place mixtures.

4.2.9. Laboratory Testing

Conduct laboratory tests on the laboratory and field cores:

a. APA tests should be conducted using the procedure outlined in Section 4.1.
b. Conduct dynamic modulus and creep tests: These tests are more basic and provide input for mechanistic design procedures.

4.2.10. Correlation of Field and Laboratory Test Results

Field rut depth measurements should be correlated with the laboratory APA rut depth measurements and other mixture characteristics. The results can be used to set up preliminary APA criteria to use for mixture evaluation.

In this section the correlation of field rut measurements with laboratory tests with the same materials and characteristics is presented. In the next section procedures are suggested for correlating APA measurements with various materials and HMA mixture design characteristics.

4.2.11. Interim APA Rutting Criteria for Minnesota

Until critical rut depth criteria have been developed for Minnesota using the information developed in Sections 4.2.1 through 4.2.10 it is recommended that the criteria presented in References 8, 9, and 10 be used. A critical value of 7 mm (0.28 in.) at 8000 passes has been used. In addition each pass of the APA wheel has been equated to about 130 rutting ESALs. The 8000 passes would then represent 1,040,000 ESALs. Until a study can be made to relate rutting ESALs to total ESALs for various locations throughout the State it is assumed that the ratio would be about 1/3. This value would be appropriate if the average high temperature is over 10C (50F) for 1/3 of the year.

Using this reasoning critical APA passes can be calculated for the levels of traffic used for Mn/DOT specification 2350 and 2360 HMA mixtures.

The average of three tests should be used for each evaluation. The average plus one standard deviation would then be the value exceeded only 16% of the time. Using the average of three minus one standard deviation would result in a critical APA rut depth of 5.64 mm (0.22 in.) based on test results in Michigan (10).

CHAPTER 5
HMA MIXTURE EVALUATIONS
USING THE APA IN MINNESOTA

5.1 Correlation of APA Rut Depth Measurements with Mixture Characteristics.

5.1.1. General

The relative effect of various HMA characteristics can be estimated using the APA rutting criteria presented in Section 4.2.11. As the testing program progresses, the criteria to evaluate mixtures may be modified. In this section parameters are listed which can be used for correlation with laboratory and field conditions. An analysis procedure is also suggested.

5.1.2. HMA Mixture Parameters

5.1.2.1. Initial Parametric Study

Two or three Mn/DOT 2350 and 2360 HMAs should be selected and tested with the APA to establish the effects of a number of design and specification criteria on the development of rut depth. On a given mixture the following variables are suggested:

- Air voids; 4, 8, and 12 percent
- Asphalt content; optimum, 0.5% less and 0.5% over optimum.

The asphalt and aggregates were held constant for the mixtures from twelve projects in Michigan. Only three of the projects showed a statistically greater rut depth when the AC content was 0.5% above optimum. For the other projects the rut depths were not sensitive to asphalt content. This is possible because at high temperatures the aggregate has more affect on the rut resistance of an HMA.

The Michigan study showed that the APA rut depth at 8000 cycles showed a significant sensitivity to changes in air void content. Only one of 12 mixtures exhibited no statistical changes in rut depth due to changes in air void content. The following general conclusions are listed in Reference 10.

- In three of the projects the APA rut depths with 8 and 12% air voids were statistically different than the 4% specimens
- In three of the projects, the APA rut depths from the 12% air void specimens were statistically different than specimens prepared to 4 and 8% voids and,
- For three of the projects, the APA rut depths from specimens' at all three air void levels were statistically different.

The Michigan study concluded that the APA rut depth is sensitive to air voids and in particular shows decreased performance with poorly compacted mixtures with voids greater than 8%. If the pavement is poorly compacted the APA rut depth measurements can help quantify the differences in performance (10).

It is recommended that a similar asphalt content and voids study be made with mixtures around Minnesota including some Mn/DOT Specification 2350 and 2360 both Low Volume (LV) and High Volume (HV) mixtures.

5.1.2.2. Comprehensive Parametric Study

As more information is developed using the APA rut tester and failure criteria are redefined it will be necessary to preserve the data so that if modifications are made in the definition of failure it will be possible to establish changes in the relationships between mixture parameters and mixture performance. To accomplish an orderly method of accumulating and preserving of data must be set up as the overall study is started. The information developed using the APA can be used as a guide for setting up the comprehensive database and should be part of it.

In Michigan regression models have been developed using the characteristics of 12 HMA mixtures with the APA rut depth measured at 8000 cycles used as the independent variable. The ten HMA properties chosen were:

- Superpave mixture design level
- Fine or coarse aggregate gradation
- Was asphalt binder grade bumped?

- Fine Aggregate Angularity
- G*/sinΔ
- Asphalt film thickness
- Fines to binder ratio
- Asphalt Content
- Air Voids
- Voids in the Mineral Aggregate

As with all regression models it was necessary to define the range of each of the variables.

With these variables regression models to predict APA rut depth at 8000 cycles were produced. The SAS system for stepwise regression analysis was used. The following procedure was followed by the data analysis:

- All main effects were used in the model
- Interaction effects between the continuous predictor variables were included in the model. The interactions were removed if the partial F-Value of that predictor was less than 0.1.
- Once a candidate model was identified, a residual plot is created by SAS to determine if a transformation of the dependent variable would help the analysis

Two regression models are presented in Reference 10 (Advanced and Simplified). Both models assume the testing is performed using the average rut depth of three APA specimens. The resulting equation with all ten variables is presented in Reference 10. The R^2 for this model was 0.806 indicating good prediction of rut depth.

A simplified regression equation was also developed omitting asphalt film thickness and G*/sinδ from the analysis. It was reasoned that these variables would not be readily available on a given field project. The simplified model resulted in an R^2 of 0.727.

Some of the effects which can be determined from the regression equations presented by Williams and Hill are:

1. Using the average of three tests increased the correlation
2. The Superpave low and medium design levels decreased the rut depths by 1.71 and 1.50 mm (0.07 and 0.06 in.).
3. The “binder bump” effect was significant; it lead to a decrease in rut depth of 2.26 mm (0.09 in.).

The other effects interact with each other and their effects can be summarized as follows:

4. VMA interacts with Average Film Thickness(AFT) and Rolling Thin Film Oven (RTFO) aged complex modulus For instance if the AFT is set at 8.9 microns ($3.5x10^{-7}$ in.), an increase in VMA of one percent results in an APA rut depth increase of 0.73 mm (0.03 in.). Similar measures can be calculated for the effects of AFT and RTFO.

Bumping the binder grade has the most significant effect on the APA rut depth in the advanced model. Changes in VMA and RTFO also have a significant effect and changes in AFT have a less significant effect.

The simplified regression model contains terms including all three Superpave design levels.

1. The E3, E10 and E30 mixtures decrease the APA rut depth by 5.90, 3.15 and 3.10 mm (0.23, 0.12 and 0.12 in.), respectively.

2. If the asphalt binder grade is “bumped” the APA rut depth decreases by 1.59 mm (0.06 in.).

3. A coarse-graded mixture will have a 2.60-mm (0.10-in.) deeper APA rut depth than a fine-grained mixture.

4. An increase of the VMA from 18 to 19% results in a 0.76-mm (0.03-in.) increase in rut depth.

5. An increase in asphalt content of 1% results in an increase in APA rut depth of 1.37 mm (0.06 in.).

The regression models were developed for use as a screening tool for predicting APA performance based on mixture characteristics. In that way the models could be used to limit the number of mix designs that undergo performance testing. Based on the APA test results at Michigan Technical University on ten different Michigan DOT mixtures there were no significant statistical differences in either APA rut depth at 8000 cycles or the number of cycles to failure. However, different test temperatures were used to evaluate the mixtures. The E3 mixtures were tested at 58C (136F) and the E10 and E30 mixtures were tested at 64C (147F). If the same testing temperature was used, different results may have been observed (11).

The results from this study were presented to:

1. Illustrate the type of experiment which can be set up and carried out to use the APA effectively as a control test for HMA evaluation.
2. Summarize the results and relationships which can be developed to help setup design analysis and criteria for HMA mixture design and evaluation.

5.2 Development of a Database for Description and Evaluation of HMA Mixes

5.2.1. General

The performance of HMA mixes is dependent on the:

1. mixture design procedure and mixture designation,
2. materials used in the mix,
3. proportions of each mixture,
4. method of handling and proportioning of the materials at the asphalt plant,
5. procedure for placing and compaction of the mixture on the project,

In addition the location of the project being evaluated must be specified.

The APA makes it possible to evaluate many of these parameters as indicated above. In this section a list of parameters suggested for use in the general evaluation of HMA mixtures and specifically using the APA is provided. The objective of another research project is to develop a comprehensive database for HMA mixtures. The parameters presented for each of these will be similar. The parameters can be setup initially in a spreadsheet, but can eventually be incorporated into a full-sized database. As the database is being developed, consideration of how information will be retrieved must be considered as much as how the information is being input.

5.2.2. Specific Parameters

A. Mixture Design Procedure (Specification)

1. Marshall Design - Mn/DOT 2350: Low Volume (LV), Medium Volume (MV), or High Volume (HV)
2. Gyratory - Mn/DOT 2360: LV, MV, or HV

B. Materials

1. Aggregate
    a. Overall
        - Nominal maximum size
        - Above, below or through restricted zone.
        - Gradation specification
    b. Coarse Aggregate
        - Source; gravel or quarry
        - Geological description; igneous, sedimentary, metamorphic.
        - Fractured faces
        - Bulk specific gravity
        - Absorption
    c. Fine aggregate
        - Fine aggregate angularity (FAA)
        - Manufactured vs natural
        - Bulk specific gravity
        - Absorption
    d. Recycled Material (RAP)
        - Percent in HMA
2. Asphalt Cement
    a. PG grade - bumped?
    b. RTFO-aged complex modulus

C. Laboratory Mixture Design

1. Method (Marshall or gyratory)
2. Design asphalt content

3. Percent aggregate

- Coarse Aggregate (CA) vs Fine Aggregate (FA)

4. Additive(s)

- Antistrip
- Other

5. Volumetrics

a. Bulk specific gravity

b. Maximum theoretical specific gravity

c. Air Voids

d. VMA

e. VFA

f. Film thickness

6. APA Test Results

a. Specimen shape - beam vs cylinder

b. Mode - rut depth, beam flexure, (wet or dry)

c. Temperature

d. Rut depth @ 8000 cycles; average & standard deviation of three tests

e. Flexure - cycles to failure

7. Dynamic Modulus

a. Test method

b. Temperature

c. Dynamic modulus

d. Creep

D. Plant (Field) Mixture Design and Construction

Same seven modules as laboratory mixtures (5.2.2.3.)

8. Laydown and Compaction

a. Transport type

b. Roller(s)

types

number of passes

c. Method of compaction control

Quality

Cores

Density achieved

Field voids, VMA, VFA

E. Field Performance

1. Location - Highway, Mile Post
2. Year built
3. Soil Type
4. Thickness design
5. Traffic - Total ESALs and “Rutting” ESALs.
6. Rut depth evaluation

a. Type, subgrade vs HMA

b. Measurements, average of three & standard deviation

CHAPTER 6.
SUMMARY AND RECOMMENDATIONS

6.1 General

The purpose of this study has been to evaluate the Asphalt Pavement Analyzer (APA) manufactured by Pavement Technologies, Inc for the Minnesota Department of Transportation. Mn/DOT is considering the purchase of the device.

The evaluation has included:

1. A review of the machine and operating procedure in Chapter 1. Appendix A presents ASTM and Appendix B, the AASHTO format procedures for conducting rut depth testing dry and wet, beam flexure and friction tests.
2. An annotated literature review to review the methods of testing and analysis using the APA by various other agencies. The APA, HWTH, FPRT and Purwheel were compared in References 5 and 7. The APA was found to evaluate mixtures as well as the other devices, was reliable and is used by many agencies in the USA.
3. A questionnaire was sent to 65 members of the APA Users Group. A listing of the Group with addresses was provided by P.T.I., Inc. Twenty five replies were returned.

   Appendix C is the questionnaire.

   Appendix D is the APA Users list and

   Appendix E is a summary list of the responses.

   The respondents stated that the APA was primarily used for evaluating rut depth dry (20), moisture susceptibility (9), flexural strength (5) and none indicated they used it for friction measurement. The majority of users rated the machine performance Excellent or Good for Durability, Repeatability, Calibration, Technical Support and Overall Operation.

   The comments indicate that the APA has been a good tool for HMA evaluation; however, the current procedures are too slow for QC/QA work.
4. The APA can be operated in the rut depth (dry), rut depth (wet), flexure or friction modes. Either beams or cylindrical specimens can be used in the APA.

A special compaction apparatus must be used for the making the beams. A Superpave Gyratory Compactor (SGC) can be used for making the 150-mm (6-in.) diameter cylindrical specimens. The cylindrical specimens are recommended for the initial work with the APA. Table 4.1.1 is a listing of the recommended APA Machine Settings and Test Methods to use.

6.2 Evaluation of Minnesota HMA Mixtures

6.2.1. General

The following procedure is suggested for evaluation of HMA mixtures in Minnesota. Mixture variables such as aggregate angularity, gradation, asphalt content, voids, VMA, and other combinations can be evaluated with well controlled testing in a few days. To set up APA rut depth criteria for Minnesota the seven steps presented in Section 4.2.1. should be followed. Then the effect of variables associated with Mn/DOT HMAs can be evaluated with the APA.

6.2.2 Minnesota APA Rut Depth Criteria

APA rut depth criteria for Minnesota must be established. A study should be setup to determine what the APA measured rut depth should be after a given number of cycles. A guide for developing APA criteria is presented in References 8 and 10. Williams and Prowell (8) present the concept of “rutting ESALs”. Rutting ESALs are defined as the number of ESALs which occur when the average daily temperature is above 10C (50F). On the average the temperature is at or above 10C (50F) about one third of the time in Minnesota. The environmental software developed for MnPAVE can be used to determine period of time the temperature is above 10C (50F) for Minnesota. Seven steps to establish APA criteria for Minnesota are listed in Section 4.2. The criteria will most likely vary around the state because of temperature differences especially from north to south. Mixtures with good, fair, and poor rutting performance from around the State should be selected. The design and in-situ parameters for the mixtures should be determined and APA testing conducted. The APA results can then be correlated with the field mixture performance and characteristics. Section 5.1.2 lists mixture parameters which can be related to APA rut depths.

Until Minnesota APA criteria have been established it is recommended that interim criteria of 7 mm (0.28 in.) at 8000 cycles be used. The average and standard deviation of three specimens should be used. Test results in Michigan indicate that an average rut depth of 5.64 mm (0.22 in.) will yield a 95% confidence level that the average rut depth will be less than 7 mm (0.28 in.). As testing is performed typical standard deviations for Minnesota can be determined.

6.2.3 Evaluation of Minnesota HMAs

Once APA performance criteria have been established, evaluation of various Minnesota mixtures and mix characteristics can be made. Sections 5.1.2.1 and 5.2.1.2. show how APA testing can be used to indicate the effect of material and volumetric parameters of a given mixture. The Michigan study summarized illustrates the effect of percent air voids and asphalt content on the rutting potential of a mixture. In Michigan 12 mixtures were evaluated at three levels of air voids. The APA rut depth is sensitive to air voids and decreased performance with mixtures compacted to greater than 8% air voids.

A more comprehensive parametric study is also outlined in Section 5.2.1.2. The Michigan study determined and correlated 10 parameters with APA rut depth performance. The sensitivity of APA rut depth performance was evaluated using regression analyses using all ten parameters and omitting two parameters. This type of analysis can be used to establish the relative effect of the parameters on rutting performance. A list of parameters which could be used for evaluating Minnesota mixtures is presented in Section 5.2. Specific levels of the following mixture parameters are suggested for correlating with rutting performance.

1. Mixture Type, 2.Traffic Level for Design, 3.Materials (asphalt, aggregate), 4.Mixture Characteristics (proportions, volumetrics), 5.APA Test (specimen configuration, test results), 6.Dynamic Modulus testing (complex modulus, creep), 7. Field Performance (location, year built, year of evaluation, type of rutting, “rutting ESALs” since construction, average and S.D. of field rutting).

To determine the sensitivity of APA rutting performance of Minnesota mixtures the following experimental design is suggested.

1. Define typical mixtures from around Minnesota

2. Use some Mn/DOT Specification 2350 and 2360 mixtures with low, medium and high traffic.
3. Establish variables for the mixtures defined.
4. Vary asphalt contents using optimum, plus 0.5% and minus 0.5%.
5. Compact mixtures to air voids of 2, 4, 8, and 12%.
6. Calculate volumetrics such as VMA, VFA, etc.
7. Vary other factors of interest such as PG grading, FAA, fractured faces of coarse aggregate.
8. Develop regression equations to establish which variables or interactions have a significant effect on rutting performance.
9. Conduct Dynamic Modulus tests on the mixtures. The dynamic modulus test will help tie the rutting performance of the HMA mixtures to a mechanistic design such as MnPAVE.

6.3 Recommendations

The following recommendations are made based on this study.

1. Mn/DOT should purchase an APA because:
    a. It provides a measure of the rutting susceptibility of a given HMA.
    b. The device has been used by over 60 agencies/contractors with good success.
    c. A users group has been formed which can provide discussion and support for how best to develop and improve the testing and analyses.
    d. Procedures for conducting the tests are available in ASTM and AASHTO formats.
    e. Preliminary criteria have been established from previous studies.
    f. Response to the questionnaire conducted as part of this study indicate that the APA can be used as a good empirical tool for measuring rutting susceptibility and that it is reasonably repeatable and reliable.
2. Evaluation of Minnesota mixtures should be conducted by:
    a. Using 150-mm (6-in.) SGC cylindrical specimens.

b. Initially, APA criteria used by a number of agencies should be used. That is 7-mm (0.28-in.) rut depth at 8000 cycles. The number of cycles should be varied depending on the design traffic for the mixture being evaluated.
c. "Rutting ESALs" should be defined for various locations around Minnesota. With software developed for MnPAVE. "Rutting ESALs" is defined using the number of days the average daily temperature is above 10C (50F).
d. Set up an experiment using HMA mixes around the state to evaluate the effect of selected parameters on rutting performance. The effect of air voids, asphalt content, PG grading of the asphalt, etc can be used. Ten variables are listed in Section 5.1.2.2. With the APA it is possible to evaluate various parameters under controlled laboratory conditions. Mixes with good, fair and poor field rutting performance should be studied. APA failure criteria can in this way be established.
e. Once Minnesota criteria are established a factorial experiment should be setup to evaluate the significance of aggregate, asphalt and mixture criteria such as FAA, air voids, VMA, etc to determine which variables are important and which are not.
f. Eventually, it may be possible to set up a performance based specification based on the APA.

3. Develop a relationship between APA rut depth performance and dynamic modulus for the mixes. The APA and dynamic modulus testing should be conducted at the same temperature.
4. Develop a comprehensive database for Minnesota asphalt mixtures. Parameters suggested for the database are presented in Section 5.2. The database will make it possible to track good and poor field performance and evaluate which parameters correlate best with rutting performance. In the next year FAA, RAP and other parameters will be studied. The APA can be a good evaluation tool for studying the effect of these parameters on the susceptibility of a mixture to the development of rut depth.

Acronym Definitions

AASHTO	American Association of State Highway and Transportation Officials
AFT	Average Film Thickness
ANOVA	Analysis of Variance
APA	Asphalt Pavement Analyzer
APAC	Asphalt Pavement Associated Contracting
CA	Coarse Aggregate
DSR	Dynamic Shear Rheometer
ESALs	Equivalent Standard Axle Loads
FA	Fine Aggregate
FAA	Fine Aggregate Angularity
FPRT	French Pavement Rutting Tester
GDT	Georgia Department Test
HV	High Volume
HWTD	Hamburg Wheel Testing Device
LSM	Large Stone Mix
LV	Low Volume
LWT	Loaded Wheel Tester
MV	Medium Volume
Mn/DOT	Minnesota Department of Transportation
NCAT	National Center for Asphalt Technology
PG	Performance Grade
QC/QA	Quality Control / Quality Assurance
RAP	Recycled Asphalt Pavement
RFTO	Rolling Thin Film Oven
SGC	Superpave Gyratory Compactor
SST	Superpave Shear Tester
TSR	Tensile Strength Ratio
V_t	Total Voids
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate

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Appendix A

STANDARD TEST METHOD FOR
DETERMINING RUTTING SUSCEPTIBILITY
USING THE ASPHALT PAVEMENT ANALYZER
(ASTM FORMAT)

APPENDIX A

STANDARD METHOD FOR DETERMINING RUTTING SUSCEPTIBILITY USING THE ASPHALT PAVEMENT ANALYZER (ASTM FORMAT)

1. SCOPE

1.1 This method describes a procedure for testing the rutting susceptibility of asphalt-aggregate mixtures using the Asphalt Pavement Analyzer (APA).
1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.
1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulations prior to use.

2. Referenced Documents

2.1 ASTM Standards

D 979 Standard Practice for Sampling Bituminous Paving Mixtures

D 2726 Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens

D 2041 Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

D 3203 Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Mixtures

E 178 Standard Practice for Dealing With Outlying Observations

D XXXX Compacting HMA Specimens Using the Asphalt Vibratory Compactor

D XXXX Test Method for the Preparation and Determination of the Relative Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

3. APPARATUS

3.1. Asphalt Pavement Analyzer (APA) - A thermostatically controlled device designed to test the rutting susceptibility of hot mix asphalt by applying repetitive linear loads to compacted test specimens through pressurized hoses.

3.1.1 The APA shall be thermostatically controlled to maintain the test temperature and conditioning chamber at any setpoint between 4 ^{o} and 72 ^{o} C within 1^{o} C.

3.1.2 The APA shall be capable of independently applying loads up to 1115 N (250 lbs.) to the three wheels. The loads shall be calibrated to the desired test load by an external force transducer.

3.1.3 The pressure in the test hoses shall be adjustable and capable of maintaining pressure up to 830 kPa.

3.1.4 The APA shall be capable of testing three beam specimens or three pairs of cylindrical specimens simultaneously.

3.1.5 The APA shall have a programmable master cycle counter which can be preset to the desired number of cycles for a test. The APA shall be capable of automatically stopping the test at the completion of the programmed number of cycles. The APA is commonly equipped with an automatic measuring system which interfaces with a personal computer to automatically measure and record rut depths at regular intervals.

3.1.6 The hoses shall be Gates 77B Paint Spray and Chemical ¾ inch (19.0 mm), 750 psi (5.17 MPa) W.P. GL 07148. The hoses should be replaced when any of the outer rubber casing has worn through and threads are exposed. Follow the APA manufacturer's instructions for the technique on replacing hoses.

3.2 Balance, 12,000 gram capacity, accurate to 0.1 gram.

3.3 Mixing utensils (bowls, spoon, spatula)

3.4 Ovens for heating aggregate and asphalt cement.

3.5 Compaction device and molds

4. PREPARATION OF TEST SPECIMENS:

4.1 Number of test specimens - One test will use either three beam (75 mm x 125 mm x 300 mm) specimens or six cylindrical (150 mm diameter x 75 mm) specimens.

4.2 Roadway Core Specimens

4.2.1 Roadway core specimens shall be 150 mm diameter with all surfaces of the perimeter perpendicular to the surface of the core within 5 mm. Cores shall be trimmed with a wet masonry saw to a height of 75 ± 1 mm.

Note 1: For cores less than 75 mm tall, plaster of Paris can be used to used to fill the bottom of the mold to support the core and bring the surface of the core to the top of the mold.

4.3 Plant Produced Mixtures

4.3.1 Samples of plant produced mixtures shall be obtained in accordance with ASTM D 979 (AASHTO T 169). Mixture samples shall be reduced to the appropriate test size and compacted while the mixture is still hot. Reheating of loose plant mixture should be avoided.

4.4 Laboratory Prepared Mixtures

4.4.1 Mixture proportions are batched in accordance to the desired Job Mix Formula. Required batch sizes are determined in accordance to APPENDIX X1.

4.4.2 The temperature to which the asphalt binder must be heated to achieve a viscosity of 170 ± 20 cSt shall be the mixing temperature. For modified asphalt binders, use the mixing temperature recommended by the binder manufacturer.

4.4.3 Dry mix aggregates and hydrated lime (when lime is used) first, then add optimum percentage of asphalt cement. Mix the materials until all aggregates are thoroughly coated.

4.4.4 Test samples shall be aged in accordance with the short-term aging procedure in AASHTO PP2

4.4.5 The temperature to which the asphalt binder must be heated to achieve a viscosity of 290 ± 30 cSt shall be the compaction temperature. For modified asphalt binders, use the compaction temperature recommended by the binder manufacturer.

4.5 Laboratory Compaction of Specimens

4.5.1 One of several devices may be used to compact specimens in the laboratory. Details regarding the procedures for compacting specimens in each device should be referenced to the equipment manufacturer's instructions.

Note 2: A 1999 ruggedness study by the APA Users Group found that samples compacted with different laboratory compaction devices can have significantly different results. Each user agency should select one method as the standard for their agency.

4.5.2 Laboratory prepared specimens shall be compacted to contain 7.0 ± 1.0% air voids.

Note 3: If a user agency chooses to test samples at an air void content other than that stated in Paragraph 4.5.2, it must be so noted in the test report, Paragraph 10.

4.5.3 Compacted specimens should be left at room temperature (approximately 25°C) to allow the entire specimen to cool for a minimum of 3 hours.

5. DETERMINING THE AIR VOID CONTENTS

5.1 Determine the bulk specific gravity of the test specimens in accordance with ASTM D 2726 (AASHTO T 166).

5.2 Determine the maximum specific gravity of the test mixture in accordance with ASTM D 2041 (AASHTO T 209).

5.3 Determine the air void contents of the test specimens in accordance with ASTM D 3203 (AASHTO T 269).

6. SELECTING THE TEST TEMPERATURE

6.1 The test temperature shall be set to the high temperature of the standard Superpave binder Performance Grade for the specifying agency. For circumstances where the binder grade has been bumped, the APA test temperature will remain at the standard PG high temperature.

7. SPECIMEN PREHEATING

7.1 Place the specimens in the molds.

7.2 Specimens shall be preheated to the test temperature selected in Paragraph 6 either in the temperature calibrated APA test chamber or a separate calibrated oven for a

minimum of 6 hours. Specimens should not be held at elevated temperatures for more than 24 hours prior to testing.

Note 4: A 1999 ruggedness study by the APA Users Group found that preheating of test specimens for either 6 or 24 hours did not yield significantly different rut depth results.

8. PROCEDURE

8.1 Set the hose pressure gage reading to 700 ± 35 kPa (100 ± 5 psi). Set the load cylinder pressure reading for each wheel to achieve a load of 445 ± 22 N (l00 ± 5 lb.).

8.2 Stabilize the testing chamber temperature at the temperature selected in Paragraph 6 .

8. Secure the preheated, molded specimens in the APA. The preheated APA chamber should not be opened more than 6 minutes when securing the test specimens into the machine. Close the chamber doors and allow 10 minutes for the temperature to restabilize prior to starting the test.

8.4 Apply 25 cycles to seat the specimens before the initial measurements. Make adjustments to the hose pressure as needed during the 25 cycles.

8.6 Open the chamber doors, unlock and pull out the sample holding tray.

8.7 Place the rut depth measurement template over the specimen. Make sure that the rut depth measurement template is properly seated and firmly rests on top of the testing mold.

8.8 Zero the digital measuring gauge so that the display shows 0.00 mm with the gauge completely extended. The display should also have a bar below the "inc." position. Take initial readings at each of the three center locations on the template. (For cylindrical specimens, the four outer locations are used). Measurements shall be determined by placing the digital measuring gauge in the template slots and sliding the gauge slowly across each slot. Record the smallest measurement for each location to the nearest 0.01 mm.

8.9 Repeat steps 8.7 and 8.8 for each beam or set of cylinders in the testing position. All measurements shall be completed within six minutes.

8.10 Push the sample holding tray in and secure. Close the chamber doors and allow 10 minutes for the temperature to equalize.

8.11 Set the PRESET COUNTER to the number of cycles for the next interval or for the end of the test. The standard test shall consist of 8000 cycles. Additional manual measurements may be made at selected intervals (commonly at 500, 2000 and 4000 cycles) for informational purposes.

8.12 Start or resume the test. When the test reaches the number of cycles set on the counter, the APA will stop and the load wheels will automatically retract.

8.13 Repeat steps 8.7 to 8.12 as necessary to complete the test.

Note 5: If the Asphalt Pavement Analyzer has been equipped with an automatic measuring system, then Paragraphs 8.6 through 8.12 for measuring manual rut depths are optional. Some users have reported significant differences in rut depths between the automatic measurements and manual measurements.

9. CALCULATIONS

9.1 The rut depth at each location is determined by subtracting the measurement for each interval (500, 2000, 4000, and 8000 cycles) from the initial measurement.

9.2 Determine the average rut depth at each interval for each test position. For beam specimens, use only the three center measurements for calculating the average rut depth. For cylindrical specimens, use the average of all four measurements to calculate the average rut depth.

9.3 Calculate the average rut depth from the three test positions. Also, calculate the standard deviation for the three test positions.

9.4 Outlier evaluation – Arrange the test values in order of increasing magnitude: $x_1 \leq x_2 \leq x_3$. *If the largest value is the suspected outlier, calculate the T-statistic as follows:*

$$T_3 = (x_3 - \underline{x})/s$$

If the smallest value is the suspected outlier, calculate the T-statistic as follows:

$$T_1 = (\underline{x} - x_1)/s$$

where:

$\underline{x}$ = *the average of the three test values*

$s = [\Sigma(\underline{x} - x_i)^2/(n-1)]^{1/2}$

If the T-statistic is greater than or equal to $T_{critical\ (\alpha = 5\%)} = 1.153$, then there is only one chance in twenty that the value is from the same population as the other values. If the T-statistic is greater than or equal to $T_{critical\ (\alpha = 1\%)} = 1.155$, then there is only one chance in one hundred that the value is from the same population as the other values. Therefore, the aberrant value may be discarded, and the remaining two rut depths averaged to represent the test result when the T-statistic is greater than or equal to 1.155. When this occurs, the testing procedure, device calibration, and test specimens should be investigated to determine possible causes for the excessive variation.

9.5 The APA rut depth for the mixture is the average of three beam specimens or six cylindrical specimens.

10. REPORT

10.1 The test report shall include the following information:
10.1.1 The laboratory name, technician name, and date of test.
10.1.2 The mixture type and description.
10.1.3 Specimen type (beams, cylinders, cores).
10.1.4 Average air void content of the test specimens.
10.1.5 The test temperature.
10.1.6 The average rut depth to the nearest 0.1 mm at 8000 cycles.

11. Precision and Bias

11.1 Work is underway to develop a precision statement for this standard. This test method should not be used to accept or reject materials until the precision statement is available.

ANNEX
(Mandatory Information)

A. CALIBRATION

The following items should be checked for calibration no less than once per six months : (1) preheating oven, (2) APA temperature, (3) APA wheel load, and (4) APA hose pressure. Instructions for each of these calibration checks is included in this section. Also, for machines with automatic measuring systems, the vertical and horizontal sensors should be calibrated according to the manufacturer's instructions at the same interval as the other components.

A.1. Temperature calibration of the preheating oven.
A.1.1 The preheating oven must be calibrated with a NIST traceable thermometer (an ASTM 65 C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.
A.1.2 Temperature Stability
A.1.2.1 Set the oven to the chosen temperature (e.g. 60 C). Place the thermometer in the well and place them on the center of the shelf where the samples and molds will be preheated.
It usually takes an hour or so for the oven chamber, well and thermometer to stabilize. After one hour, open the oven door and read the thermometer without removing it from the well. Record this temperature. Close the oven door.
A.1.2.2 Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature. If the readings from step2.1 and 2.2 are within 0.4 C, then average the readings. If the readings differ by more than 0.4 C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4 C on two consecutive readings.
A.1.3 Temperature Uniformity
A.1.3.1 To check the uniformity of the temperature in the oven chamber, move the thermometer and well to another location in the oven so that they are on a shelf where samples and molds will be preheated, but as far as possible from the first location. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4 C.
A.1.3.2 Compare the average of the two readings at the first location with the average of the stabilized temperature at the second location. If the average temperatures from the two locations are within 0.4 C, then the oven temperature is relatively uniform and it is suitable for use preheating APA samples. If the average of the readings at the two locations differ by more than 0.4 C then you must find another oven that will hold this level of uniformity and meets calibration.
A.1.4 Temperature Accuracy

A.1.4.1 Average the temperatures from the two locations. If that average temperature is within 0.4 C of the set point temperature on the oven, then the oven is reasonably accurate and calibration is complete.

A.1.4.2 If the set point differs from the average temperature by more than 0.4 C, then adjust the oven set point appropriately to raise or lower the temperature inside the chamber so that the thermometer and well will be at the desired temperature (e.g. 60 C).

A1.4.3 Place the thermometer and well in the center of the shelf. At thirty-minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4 C, and the average of the two consecutive readings are within 0.4C of the desired test temperature (e.g. 60 C), then the oven has been properly adjusted and calibration is complete. If these two conditions are not met, then repeat steps A.1.4.2 and A.1.4.3.

A.2 APA Temperature Calibration

A.2.1 The APA must be calibrated with a NIST traceable thermometer (an ASTM 65 C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.

A.2.2 Temperature Stability

A.2.2.1 Turn on the APA main power and set the chamber temperature controller so that the temperature inside the testing chamber is about 60 C. Also, set the water temperature controller to achieve approximately 60 C water temperature.

Place the thermometer in the well and place them on the left side of the shelf where the samples and molds will be tested. (Note-it may be helpful to remove the hose rack from the APA during temperature calibration to avoid breaking the thermometer.)

A.2.2.2 It usually takes about five hours for the APA temperature to stabilize. After the temperature display on the controller has stabilized, open the chamber doors and read the thermometer without removing it from the well. Record this temperature. Close the chamber doors.

A.2.2.3 Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature. If the readings from step A.2.2.2 and A.2.2.3 are within 0.4 C, then average the readings. If the readings differ by more than 0.4 C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4 C on two consecutive readings.

A.2.3 Temperature Uniformity

A.2.3.1 To check the uniformity of the temperature in the APA chamber, move the thermometer and well to the right side of the shelf where the samples are tested. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4 C.

A.2.3.2 Compare the average of the two readings at the left side with the average of the stabilized temperature at the right side. If the average temperatures from the two locations are within 0.4 C, then the APA temperature is relatively uniform and it is suitable for use. If the average of the readings at the two locations differ by more than 0.4 C then consult with the manufacturer on improving temperature uniformity.

A.2.4 Temperature Accuracy

A.2.4.1 Average the temperatures from the two locations. If that average temperature is within 0.4 C of the desired temperature of 60 C, then the APA temperature is reasonably accurate and calibration is complete.
A.2.4.2 If the average temperature differs from the desired temperature of 60 C by more than 0.4 C, then adjust the APA temperature controller so that the thermometer and well will be at the desired temperature of 60 C.
A.2.4.3 Place the thermometer and well in the center of the shelf. At thirty minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4 C, and the average of the two consecutive readings are within 0.4C of the desired test temperature of 60 C, then the APA temperature has been properly adjusted and calibration at that temperature is complete. Record the current set points on the temperature controllers for later reference. If these two conditions are not met, then repeat steps A.2.4.2 and A.2.4.3.

A.3 APA Wheel Load calibration of the air cylinders at the three test positions
A.3.1 The APA wheel loads will be checked with the calibrated load cell provided with the APA. The loads will be checked and adjusted one at a time while the other wheels are in the down position and bearing on a dummy sample or wooden block of approximately the same height as a test sample. Calibration of the wheel loads should be accomplished with the APA at room temperature. A sheet is provided to record the calibration loads.
A.3.1.1 Remove the hose rack from the APA.
A.3.1.2 Jog the wheel carriage until the wheels are over the center of the sample tray when the wheels are in the down position.
A.3.1.3 Raise and lower the wheels 20 times to heat up the cylinders.
A.3.1.4 Adjust the bar on top of the load cell by screwing it in or out until the total height of the load cell-load bar assembly is 105 mm.
A.3.1.5 Position the load cell under one of the wheels. Place wooden blocks or dummy samples under the other two wheels.
A.3.1.6 Zero the load cell.
A.3.1.7 Lower all wheels by turning the cylinder switch to CAL.
A.3.1.8 If the load cell is not centered left to right beneath the wheel, then raise the wheel and adjust the position of the load cell. To determine if the load cell is centered front to back beneath the wheel, unlock the sample tray and move it SLOWLY until the wheel rests in the indention on the load cell bar (where the screw is located).
A.3.1.9 After the load cell has been properly centered, adjust the pressure in the cylinder to obtain 100 ± " 1 lbs. Allow three minutes for the load cell reading to stabilize between adjustments. Record the pressure and the load.
A.3.1.10 With the wheel on the load cell remaining in the down position, raise and lower the other wheels one time. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.
A.3.1.11 With the other wheels remaining in the down position, raise and lower the wheel over the load cell. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.
A.3.1.12 Repeat steps A.3.1.5 through A.3.1.11 for each wheel/cylinder.
A.3.1.13 Return the load cell to the first wheel and repeat steps A.3.1.5 through A.3.1.11.

A.3.1.14 Place the load cell under the second wheel and repeat steps A.3.1.5 through A.3.1.11.
A.3.1.15 Place the load cell under the third wheel and repeat steps A.3.1.5 through A.3.1.11. The current cylinder pressures will be used to set wheel loads to 100 lbs.

A.4 Replacement of the APA hoses.
A.4.1 New hoses shall be placed in service in accordance with 3 .1.6
A.4.1.1 Remove the hose rack from the APA.
A.4.1.2 Remove the used hoses from the hose rack. Place the new hoses on the barbed nipples and secure with the hose clamps.
A.4.1.3 Position the hoses in the rack such that the hose curvature is vertical. Tighten the nuts at the ends of the hoses only until the hoses are secure. Over-tightening will effect the contact pressure and hose life.
A.4.1.4 Place the hose rack back into the APA and make sure that the hoses are aligned beneath the wheels.
A.4.1.5 Prior to testing, break in the new hoses by running 8000 cycles on a set of previously tested samples at a temperature of 55 C (131 F) or higher.

A.5 APA Hose Pressure Check
A.5.1 The air pressure in the APA test hoses shall be checked with a NIST traceable test gauge or transducer with a suitable range. The check shall be made while the APA is operating. Since the hoses are connected in series, it is satisfactory to connect the test gauge to the end of the right-most hose. The pressure should not fluctuate outside of the range of 700 ± 35 kPa (100 ± 5 psi) during normal operation. Adjust the pressure as necessary with the hose pressure regulator.

Note: The Ashcroft test gauge model 450182As02L200# has been found to be satisfactory for this purpose. This gauge may available through Grainger (Stock No. 2F008).

APPENDIX

(Nonmandatory Information)

X1. Calculation of Specimen Masses

X1.1 Beam Specimens
X1.1.1 Volume of specimen = 75 mm x 125 mm x 300 mm = 2812.5 cm^3.
X1.1.2 Total mass of beam specimen, g = Gmm @ Opt. A.C. x 0.93 x 2812.5 cm^3
X1.1.3 Beams may be batched in 1, 2 or 3 layers. Divide the total mass by the number of layers.
X1.1.4 Individual weights for dry aggregate, lime and liquid A. C. per layer
X1.1.4.1 Mass of asphalt cement, g = grams/layer x % A. C. @ Opt.
X1.1.4.2 Mass of aggregate, g = grams/layer - grams of A. C. (This includes lime, if used in the mixture).

X1.1.4.3 Mass of aggregate excluding lime, g = grams of aggregate/1.01

X1.1.4.4 Mass of lime, g = grams of aggregate - grams of aggregate excluding lime

X1.2 Cylindrical Specimens

X1.2.1 Volume of Specimen = (3B x (150 mm)^2 x 75 mm)/1000 = 1325.4 cm^3

X1.2.2 Total mass of cylindrical specimen, g = Gmm @ Opt. A.C. x 0.93 x 1325.4 cm^3

X1.2.3 Individual weights for dry aggregate, lime and liquid A. C. per layer

X1.2.3.1 Mass of asphalt cement, g = grams/layer x % A. C. @ Opt.

X1.2.3.2 Mass of aggregate, g = grams/layer - grams of A. C. (This includes lime, if used in the mixture).

X.1.2.3.3 Mass of aggregate excluding lime, g = grams of aggregate/1.01

X1.2.3.4 Mass of lime, g = grams of aggregate - grams of aggregate excluding lime

Appendix B

STANDARD METHOD FOR DETERMINING RUTTING SUSCEPTIBILITY OF ASPHALT PAVING MIXTURES USING THE ASPHALT PAVEMENT ANALYZER (AASHTO FORMAT)

APPENDIX B

STANDARD METHOD FOR DETERMINING RUTTING SUSCEPTIBILITY OF ASPHALT PAVING MIXTURES USING THE ASPHALT PAVEMENT ANALYZER

(AASHTO FORMAT)

1. SCOPE

1.1 This method describes a procedure for testing the rutting susceptibility of asphalt-aggregate mixtures using the Asphalt Pavement Analyzer (APA).
1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.
1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards
T 169 Standard Practice for Sampling Bituminous Paving Mixtures
T 166 Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
T 209 Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
T 269 Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Mixtures
MP-2 Standard Specification for Superpave Volumetric Mix Design
PP-35 Practice for Evaluation of Superpave Gyratory Compactors (SGCs)

3. APPARATUS

3.1 Asphalt Pavement Analyzer (APA) - A thermostatically controlled device designed to test the rutting susceptibility of asphalt-aggregate mixtures by applying repetitive linear loads to compacted test specimens through three pressurized hoses via wheels.
3.1.1 The APA shall be thermostatically controlled to maintain the test temperature and conditioning chamber at any setpoint between 4° and 72°C (40° and 160°F) within 1°C (2°F).
3.1.2 The APA shall be capable of independently applying loads up to 534 N (120 lbs) to the three wheels. The loads shall be calibrated to the desired test load by an external force transducer.

8.6 Place the rut depth measurement template over the specimen. Make sure that the rut depth measurement template is properly seated and firmly rests on top of the testing mold.
8.7 Zero the digital measuring gauge so that the display shows 0.00 mm with the gauge completely extended. The display should also have a bar below the "inc." position. Take initial readings at each of the four outside locations on the template. The center measurement is not used for cylindrical specimens. Measurements shall be determined by placing the digital measuring gauge in the template slots and sliding the gauge slowly across the each slot. Record the smallest measurement for each location to the nearest 0.01 mm.
8.8 Repeat steps 8.6 and 8.7 for each set of cylinders in the testing position. All measurements shall be completed within six minutes.
8.9 Push the sample holding tray in and secure. Close the chamber doors and allow 10 minutes for the temperature to equalize.
8.10 Set the PRESET COUNTER to 8000 cycles.
8.11 Start the test. When the test reaches 8000 cycles, the APA will stop and the load wheels will automatically retract.
8.12 Repeat steps 8.5 through 8.8 to obtain final measurements.

Note 1: Some APA's have been equipped with automatic measurement systems which makes steps 8.5 through 8.12 unnecessary. Some APA users have reported significant differences in rut depths between the automatic measurements and manual measurements.

9. CALCULATIONS

9.1 The rut depth at each location is determined by subtracting the final measurement from the initial measurement.
9.2 Determine the overall average rut depth for each test position. Use the average of all twelve measurements to calculate the average rut depth.
9.3 Calculate the average rut depth from the three test positions. Also, calculate the standard deviation for the three test positions.
9.4 Outlier evaluation - If the standard deviation of the set is greater than or equal to 2.0 mm, then the position with the rut depth farthest from the average may be discarded. The testing procedure, device calibration, and test specimens should be investigated to determine the possible causes for the excessive variation.
9.5 The APA rut depth for the mixture is the average of the six cylindrical specimens at 8000 cycles.

10. REPORT

10.1 The test report shall include the following information:
10.1.1 The laboratory name, technician name, and date of test.
10.1.2 The mixture type and description.
10.1.3 Average air void content of the test specimens.
10.1.4 The test temperature.

3.1.3 The pressure in the test hoses shall be adjustable and capable of maintaining pressure up to 830 kPa (120 psi).
3.1.4 The APA shall be capable of testing six cylindrical specimens simultaneously.
3.1.5 The APA shall have a programmable master cycle counter which can be preset to the desired number of cycles for a test. The APA shall be capable of automatically stopping the test at the completion of the programmed number of cycles.
3.1.6 The hoses shall be Gates 77B Paint Spray and Chemical 19.0 mm (3/4 inch), 5.17 MPa (750 psi) W.P. GL 07148. The hoses should be replaced when any of the outer rubber casing has worn through and threads are exposed. Follow the APA manufacturer's instructions for the technique on replacing hoses.
3.2 Balance, 12,000 gram capacity, accurate to 0.1 gram.
3.3 Mixing utensils (bowls, spoon, spatula).
3.4 Ovens for heating aggregate and asphalt binder.
3.5 Superpave gyratory compactor and molds.

4. PREPARATION OF TEST SPECIMENS

4.1 Number of Test Specimens - Six cylindrical (150 mm diameter x 75 mm) specimens.
4.2 Roadway Core Specimens
4.2.1 Roadway core specimens shall be 150 mm diameter with all surfaces of the perimeter perpendicular to the surface of the core within 5 mm. Cores shall be trimmed with a wet masonry saw to a height of 75 ± 3 mm. If the core has a height of less than 75 ± 3 mm, plaster-of-Paris may be used to achieve the proper height. Testing shall be conducted on the uncut face of the core.
4.3 Plant Produced Mixtures
4.3.1 Samples of plant produced mixtures shall be obtained in accordance with AASHTO T 169. Mixture samples shall be reduced to the appropriate test size and compacted to the appropriate number of gyrations as determined in AASHTO MP-2 while the mixture is still hot. Reheating of loose plant mixture should be avoided.
4.4 Laboratory Prepared Mixtures
4.4.1 Mixture proportions are batched in accordance to the desired Job Mix Formula.
4.4.2 The temperature to which the asphalt binder must be heated to achieve a viscosity of 170 ± 20 cSt shall be the mixing temperature. For modified asphalt binder use the mixing temperature recommended by the binder manufacturer.
4.4.3 Dry mix aggregates and hydrated lime (when lime is used) first, then add optimum percentage of asphalt cement. Mix the materials until all aggregates are thoroughly coated.
4.4.4 Test samples shall be aged two hours at compaction temperature or in accordance with the short-term aging procedure in AASHTO PP2.
4.4.5 The temperature to which the asphalt binder must be heated to achieve a viscosity of 290 ± 30 cSt shall be the compaction temperature. For modified asphalt binders, use the compaction temperature recommended by the binder manufacturer. The mixture shall not be heated at the compaction temperature for more than two hours.
4.5 Laboratory Compaction of Specimens

4.5.1 A Superpave gyratory compactor approved in accordance with AASHTO PP-35 should be used to compact samples.
4.5.2 Laboratory prepared specimens shall be compacted to the design number of gyrations (N_{des}) as determined in AASHTO MP-2 with a final height of 115 ± 5 mm. If the APA does not accommodate 115 mm high compacted specimens, the specimens shall be sawed to a height of 75 ± 1 mm. Only the bottom portion of the compacted specimens should be sawed off. The uncut side of the specimen shall be tested.
4.5.3 Compacted specimens should be left at room temperature ,approximately 25°C (77°F), to allow the entire specimen to cool, for a minimum of 3 hours.

5. DETERMINING THE AIR VOID CONTENTS

5.1 Determine the bulk specific gravity of the test specimens in accordance with AASHTO T 166.
5.2 Determine the maximum specific gravity of the test mixture in accordance with AASHTO T 209.
5.3 Determine the air void contents of the test specimens in accordance with AASHTO T 269.

6. SELECTING THE TEST TEMPERATURE

6.1 The test temperature shall be set to the high temperature of the standard Superpave binder Performance Grade for the specifying agency. For circumstances where the binder grade has been bumped, the APA test temperature will remain at the standard PG high temperature.

7. SPECIMEN PREHEATING

7.1 Place the specimens in the molds.
7.2 Specimens shall be preheated in the temperature calibrated APA test chamber or a separate calibrated oven for a minimum of 6 hours. Specimens should not be held at elevated temperatures for more than 24 hours prior to testing.

8. PROCEDURE

8.1 Set the hose pressure gap reading to 700 ± 35 kPa (100 ± 5 psi). Set the load cylinder pressure reading for each wheel to achieve a load of 445 ± 22 N (100 ± 5 lb.).
8.2 Stabilize the testing chamber temperature at the temperature selected in Paragraph 6.
8.3 Secure the preheated, molded specimens in the APA. The preheated APA chamber should not be open more than 6 minutes when securing the test specimens into the machine. Close the chamber doors and allow 10 minutes for the temperature to restabilize prior to starting the test.
8.4 Apply 25 cycles to seat the specimens before the initial measurements. Make adjustments to the hose pressure as needed during the 25 cycles.
8.5 Open the chamber doors, unlock and pull out the sample holding tray.

10.1.5 The average rut depth, to the nearest 0.1 mm, at 8000 cycles.

11. PRECISION AND BIAS

11.1 Work is underway to develop a precision statement for this standard.

ANNEX
(Mandatory Information)

A. CALIBRAT1ON

The following items should be checked for calibration no less than once per year: (1) preheating oven, (2) APA temperature, (3) APA wheel load, and (4) APA hose pressure. Instructions for each of these calibration checks is included in this section.

A.1. Temperature calibration of the preheating oven.
A.1.1 The preheating oven must be calibrated with a NIST traceable thermometer (an ASTM 65°C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.
A.1.2 Temperature Stability
A.1.2.1 Set the oven to the chosen temperature (e.g., 67°C). Place the thermometer in the well and place them on the center of the shelf where the samples and molds will be preheated. It usually takes an hour or so for the oven chamber, well and thermometer to stabilize. After one hour, open the oven door and read the thermometer without removing it from the well. Record this temperature. Close the oven door.
A.1.2.2 Thirty minutes after obtaining the first reading obtain another reading of the thermometer. Record this temperature. If the readings from step A.1.2.1 and A.1.2.2 are within 0.4°C, then average the readings. If the readings differ by more than 0.4°C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4°C on two consecutive readings.
A.1.3 Temperature Uniformity
A.1.3.1 To check the uniformity of the temperature in the oven chamber, move the thermometer and well to another location in the oven so that they are on a shelf where samples and molds will be preheated, but as far as possible from the first location. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4°C.
A.1.3.2 Compare the average of the two readings at the first location with the average of the stabilized temperature at the second location. If the average temperatures from the two locations are within 0.4°C, then the oven temperature is relatively uniform and it is suitable for use in preheating APA samples. If the average of the readings at the two locations differ by more than 0.4°C then you must find another oven that will hold this level of uniformity and meets calibration.
A.1.4 Temperature Accuracy
A.1.4.1 Average the temperatures from the two locations. If that average temperature is within 0.4°C of the set point temperature on the oven, then the oven is reasonably accurate and calibration is complete.

A.1.4.2 If the set point differs from the average temperature by more than 0.4°C, then adjust the oven set point appropriately to raise or lower the temperature inside the chamber so that the thermometer and well will be at the desired temperature (e.g., 67°C).
A.1.4.3 Place the thermometer and well in the center of the shelf. At thirty-minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4°C, and the average of the two consecutive readings are within 0.4°C of the desired test temperature (e.g., 67°C), then the oven has been properly adjusted and calibration is complete. If these two conditions are not met, then repeat steps A.1.4.2 and A.1.4.3.

A.2 APA Temperature Calibration
A.2.1 The APA must be calibrated with a NIST traceable thermometer (an ASTM 65°C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.
A.2.2 Temperature Stability
A.2.2.1 Turn on the APA main power and set the chamber temperature controller so that the inside the testing chamber is at anticipated testing temperature (e.g., 67°C). Also, set the water temperature controller to achieve the anticipated testing temperature. (Note: Experience has shown that the temperature controller on the APA is not always accurate. The thermometer should always be considered chamber temperature.) Place the thermometer in the well and place them on the left side of the APA where the samples and molds will be tested (Note: It may be helpful to remove the hose rack from the APA during temperature calibration to avoid breaking the thermometer).
A.2.2.2 It usually takes about five hours for the APA to stabilize. After the temperature display on the controller has stabilized, open the chamber doors and read the thermometer without removing it from the well. Record this temperature. Close the chamber doors.
A.2.2.3 Thirty minutes after obtaining the first reading obtain another reading of the thermometer. Record this temperature. If the readings from step A.2.2.2 and A.2.2.3 are within 0.4°C, then average the readings. If the readings differ by more than 0.4°C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4°C on two consecutive readings.
A.2.3 Temperature Uniformity
A.2.3.1 To check the uniformity of the temperature in the APA chamber, move the thermometer and well to the right side of the APA, where the samples are tested. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4°C.
A.2.3.2 Compare the average of the two readings obtained in A.2.2.3 and A.2.3.1. If the average temperatures from the two locations are within 0.4°C, then the APA temperature is relatively uniform and it is suitable for use. If the average of the readings at the two locations differ by more than 0.4°C then consult with the manufacturer on improving temperature uniformity.
A.2.4 Temperature Accuracy
A.2.4.1 Average the temperatures from the two locations. If that average temperature is within 0.4°C of the desired test temperature (e.g., 67°C), then the APA temperature is reasonably accurate and calibration is complete.
A.2.4.2 If the average temperature differs from the desired test temperature (e.g., 67°C) by more than 0.4°C, then adjust the APA temperature controller so that the thermometer

and well will be at the desired test temperature. (Note: It is advisable to keep the water bath set at the same temperature as the test chamber.)

A.2.4.3 Place the thermometer and well in the center of the shelf. At thirty minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4°C, and the average of the two consecutive readings are within 0.4°C of the desired test temperature (e.g., 67°C), then the APA temperature has been properly adjusted and calibration at that temperature is complete. Record the current set points on the temperature controllers for later reference. If these two conditions are not met, then repeat steps A.2.4.2 and A.2.4.3.

A.3 APA Wheel Load calibration of the air cylinders at the three test positions.

A.3.1 The APA wheel loads will be checked with the calibrated load cell provided with the APA. The loads will be checked and adjusted one at a time while the other wheels are in the down position and bearing on a dummy sample or wooden block of approximately the same height as a test sample. Calibration of the wheel loads should be accomplished with the APA at room temperature. A sheet is provided to record the calibration loads.

A.3.1.1 Remove the hose rack from the APA.

A.3.1.2 Jog the wheel carriage until the wheels are over the center of the sample tray when the wheels are in the down position.

A.3.1.3 Raise and lower the wheels 20 times to heat up the cylinders.

A.3.1.4 Adjust the bar on top of the load cell by screwing it in or out until the total height of the load cell-load bar assembly is 105 mm.

A.3.1.5 Position the load cell under one of the wheels. Place wooden blocks or dummy samples under the other two wheels.

A.3.1.6 Zero the load cell.

A.3.1.7 Lower all wheels by turning the cylinder switch to CAL.

A.3.1.8 If the load cell is not centered left to right beneath the wheel, then raise the wheel and adjust the position of the load cell. To determine if the load cell is centered front to back beneath the wheel, unlock the sample tray and move it SLOWLY until the wheel rests in the indentation on the load cell bar (where the screw is located).

A.3.1.9 After the load cell has been properly centered, adjust the pressure in the cylinder to obtain 445 ± 5 N (100 ± 1lbs.). Allow three minutes for the load cell reading to stabilize between adjustments. Record the pressure and the load.

A.3.1.10 With the wheel on the load cell remaining in the down position, raise and lower the other wheels one time. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.

A.3.1.11 With the other wheels remaining in the down position, raise and lower the wheel over the load cell. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.

A.3.1.12 Repeat steps A.3.1.5 through A.3.1.11 for each wheel/cylinder.

A.3.1.13 Return the load cell to the first wheel and repeat steps A.3.1.5 through A.3.1.11.

A.3.1.14 Place the load cell under the second wheel and repeat steps A.3.1.5 through A.3.1.11.

A.3.1.15 Place the load cell under the third wheel and repeat steps A.3.1.5 through A.3.1.11. The current cylinder pressures will be used to set wheel loads to 445 N (100 lbs.).

A.4 Replacement of the APA hoses

A.4.1 New hoses shall be placed in service in accordance with 2.1.6.

A.4.1.1 Remove the hose rack from the APA.

A.4.1.2 Remove the used hoses from the hose rack. Place the new hose on the barbed nipples and secure with the hose clamps.

A.4.1.3 Position the hoses in the rack such that the hose curvature is vertical. Tighten the nuts at the ends of the hoses only until the hoses are secure. Over-tightening will effect the contact pressure and hose life.

A.4.1.4 Place the hose rack back into the APA and make sure that the hoses are aligned beneath the wheels.

A.4.1.5 Prior to testing, break in the new hoses by running 8000 cycles on a set of previously tested samples at a temperature of 55°C (131°F) or higher.

A.5 APA Hose Pressure Check

A.5.1 The air pressure in the APA test hoses shall be checked with a NIST traceable test gauge or transducer with a suitable range. The check shall be made while the APA is operating. Since the hoses are connected in series, it is satisfactory to connect the test gauge to the end of the right-most hose. The pressure should not fluctuate outside of the range of 690 ± 35 kPa (100 ± 3 psi) during normal operation. Adjust the pressure as necessary with the hose pressure regulator.

Note: The Ashcroft test gauge model 450182As02L200# has been found to be satisfactory for this purpose. This gauge may be available through Grainger (Stock No. 2F008).

Appendix C

APA QUESTIONNAIRE FOR MN/DOT

APPENDIX C

ASPHALT PAVEMENT ANALYZER (APA) QUESTIONNAIRE FOR MN/DOT

I. Model(s) Owned: a. ________________
b. ________________

II. Number of years ___________

III. Used for:
- a. Research _____
- b. Mix Evaluation _____
- c. Mix Design _____
- d. Quality Control _____
- e. Quality Assurance _____
- f. Other __________________________

IV. Does the APA work well for evaluating bituminous mixes during the mix design process? Yes ___ No ___
What are the good/bad points? ________________________
____
____

V. Would the APA work well for evaluating bituminous mixtures during mix production for QC / QA? Yes ___, No ___
What are its good and/or bad points ___________________
____
____

VI. Type of Testing
- a. Rut Depth Development (dry) ______
- b. Moisture Susceptibility ______
- c. Flexural Strength, Stiffness, Fatigue ______
- d. Friction ______
- e. Other ____________________________________

VII. Machine Performance:	Excellent	Good	Fair	Poor
a. Durability	____	____	____	____
b. Repeatability	____	____	____	____
c. Calibration	____	____	____	____
d. Technical Support	____	____	____	____

e. Overall ____ ____ ____ ____

f. Comments ________________________________

____

VI. Respondent (optional)

Name: ________________________________

Agency/Company ________________________________

Appendix D

MASTER ASPHALT PAVEMENT ANALYZER
USERS LIST

Appendix D
Master Asphalt Pavement Analyzer Users List

Departments of Transportation

Alabama DOT	Lockett, Larry Mountcastle, Randy	1409 Coliseum Blvd. Montgomery, AL 36130	334-206-2335	334-834-6799	lockettl@dot.state.al.us mountcastler@dot.state.al.us
Arkansas State Highway & Transportation	Gee, Jim Westerman, Jerry Limbird, Mike Hardison, Terry	PO Box 2263 Little Rock, AR 72203	501-569-2599	501-569-2360	Jim.gee@ahtd.state.ar.us Jerry.westerman@ahtd.state.ar.us Mike.limbird@ahtd.state.ar.us Terry.hardison@ahtd.state.ar.us
California DOT	Bressett, Terri Cook, Mike	PO Box 942873 Sacramento, CA 94273-0001	916-227-7300	916-227-7301	Terrie_bressette@dot.ca.gov Mike_cook@dot.ca.gov
Delaware DOT Materials & Research	Curtiss, Steve	PO Box 778 Dover, DE 19903	302-760-2400	302-739-5270	scurtiss@mail.dot.state.de.us
Florida DOT	Malerk, Tom Upshaw, Pat Sholar, Greg	2006 N.E. Waldo Road Gainesville, FL 32609-8901	352-337-3160	352-334-1649	Tom.malerk@dot.state.fl.us.com Patrick.upshaw@dot.state.ft.us.com Greg.sholar@dot.state.fl.us.com
Georgia DOT	Geary,Georgene Wu, Peter	15 Kennedy Drive Forrest Park, GA 30050	404-363-7512	404-675-6092	Georgene.geary@dot.state.ga.us Peter.wu@dot.state.ga.us
Idaho DOT	Baker, Tom Smith, Bob	PO Box 7129 Boise, ID 83709-1129	208-334-8439	208-334-8595	tbaker@idistate.id.us bsmith@idistate.id.us
Illinois DOT	Garrott, Fred Zehr, Tom	126 E. Ash Street Springfield, IL62704	217-524-7268	217-782-2572	garrottfc@nt.dot.state.il.us zehrtg@nt.dot.state.il.us
Kentucky Transportation Cabinet Dept. of Highways Division of Materials	Meyers, Allen Black, Michael	1227 Wilkinson Blvd. Frankfort, KY 40601-1226	502-564-3160	502-564-7034	Allen.Meyers@mail.state.ky.us mblack@mail.kytc.state.ky.us
Maricopa County DOT	Erdman, Bob Phillips, Joe	2919 West Durango St. Phoenix, AZ 85009-6357	602-506-1317	602-506-4937	boberdman@mail.maricopa.gov joephillips@mail.maricopa.gov

Michigan DOT	Frankhouse, Mike Mayes, Gary	425 W. Ohawa St. PO Box 30050 Lansing, MI 48909	517-322-5668	517-322-5226	frankhousem@state.mi.us mayesg@state.mi.us
Mississippi DOT	Brumfield, Jimmy	PO Box 1850 Jackson, MS 39215-1850	601-359-1666	601-359-1716	jbrumfield@mdot.state.ms.us
Missouri DOT	Shelton, Mark	PO Box 270 Jefferson City, MO 65102	573-751-1037	573-526-4354	sheltm@mail.modot.state.mo.us
Nebraska DOT	Weishahn, Laird	PO Box 94759 Lincoln, NE 68509-4759	402-479-4675	402-479-4854	lweishah@dot.state.ne.us
Nevada DOT	Weitzel, Dean Sebaly, Peter Dunn, Michael	1263 South Stewart Street Carson City, NV 89712	775-888-7872	775-888-7323	dweitzel@dot.state.nv.us psebaly@dot.state.nv.us mdunn@dot.state.nv.us
North Carolina DOT	Jones, Cecil Bachhi, Chris	1801 Blue Ridge Road Raleigh, NC 27607	919-733-3563	919-733-8742	cljones@dot.state.nc.us cbacchi@dot.state.nc.us
Oklahoma DOT	Roberts, Eric Hobson, Kenneth	200 NE 21st Street Oklahoma City. OK 73105	405-522-4918	405-522-0552	eroberts@odot.org khobson@odot.org
South Carolina DOT	Fletcher, Milt Hawkins, Chad	1406 Shop Road Columbia, SC 29201	803-737-6700	803-737-6649	fletcherm@dot.state.sc.us hawkinsc@dot.state.sc.us
South Dakota DOT	Rowan, Rick	104 S. Garfield, Building B Pierre, SC 57501	605-773-3427	605-773-2732	rickrowen@state.dot.sd.us
Tennessee DOT	Head, Gary	6601 Centennial Blvd. Nashville, T N 37423-0360	615-350-4150	615-350-4128	ghead@mail.state.tn.us
Texas DOT	Rand, Dale Izzo, Richard	2311 West Rundberg Lane Austin, TX 78758	512-232-1904	512-232-1939	drand@dot.state.tx.us rizzo@mailgw.dot.state.tx.us
Utah DOT	Niederhauser, Steve	4501 S. 2700 W. Salt Lake City. UT 84119	801-965-4293	801-965-3843	sniederha@dot.state.ut.us
Virginia DOT	Mergenmeier, Andy Bailey, Bill Wells, Mike	1221 East Broad St. Richmond, VA 23219	804-328-3102	804-328-3136	Andrew.mergenmeier@virginiadot.org Bill.bailey@virginiadot.org Michael.wells@virginiadot.org

Wyoming DOT	Harvey, Rick	5300 Bishop Blvd. Cheyenne, WY 82009-3340	307-777-4476	307-777-4481	Rick.Harvey@dot.state.wi.us

Universities

University of Akron	Dr. Liang, Robert	Auburn Science and Eng. Akron, OH 44325-3905	330-972-7190	330-972-6020	rliang@uakron.edu
University of Arkansas	Hall, Kevin	4190 Bell Engineering Center Fayetteville, AR 71701	501-575-8695	501-575-7168	Kdh3@engr.uark.edu
Clemson University	Dr. Amirkhanian, Serji	212 Lowry Hall Box 340911 Clemson, SC 29634-0911	864-656-3000	864-656-2670	Serji.amirkhanian@ces.clemson.edu
Ergon Technical Development	Baumgardner, Gaylon Burrow, Marty Hemsley, Mike	390 Carrier Blvd. Richland, MS 39218	601-932-8365	601-932-9466	Gaylon.baumgardner@ergon.com Marty.burrow@ergon.com Mike.hemsley@ergon.com
University of Kansas	Cross, Steve	2006 Learned Hall Lawrence, KS 66045	785-864-4290	785-864-3199	sac@ukans.edu
Louisiana Trans. & Research Center	Mohammad, Louay Abadie, Chis	4101 Gourrier Ave. Baton Rouge, LA	225-767-9126	225-767-9108	louaym@ltrc.lsu.edu chrisabadie@dot.state.la.us
University of Mass.	Dr.Mogawer, Walaa	285 Old Westport Rd. N. Dartmouth, MA 02747	508-999-8468	508-999-8964	wmogawer@umassed.edu
Michigan Technological University	Williams, Chris R.	Dept. of Civil Engineering Houghton, MI 49931	906-487-1630	906-487-1620	Williams@mtu.edu
University of Mo-Rolla	Dr. Richardson, Dave	Dept. of Civil Engineering Rolla, MO 65409	573-341-4487	573-341-4729	Richardd@umr.edu
Ohio University	Sargand, Shad	105 Research & Tech. Ctr. Athens, OH 45701-2979	740-593-1467	740-593-0379	sargand@oak.cats.ohiou.edu
University of Oklahoma	Zaman, Musharraf	202 W. Boyd Street, Room 334 Norman, OK 73019	405-325-4236	405-325-4217	zaman@ou.edu

Rutgers University	Bennert, Tom	623 Bowser Road Piscataway, NJU 08854-8014	732-445-5376	732-445-0577	bennert@eden.rutgers.edu
Texas A & M University	Dr. Little, Dallas Button, Joe	CETITTI Bldg. 800 College Station, TX 77843	979-845-9847	979-845-9356	d-little@tamu.edu j-button@tamu.edu
Virginia Trans. Research Center	Maupin, Bill Dudley, Mike	530 Edgemont Road Charlottesville, VA 22903	804-293-1919	804-293-1990	Bill.maupin@virginiadot.org mdudley@virginiadot.org
West Virginia University	Dr. Zaniewski, John Kincell, Andy	PO Box 6103 Morgantown, WV26505-6103	304-293-3031	304-293-7109	John.zaniewski@mail.wvu.edu Andy.kincell@mail.wvu.edu
Worchester Polytechnic Inst.	Mallick, Rajib	100 Institute Road Worchester, MA 01609	508-831-5289		rajib@PI.edu

Contractors & Suppliers

APAC, Inc	West, Randy Messersmith, Paul	3005 Port Cobb Drive Marietta, GA 30080	404-603-2775	404-603-2770	rwest@ashland.com pmessersmith@ashland.com
APAC, Inc.	Johnson, Steve	PO Box 3285 Shawne, OK 74802-3285	405-273-7575	405-273-7598	sjohnson@ashland.com
APAC, Inc.	Mumfort, Tom	218 Rockwood Rd. Tyron, GA 30290	770-487-6200	770-487-6676	Tmjrmonfort@ashland.com
Barrett Paving Ohio	Jebson, Jim	7374 Main St. Cincinnati, OH 45244	513-271-6200	513-271-2875	bpohlabmws@alo.com
C.W. Matthews Contracting Co.	Young, Ken	1600 Kenview Drive Marietta, GA 30061	770-422-7520	770-422-1068	kennethy@cwmatthews.com
Clarke County Dept. of Public Works	Dunning, Michael	5051 S. Paradise Las Vegas, NV 89119	702-455-7430	702-739-1558	dunning@co.clark.nv.us
Construction Materials Services, Inc.	Johnson, Andrew	105 Park 42 Dr. Suite A Locust Grove, Ga 30234	770-914-1744	770-914-0412	Anna6598@bellsouth.net

Douglas Asphalt Co., Inc.	Davis, Sammy	PO Box 1110 Douglas, GA 31533	912-384-4419	912-393-1330	Sdavis999@hotmail.com
Frankfort Testing Lab	Quire, Scott	PO Box 797 Frankfort, KY 40602	502-223-3254	502-875-5507	stltest@dcr.net
Gerkin Paving	Gerkin, Brent	9-072 US Route 24 Napoleon, OH 43545	419-533-7701	419-533-6393	bgerkin@gerkinpaving.com
H.O. Weaver	Weaver, Paul	7450 Howells Ferry Road Mobile, AL 36689	251-342-3025	251-342-0108	weavson@bellsouth.net
Koch Materials	Dr. King, Gayle Blankenship, Phil Thomas, Todd	PO Box 1875 Wichita, KS 67201	316-828-6737	316-828-7385	king@kochind.com Blankenship@kochind.com thomast@kochind.com
Kokosing Materials, Inc.	Baldwin, Trent L	16075 Upper Fredericktown Road Fredericktown, OH 43019	740-694-1634	740-694-5772	tlb@kokosing-inc.com
Lehman-Roberts Co.	Moore, Rick Williford Hall Brewer, Dale	PO Box 1603 Memphis, Tn 38101	901-948-3309	901-947-5736	rmoore@lehmanroberts.com hwilliford@lehmanroberts.com dbrewer@lehmanroberts.com
Martin Marietta Aggregates	Johnson, Sam Birdsall, Brian	PO Box 37 Garner, NC 27529	919-772-9665	919-779-1526	Sam.Johnson@martinmarietta.com Brian.birdsall@martinmarietta.com
Materials & Testing of Arkansas	Garrett, Steven	PO Box 23715 Little rock, AR 72221	501-753-2526	501-753-5747	MTAsphalt@aol.com
National Ctr. For Asphalt Tech (NCAT)	Dr. Brown, Ray Watson, Don Coley, Alan	277 Tech Pkwy Auburn, AL 36830	334-844-6228	334-844-6248	rbrown@engr.auburn.edu dwatson@engr.auburn.edu coolela@eng.auburn.edu
Oregon Asphalt Assoc.	Huddleston, Jim Thompson, Gary	5240 Gaffin Rd. S.E. Salem, OR 97301	503-363-3858	503-363-5571	jhudd@adao.org gthompson@adao.org
QORE Property Sciences	Arnold, Chris Payne, Wade	1039 Industrial Court Suwannee, GA 30024	678-482-0638	678-482-9677	carnold@qore.ent wpayne@qore.ent
Reeves Construction Co.	Morris, Tommy	PO Box 547 Americus, GA 31709	229-924-7574	229-924-8336	tmorris@reevescc.com

S.T. Wooten	Crooms, Chris	PO Box 2408; 3801 Black Creek Wilson, NC 27894	252-291-5165	252-243-0900	chris@stwcorp.com
Scotty's Contracting	Law, Mike	2300 Barren River road Bowling Green, KY 42102	270-781-3998	270-781-3690	mikel@scottyscontracting.com
Spartan Asphalt Paving Co.	Penfield, Jeff Thompson, Bob	2800 Wood St. Lansing, MI 48906	517-482-9611	517-482-4854	jpenfield@thompsonmccully.com bthompson@thompsonmccully.com
Tri-State Testing	Waite, Glenn Owens, Guy	992 E. 770 North St. George, UT 84770	435-656-8378	435-703-1293	gnwaite@infowest.com same e-mail address (company)
United Asphalt Corp.	Shively, Larry Russell, Steve	PO Box 266 16E. Columbus St. Thornville, OH 43076	740-246-6315	740-246-4715	lshively@shellyco.com srussell@shellyco.com
Vulcan Materials	Chapman, Dan	6232 Santos Diaz St. Azusa, CA 91702	626-856-6190	626-969-6143	chapmandh@hotmail.com
Warren Paving	Warren, Lawrence Sullivan, John	562 Elks Lake Road Hattiesburg, MS 39401	601-544-7811	601-544-2047	lawrencewarren@warrenpaving.com bobbysullivan@warrenpaving.com
Witaker Contracting	Reed, David	PO Box 306 Guntersville, AL 35976	256-582-2636	256-582-2672	N/a

International

Changsha Communication University	Mr. Jun, Xie	No. 45, chilling Rd Tianxin Distr. Changsha, Hunan, China 410076	0731-5219407	0731-5215709	howardxj@cs.hn.cn
Dubai Municipality	Badri, Mohammed	Dubai, U.A.E.	9714-321-5555	9714-336-5463	
John Emery Geotechnical Eng. Limited (JEGEL)	Soanes, David	1109 Woodbine Downs Blvd. Toronto, Ontario M9W 6Y1 Canada	416-231-1060	416-213-1070	dsoanes@jegel.com
Kolo Veidekke AS	Mr. Larsen, Olle	Oslo, Norway	476-497-4700		

Lanavial (Div. Ministry of Transp)	Ms. Morgado, Myriam de	Caracas, Venezuela	582-12-351-4945		
NCC Ballast Teknik	Mr. Kullander	Stockholm, Sweden	468-590-95665	46-70-491-3250	Bjorn.kullander@ncc.se
New Mexico DOT	Stokes, Jim	PO Box 1149 Santa Fe, New Mexico 87504	505-827-5541	505-827-5649	James.stokes@nmshtd.state.nm.us
Petrobras Research Center	Leite, Leni Constantino, Romulo	Petrobras Distribuidora, S.A. Rio de Janeiro, Brazil	55-21-3865-6736	55-21-3865-6998	romulo@cenpes.petrobras.com.br
Qatar Testing Laboratories	Mr. Kelzieh, Ameer	Doha, Qatar	974-431-0398		
Skanska Anlaggning AB	Mr. Olsson, Kenneth	Asphalt Technology Center Farsta, Sweden	468-605-7315	468-605-7315	
South China University of Technology	Mr. Xiaoning, Zhang	Wushan Rd. Guangzhou, China 510641	020-87111030 x3623	same	
Tomakomai National College of Tech.	Dr. Yoshida, Takakei	Tokyo, Japan	8144-67-8057	8144-67-8028	yoshida@civil.tomakomai-ct.ac.jp
Tongji University	Mr. Qin, Wang	No. 1239, Siping Rd. Shanghai 200092	021-62415888	02165981427	
Transfield Pty., Ltd.	Wenban, Keith	30 Alfred Street Milson's Point, NSW 2061 Australia	612-9929-8600	612-9978-8555	
University of Costa Rica	Mr. Arce, Mario Mr. Castro, Pedro	National Materials & Structural. Lab San Jose, Costa Rica	505-207-5423	506-207-4442	

Appendix E

Asphalt Pavement Analyzer (APA) Survey Summary for the Mn/DOT

Year(s) Owned:

APA	
# OF YEARS	SURVEY(S)
New	1
1	2
2	4
3	3
4	4
5	8
6	3
7	1
>7	0

Used for:		No response (leave blank)	
Research:	22	Research:	2
Mix Evaluation:	18	Mix Evaluation:	6
Mix Design:	10	Mix Design:	14
Quality Control:	5	Quality Control:	19
Quality Assurance:	5	Quality Assurance:	19
Other:			

Does the APA work well for evaluating bituminous mixes during the mix design process?

Yes:	19	No response:	1
No:	4		

Would the APA work well for evaluating bituminous mixtures during mix production for QC/QA?

Yes:	7	Unknown:	4
No:	12		

Type of Testing	**Total**	**No Response**
Rut Depth Development (dry)	20	4
Moisture Susceptibility	9	15

Flexural Strength, Stiffness, Fatigue	5	19
Friction		23
Other	1	

Machine Performance	Excellent	Good	Fair	Poor	
Durability	7	8	9		
Repeatability	3	14	6	1	
Calibration	8	14	2		
Technical Support	7	16	1		
Overall	3	15	4	1	No resp: 2

Comments from Agencies/Companies:

- Our machine seems to have a lot of air leaks.
- Overall performance has been good; amount of down time has been limited due to very good technical support.
- We have had to replaced air regulators, cylinders to raise/lower to sample tray, cylinders to tighten sample molds in the tray, and several other relatively small internal parts. One of the brackets holding a wheel on the load carriage broke and needed to be re-welded. Otherwise, the machine has operated reliably. PTI has always been very supportive with technical assistance and parts!
- Had minor problems with testing software-not very user friendly.
- Extra parts should order if production needs are critical. The jog arm can come loose and damage parts. The slide bar measures position and is easily damaged. Computer software problems require shipping computer back to PTI. We use the CoreLok to obtain 93% +/- 1% density. Our method OHD L-43 is more like the ASTM method than AASHTO. The fatigue test is mot repeatable and automated rut depths. We require automated measurements. Does it correlate to field performance? That’s a tough one. Sub base, lift thickness and more play such a significant role. We have two test sections at the MCAT test track that we hope to evaluate. Obviously, the opposite of rut failures is fatigue failures. I’m not sure VMA adequately addresses that issue. PTI has proposed a mix design method that considers volumetric and results from APA rut and fatigue testing.
- We have an older model that has been retrofitted with electronics. If we had to do it over again, we would still have an APA.
- The one problem we have run into is trying to run say six different samples as far as AC or something. The machine automatically averages the rut depths of two samples. Therefore you can only run vary similar samples in each bay (left, center, or right). Of course you will could run two very different mixed in the left and right bays, to compare.

- We have on eof the first machines that PTI produced; we have had it upgraded to produce automatic data. We have had very few problems with our machines and have been able to produce very accurate and reliable data.
- In the seven years we have used the APA machines we have only performed routine maintenance on the equipment such as replacing hoses.
- High Maintenance Machine.
- Vertical calibration procedure is cumbersome and needs refining.

What are its good and/or bad points of using APA for evaluating bituminous mixes during the mix design process:

- We have used the APA to try characterized mixtures that are used in Illinois. The APA seems to do a good job of ranking mixed for dry rutting, according to the design traffic level of the mix. (i.e. weak, low-traffic, mixes rut more and have run in the APA have been from plant-produced mix. We have mot used the APA to evaluate and approve/reject mixes during the design process.
- Although APA could not predict how much rutting will occur on road under traffic, it does rank the mixes with high, medium or low rutting.
- Possibly, to rank good or bad mixtures, it may not predict actual rutting depts. Like a deal performance would.
- Can detect mix differences and problems in QC. Takes too long, need short time corelation.
- At present we are using 75mm samples; depending upon how coarse the mixes, it is something difficult to obtain 4% air voids. We are ordering 115 mm molds to see if we'll get more consistent air voids.
- Reproducibility, timeline, adjustable test temperature, pressure, cycles.
- We believe the APA has and is working well for evaluating mix designs; our maximum allowable rutting has been to the conservative side since we are still looking at field performance vs. APA performance. The requirement to test additional samples could be problem for some DOT's; we verify mix designs submitted by Contractors. Contractors supply pre-batched design gradations and PG binder.
- If you don't have a specification, then result could be meaningless; however, one will have a pretty good idea what performance can be expected on the roadway (good point). Without a correlation between performance on the road (in-place rut depth) and result from the APA, one wouldn't know what to specify if used as a design tool. No research to date whether there should be various cycles used for the different levels of super-pave designed mixtures; i.e. – is it parper to use the same 8000 cycles for all design levels? Probably so, if there has been a correlation bet3ween that 8000 cycles and in-place field values.
- The APA specimen preparation time is the most time consuming issue, but in the mix design phase one should have ample time to evaluate mixture.
- Identifies sensitivity to permanent deformation.
- Its hard to tell, we haven't seen too many problems in the field with mixes we have tested in the lab.

- Time consuming, expensive, few design labs have them. It culls more rut prone mixtures in the early phase when compared to maximum rut depth specification limits. We required mix design labs to submit 6 super pave Gyratory Compacted specimen for APA rut testing for each mix design. This expedites testing somewhat and alleviates financial burdens for the smaller mix design laboratories.
- What are the good/bad points? Good – ease of using SGC pills. Data is good for pass/fail criteria rather that a strict predictor of field rut depth. Most valuable when tested with water. Latest recommendations from ETG should improve what considered in the past to be high variability.
- Uses 6 in samples from the Gyratory, although not all states have a requirement we evaluate. All mixes designed in we lab.
- It can evaluate ma mix performance, testing time is high.
- No Answer.
- Can give a idea of possible problems in mix.
- Only use the rank mixes cannot estimate actual performance.
- Good: Automatic sampling of rut depths. Bad: Frequent Calibration it seems.
- Good-data is very repeatable and accurate in "predicting" rut susceptible mixes. Bad - amount of material/samples needed for verification and the number of replicates.
- The APA does a good. Our experience has showed the results are dependent on the performance grade (modified or not) of the binders perhaps more than the stone structure. However, we believe that it gives us a good indication the stability of the mix.
- Very good for predicting rut prone mixtures. Notes very dependable and tends to need mechanical electric attention on a routine basic.
- We have not been able to establish a solid enough relationship between design and performance to use the result on a routine basic for mix design.

What are its good and/or bad points of using APA for evaluating bituminous mixtures during mix production for QC/QA:

- We have used the APA to try to characterize mixtures that are used in Illinois. The APA seems to do a good job of ranking mixes for dry rutting, according to the design traffic tough, high-traffic, according to the design traffic tough, high-traffic, mixes rut less.) Most of the samples we have run in the APA have been from plant-produced mix. We have not used the Apa to evaluate and approve/reject mixes during the designing process.
- GDOT is currently using APA for field verification of plant mixes and cores if the mixes are questioned and use it as criteria to keep them or remove from road. However, due to the high cost and size of APA, it's not feasible to have the unit in every QC/QA field laboratory. Test has to be performed in central lab or a district lab.
- If you have the time, it may work. I am not aware of the sensitivity of the rut depths in the APA to normal production variability.
- We are currently conducting a research project testing plant-produced samples. The project should begin this week or the next; we do not have any result yet.
- We have been doing that. Need more research, which we are doing.

- Two day time frame to fabricate and test not timely for QC/QA.
- Size, cots, and utilities required (compressed air) would make QC/QA at asphalt plat difficult; device seems best suited in our situation as a mix design tool rather than QC/QA.
- Test takes too long for use in trying to control a mixture produced under QC/QA specifications at a HMA plant. Before you knew the results, mixture produced would already be in place on the roadway. Of course this is with most all tests. If one specified a penalty for produced mixture not meeting a certain APA value, the APA could probably be used to penalize a Contractor for what "could" be a "bad" mixture. Ideally one would want to know through the use of the APA that a mixture was designed to give a certain APA rut value, and then control that mixture in the field through volumetric.
- The agency does not intend to use the APA for QC/QA.
- Would identify a chance form mix design that affected permanent deformation.
- We have not tried that, but I think evaluating mixes during design would be a better way to utilize the APA.
- Too time consuming, too expensive, more personnel during lay down.
- No of QC gradations, volumetric data, etc. Will tell you faster if or why a problem is occurring during production of JMF. Yes for QA potentially use as a reference test to examine questionable lots.
- By the time you had your result, a lot of the asphalt being tested would already be in place.
- IIMHO too slow for production quality control.
- It is fairly fast way of comparing samples when using different graduations of AC's. Very little variation in results from different operators.
- The amount of the time that it would take to conduct the actual test and produce useable data.
- We do not have any experience using the APA during production for QC/QA. With our limited research, we have not been able to correlate lab data and field performance.
- It would if the rut depths could be validated for plant aged mixtures. No research has been in this area that I am aware of (i.e. is 5 mm rut during mix design the same as 5 mm rut with plant produced mix.
- At this time we would have a difficult time establishing limits for use in QA. The testing will be useful in identifying mixes with poor performance characteristics and is able to provide good data for comparison of proposed changes.

Surveys Sent:	100
Number of Responses:	25
% Responses received:	25

Respondents:

Name	Agency/Company
Tom Zehr	Illinois Department of Transportation

Peter Wu	Office of Materials and Research, Georgia Department of Transportation
Greg Sholar	Florida Department of Transportation
Randy Mountcastle	Alabama Department of Transportation
Jim Huddleston/Gary Thompson	Asphalt Pavement Associate of Oregon Department of Transportation
Jim Gee	Materials Division /Arkansas Highway and Transportation Department.
Jimmy Brumfield	Mississippi Dept. of Transportation
Michael T. Black, PE	Nevada Department of Transportation
Chris Bacchi	North Carolina Department of Transportation
Kenneth Hobson	Oklahoma Department of Transportation
Todd Thomas and Phil Blankenship	Koch Pavement Solutions
Brian Bizdsall	Martin Marietta Materials
Rafiqul A. Tarafder	University of Oklahoma
Joe Button	TTI/Texas A&M
Andy Kincell	West Virginia University
John Zaniewski	West Virginia University
Johathan S. Gould	Worcester Polytechnic Institute
Mike Hemsley	Paragon Technical Services/Ergo
Brian Egan	Tennessee Department of Transportation
Chad Hawkins, PE	South Carolina Department of Transportation
Rick Rowen	South Dakota Department of Transportation
Michael Dunning	Clark County Public works, NV
Rick Harvey	Wyoming Department of Transportation