KICEM Journal of Construction Engineering and Project Management
Online ISSN 2233-9582

www.jcepm.org
http://dx.doi.org/10.6106/JCEPM.2016.6.3.014

A Case Study of Asphalt Pavement Construction Quality Assurance Using the Quality Related Specification Software

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Abstract: One of the major issues in the material-based or acceptance quality characteristics asphalt pavement Quality Assurance (QA) is that the method does not have rationality to link between the individual materials and the projected performance of the pavement. A new asphalt mix QA method has been recently developed under a national research project using the probabilistic Performance Related Specification (PRS). This advanced PRS QA methodology integrates the AASHTOWare Pavement ME Design® technology with the simple performance test concept that bridges the material characteristics with the pavement performance. This paper presents a case study of asphalt pavement performance using the developed PRS QA computer program, named Quality Related Specification Software (QRSS), with an actual pavement project, to demonstrate the developed PRS procedure and to assess the robustness of QRSS in terms of the rationality of the distress predictions. The results of this limited case study show that the new PRS QA method reasonably predicts the pavement performance, properly applied the probabilistic methods, and produced rational pay adjustment.

Keywords: Performance Related Specification, Quality Assurance, Asphalt Pavement, Pavement Distress

I. INTRODUCTION

A. Background

Traditional quality assurance (QA) practice of asphalt pavement construction has been known to be based upon several key volumetric parameters such as aggregate gradation, asphalt content, and air voids. Since these parameters are related to pavement performance in the long run, it is found in many agencies that they are used as key players for the determination of incentive / disincentive factors to contractors in terms of the construction quality. One of the major disadvantages in the current material-based QA system is that the inter-relationship established between the key parameters is not considered in the system and the pavement performance that is derived from the inter-relationship is empirically assumed. As a consequence, the incentive / disincentive determination is primarily based upon engineering judgment and local experience with no direct consideration of the pavement performance [1].

A few years ago, an advanced QA methodology for asphalt pavement was developed on the basis of probabilistic Performance Related Specification (PRS) under a national research project, National Cooperative Highway Research Program (NCHRP) 9-22 [1,2]. This state-of-the-art QA tool integrated the AASHTOWare Pavement ME Design® technology (formerly known as Mechanistic-Empirical Pavement Design Guide - MEPDG) with the simple performance test concept [1,2]. To forecast the future pavement performance, the QA methodology uses three asphalt pavement distress models developed based upon the MEPDG distress prediction (i.e., asphalt concrete (AC) permanent deformation, bottom-up fatigue cracking, and low temperature cracking) [3,4,5]. In addition, the QA methodology incorporated 1) the effective temperature concept to characterize the environmental effect on asphalt pavement [6], 2) the service life concept to quantify the predicted pavement performance between job mix formula (JMF) design mix and as-constructed or as-built mix [2], and 3) stochastic solution considering the material variability by utilizing the Monte Carlo simulation and Rosenblueth approach [7].

One of the featured accomplishments in the NCHRP 9-22 project was to produce a computerized QA tool, named Quality Related Specification Software (QRSS), capable of automating the entire asphalt pavement evaluation process on the basis of probabilistic PRS. The researcher who involved the program development claim that the program provides the user-friendly interface so that the users can conveniently enter all required input data pertaining to asphalt structure and materials; computes a myriad of complex computations in a fast and reliable way; and displays summarized output data which is the long-term pavement performance related to the three distress modes [1,2].

However, to simplify the computation steps and expedite the operating process of the software, the QRSS used several assumptions which may cause significant errors during the computations resulting in inaccurate results.

B. Objective and Scope of Work

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The objective of this study is to examine the validity of the QA methodology incorporated in the QRSS. This paper reviews the QRSS program with respect to the input and output system of the program and the computation process through a case study using an actual pavement project data. The validity is evaluated based on the predicted distress and the trend of distress amount with the change of environmental locations. Also, the measured in-place air voids of constructed pavement are utilized to be compared with the predicted distress from the QRSS as a part of the validation. The analysis of the case study focuses upon the three predicted distresses (AC permanent deformation or rutting, bottom-up fatigue cracking, and thermal cracking) and the three climatic locations including two extreme areas (cold and warm climate) and one intermediate area (mild climate) in between.

II. QUALITY RELATED SPECIFICATION SOFTWARE

A. Introduction

The QRSS was developed as a Windows-based program and was encoded under the Microsoft .NET framework [1]. The software integrated all technologies developed and implemented in the NCHRP 9-22 project. The following summarizes the essential technologies [2]:

1. Effective temperature concept to characterize the climatic effects
2. Three distress prediction models developed based upon the MEPDG (AC rutting, bottom-up fatigue cracking, and thermal fracture)
3. Prediction of dynamic modulus based upon key mix volumetric properties (Witczak Predictive Equation)
4. Statistical application in finding a variance from a multivariate function (Monte Carlo simulation and Rosenblueth method)
5. Normal and Beta frequency distribution
6. Pavement performance (service) life calculation
7. Analysis of variance for the as-built mix
8. Predicted service life difference calculation between as-design and as-built mixes
9. Determination of pay incentive / disincentive
10. Inclusion of surface roughness in adjusting the final payment

Figure I outlines a simplified flowchart including the input and output system of the QRSS. There are three significant steps for a complete program operation. The first step (Mode II in the figure) is determination of suitability for design mix. In this step, the program provides a set of deterministic solution of Job Mix Formula (JMF) mix with which users can conclude whether the job mix or pavement structure given is revised. The second step (Mode I in the figure) is to apply stochastic techniques to obtain the average and dispersion of the design mix in terms of the amount of predicted distress and corresponding service life. The last step (the last four boxes in Mode I in the figure) is to evaluate the as-built mix in field in the stochastic framework. Eventually, the QRSS can compare the stochastic solutions between as-design and as-built mixes and determine the incentive / disincentive to contractor.

B. Major Input Components

As with other pavement-related computer applications, the QRSS requires the user to input all necessary information to properly run the program. It is of importance to understand that the QRSS utilizes the dynamic modulus as a governing AC mixture quality indicator for both as-design and as-built mixes; and it is estimated by the key AC mix volumetric properties using the Witczak Predictive Equation, 1999 version [8]. This dynamic modulus calculation is essentially the same method as the one used in the levels 2 and 3 analysis in the MEPDG program. The major input components of the QRSS consist of the following information data groups:

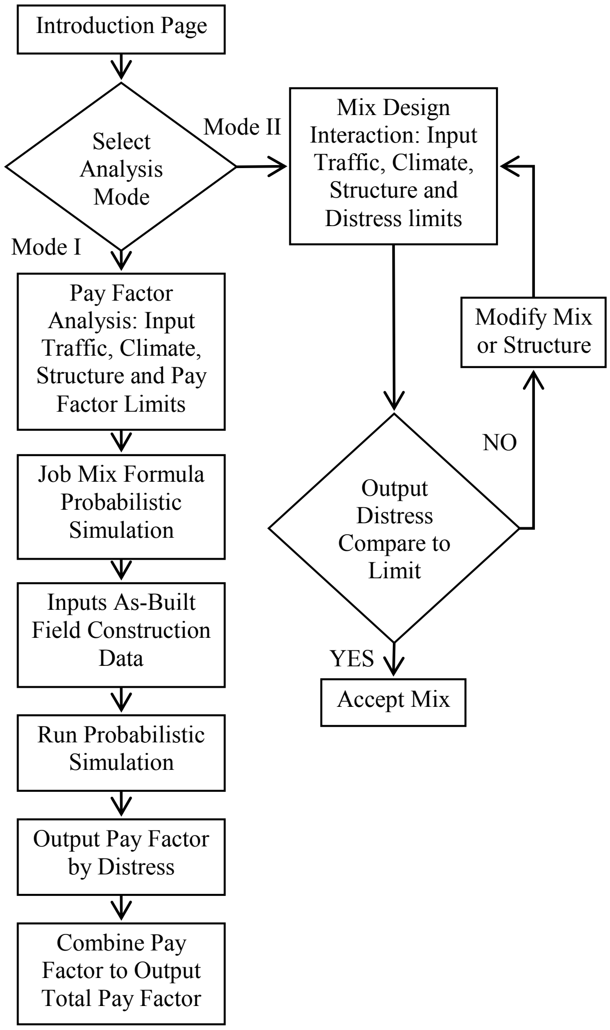


FIGURE I
FLOW CHART FOR THE QRSS [1]

- Project traffic data
- Project design structure / mix volumetric data
- Project climatic data
- Distress selection and allowable distress limits
- Pay factors data
- QA general field information

- QA as-constructed mix data

The project traffic data is associated with projecting the future traffic volume during the project design life (i.e., total equivalent single axle loads – ESALs). The QRSS calculates the ESALs based on the year 1 (first year) daily traffic repetition (ESAL0), design traffic speed, and annual growth rate with a mathematical model shown in Equation 1.

$$ESAL = \frac{(ESAL_0)(365)}{Ln(1+r)}\left[(1+r)^Y - 1\right] \quad \text{(Equation 1)}$$

where
ESAL = total ESAL after design life
$ESAL_0$ = year one, initial daily ESALs on the day traffic is opened,
r = growth rate (rate of traffic increase per year), and
Y = design life in years.

For a pavement structure to be analysed, the program allows up to three AC layers (AC surface, AC binder, and AC base) and three unbound material layers (granular base, subbase, and subgrade) in the structure for the analyses. Design thickness for all selected layers except for subgrade must be specified. The stiffness of the unbound layers represented by resilient modulus value is estimated for the fatigue distress analysis. For the AC rutting analysis, it is assumed that a subgrade layer with a resilient modulus of 14,500 psi is present regardless of the actual subsurface unbound layers [3]. The thermal fracture analysis does not consider the effect of the unbound layers [5]. Figure II is a screen shot of design structure and desired distress selection input taken from the QRSS. The user can choose desired distress to be analysed by checking the distress box in the screen.

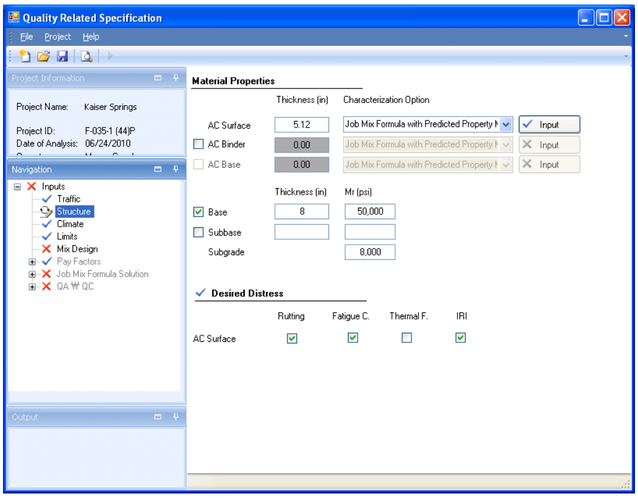


FIGURE II
SCREEN SHOT OF DESIGN STRUCTURE AND DESIRED DISTRESS INPUT

The design JMF volumetric property inputs include lab design air voids, asphalt content by weight, AC binder specific gravity with binder type (PG or AC grade or Pen grade), target in-situ air voids, bulk specific gravity of aggregate, and maximum theoretical specific gravity of AC mix. The in-situ mix volumetrics such as bulk density, effective binder content by volume, voids in mineral aggregate, and voids filled with asphalt are calculated from the relationship between the key volumetric properties. For the aggregate gradation, it is an absolute minimum requirement to enter a percent passing value for the following four sieves because these are critical variables for the mix volumetric-based the Witczak predictive equation for dynamic modulus: 19 mm, 9.5 mm, #4, and #200.

The climatic environmental location should be selected for the consideration of climatic effects on the distress prediction. The QRSS provides two options for the user. The first option is to manually enter the following five key climatic characteristics of the project location into the program: mean annual temperature, standard deviation of mean monthly air temperature, mean annual wind speed, mean annual sunshine, and mean cumulative rainfall depth. These summarized climatic factors are direct variables used for effective temperatures of rutting and fatigue distresses. The second and most convenient option is to choose the weather station near the desired project site from preselected station list. This is identical to the approach used in the MEPDG program. The same routine was incorporated in the QRSS.

The allowable distress limit input is a guideline that the user has to set for the mix and structure pavement design. The amount of distress deterministically predicted from the given input variables for the selected distresses should be less than the allowable distress limit for acceptance. If not, it implies that the design mix or structure or both does not comply with the specification and should be modified to meet the requirement. The program will indicate whether the combination of design mix and structure is acceptable in terms of the allowable distress limit.

For the pay adjustment factors input, the user can either use default values provided by the program or define the factors for a particular project. The factor values are required for each selected distress (i.e. the user can use different pay adjustment schedule by distress). Based upon the pay schedule, the program determines the degree of penalization or award contractors should receive.

For the field mix information, there are two categories: general field information and as-constructed mix information. In the beginning, the user is required to specify the mix design type (e.g., Superpave, or Marshall or others), the tonnage per lot, and the number of lots for each mix. This information is categorized as the general information regarding the field condition. The user is then required to input any necessary as-constructed mix volumetric properties including the key gradation, asphalt content, Rice specific gravity, in-situ bulk density, in-situ AC thickness, and aggregate specific gravity. It is obvious that, unlike the as-design mix input, the as-constructed mix input is done on a lot by lot basis.

C. Major Output Components

Based upon the user input, the program performs necessary computations and provides the results while operated as well as at the end of the program operation. There are four major output components as follows:

- As-design mix deterministic solution
- As-design mix stochastic solution
- As-constructed mix stochastic solution (by lot and by distress)
- Total pay incentive and disincentive summary

The as-design mix deterministic solution shows results deterministically calculated, without considering the variability of the mix property, such as a combination of effective temperature and frequency, Simple Performance Test (SPT) recommended frequency and temperature, allowable dynamic modulus, and most importantly, predicted effective dynamic modulus and distress. With this deterministic solution, the user can determine whether the designed mix and structure given is acceptable to meet a user defined allowable distress requirement. Figure III shows a screen shot of the deterministic solution.

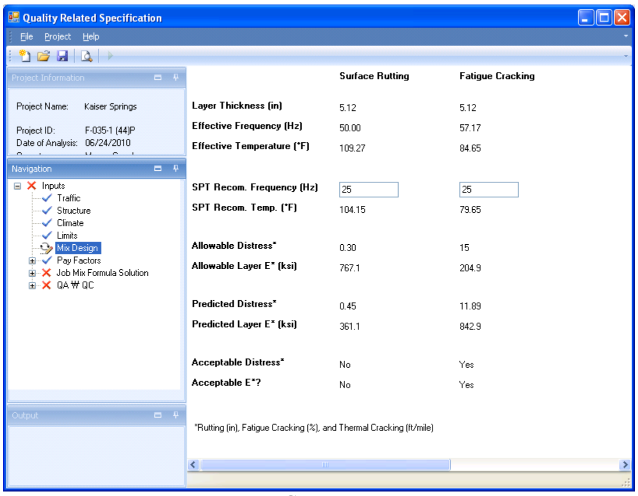


FIGURE III

SCREEN SHOT OF AS-DESIGN MIX DETERMINISTIC SOLUTION

The as-design mix stochastic solution is a solution represented by the mean and variance of the design JMF mix. This solution is obtained considering the design mix and structure variability. In this output, the dynamic modulus, selected distresses, and their service life are expressed in an appropriate type of the frequency distribution (Normal or Beta). The mean and the standard deviation values are estimated from the Monte Carlo simulation or Rosenblueth method based upon the volumetric-involved predicted equations by using historically collected mix variability.

The as-built mix output is one of the core output components. It is displayed in a large table where all essential as-built mix outputs are placed by lot and by distress. The key items include predicted as-built mix dynamic modulus, predicted distress, predicted service life, predicted life difference, and incentive/disincentive.

D. Limitations

Although the researchers who involved the development of the QRSS program claimed the program would enhance the current QA system by incorporating the PRS concept, the users need to be cautious in using the program for pavement quality assurance due to the fact that the prediction procedure contains several important assumptions and they may cause errors. The limitations of the program are discussed as follows.

1) Limit of Applications: The QRSS can be only applicable to a newly constructed asphalt pavement. The program was developed and solely validated with a new construction [1, 2]. The prediction accuracy for other types of pavement construction such as overlay and rehabilitation is not guaranteed. Additionally, when analysing non-conventional asphalt materials including warm mix, stone matrix, reclaimed asphalt, open graded, modified binder, the program may produce inaccurate results and the reliability may be substantially reduced.

2) Distress Prediction Model: The distress prediction models incorporated in the QRSS were originally developed based upon the MEPDG 0.7 version of 2005 [1]. A few years later, the models were once updated in accordance with the upgraded version of the MEPDG. Since then, the MEPDG was newly transformed into the AASHTOWare Pavement ME Design® software with some modifications. Thus, the QRSS prediction models will also be required to keep being updated to stay compatible.

The thermal cracking model was developed as an independent subroutine with the Fortran computer programming language [1,5]. This language is going out of date and thus it will be very difficult to make revision in case it requires an update. Developing a new thermal cracking model for the QRSS is vital. For the rutting distress model, it is only usable for asphalt concrete, not considering the sub asphalt layers [1,3]. In view of the mechanism of the pavement rutting where it is mainly due to insufficient stiffness of AC layers and possibly combined with weak unbound granular layers, the QRSS needs to address this issue to predict more realistic rutting of the entire asphalt pavement structure. The fatigue cracking model has a similar problem. The current model only considers cracks that are propagated from the bottom of the AC structure (i.e., bottom-up fatigue cracking) but does not consider the top-down cracking [1,4]. In fact, this is not the QRSS issue, rather it is an issue of the MEPDG. At the time of the model development, the MEPDG did not have a reliable top-down model and thus the project panel decided not to include the top-down model.

3) Dynamic Modulus Prediction Model: As indicated earlier, the QRSS chose the dynamic modulus as a key material property in the rutting and fatigue distress prediction. The modulus prediction model currently embedded in the QRSS is based upon the 1999 version of Witczak Predictive Equation. However, research shows that this equation does not comprehensively explain various asphalt material types, especially when modified asphalt binders are used. It's widely known that the prediction accuracy of the model drops significantly with the modified materials. Therefore, the practitioners need to be careful when using the QRSS for non-conventional asphalt mix materials.

III. CASE STUDY

A. Project Selection and Input Data

One of the real pavement sites constructed in Arizona was selected for this case study. The project named "Kaiser Springs" was a new AC construction located on the Arizona highway system, US-93, which connects the centre of Arizona to Nevada. The design traffic speed was 65 mph and the expected traffic volume during the designed pavement service life of 20 years was found to be 6.0 million ESALs.

To see the effect of environment on the pavement distresses, the same input data of the selected pavement section was applied to two other climatic regions: mild and cold (i.e. three climatic regions including the original site location – Arizona). The selected locations are listed as follows:

- Anchorage, Alaska (AK) as a cold climatic region
- Omaha, Nebraska (NE) as intermediate climatic region
- Phoenix, Arizona (AZ) as a hot climatic region

The structure of the project consisted of one AC layer and one unbound granular base on top of subgrade. The thickness of the base was 8.0 inches. Since the stiffness information of the unbound layer was not available, it was reasonably assumed that the stiffness values of the base and subgrade were to be 345 MPa (50,000 psi) and 55 MPa (8,000 psi), respectively. It should be noted that the same structure and volumetrics were applied to all three locations to see the effect of climate on the distresses.

The summary of the as-design mix volumetric properties in the selected site for the AC layer is presented in Table I. Arizona Department of Transportation (ADOT) performed the mix design for the project in accordance with the ADOT asphalt pavement design specifications and the final JMF was obtained. The volumetric properties listed in the table are essential to properly run the QRSS. The properties include the design and target air voids, asphalt content, four aggregate gradations, maximum theoretical mix specific gravity (Gmm), combined aggregate specific gravity (Gsb), asphalt binder specific gravity (Gb). Several volumetrics (Gmb, Vbeff, Voids in the Mineral Aggregate, and Voids Filled with Asphalt) were calculated based on the other key properties. In the table, note that the specific gravity values are dimensionless.

TABLE I
INPUT VARIABLE USED FOR THE CASE STUDY

Category	Parameter	Value
AC Mix Properties	Design Air Voids (%)	5.0
	Target In-Situ Air Voids (%)	7.0
	AC Content (%)	4.8
	Aggregate Passing 3/4" (%)	92
	Aggregate Passing 3/8" (%)	53
	Aggregate Passing #4 (%)	34
	Aggregate Passing #200 (%)	4.1
	Theoretical Maximum Specific Gravity of HMA: G_{mm}	2.473
	Specific Gravity of Bulk Aggregate: G_{sb}	2.616
	Specific Gravity of HMA: G_{mb}	2.300
	Effective Binder Content by Volume: V_{beff} (%)	9.480
	Voids in the Mineral Aggregate: VMA (%)	16.5
	Voids Filled with Asphalt: VFA (%)	57.5
AC Binder Properties	Binder Type:	PG 70-16
	Ai: Intercept of the Temperature - Viscosity Equation in the Short-Term Aging Condition	10.641
	VTSi: Slope of the Temperature – Viscosity Equation in the Short-Term Aging Condition	-3.548
	Specific Gravity of AC Binder: G_b	1.027

A large amount of QA/QC data collected in the "Kaiser Springs" site was used to run the QRSS for the as-built mix analysis. Total 10 lots were used and each lot was defined as daily tonnage (asphalt mix production per day). Based on the input data prepared for each lot as shown in Table II, a comprehensive analysis of the project sections was conducted with the QRSS. Note that the values in the table is the average of four sublots within each individual lot. The average and standard deviation of each variable are used in the stochastic solution (Monte Carlo Simulation or Rosenblueth method). The Kaiser Springs project is actually located in the northern part of AZ and the mean annual air temperature was reported to be 14.7 °C. It implies that the magnitude of predicted distress amount may not be realistic to some regions when the same QA/QC data which is suitable with the particular environmental location is applied to different environmental regions. However, considering that the purpose of using the same data to diverse regions is to validate the reasonableness of the QRSS performance by relatively comparing the program outputs, the same QA/QC data set for all three environmental locations was used.

TABLE II
SELECTED AS-BUILT MIX INPUT VARIABLE (AVERAGE VALUES ONLY)

LOT No.	Air Voids (%)	Asphalt Content (%)	Pass. 19mm (%)	Pass. 9.5mm (%)	Pass. #4 (%)	Retained #200 (%)
1	6.1	4.9	95	60	40	3.6
2	6.9	5.0	96	61	39	3.2
3	8.2	5.1	94	58	37	3.2
4	8.5	4.6	94	52	34	3.2
5	8.9	4.8	94	55	34	3.0
6	5.8	4.9	95	56	34	3.3
7	6.1	5.0	95	58	36	3.5
8	6.7	5.2	95	59	37	3.5
9	6.2	4.9	96	60	38	3.5
10	7.2	4.8	95	54	34	3.2

B. Project Result and Discussion

1) Effective Temperature and Frequency: The top portion of Table III summarizes the effective temperature and frequency of the AC layer determined for each distress and each location. It is obvious that the effective temperature in a colder location is lower than that in a warmer location for both distresses. It should be noticed that the rutting effective temperature is higher than fatigue distress effective temperature. Also, it is important to notice that the fatigue effective frequencies for all three locations are the same. This is because the fatigue effective frequency is a function of the design tire radius (*a*), the equivalent AC thickness (h_{eq}), and the design traffic speed (*v*) as shown in Equation 2 [4]:

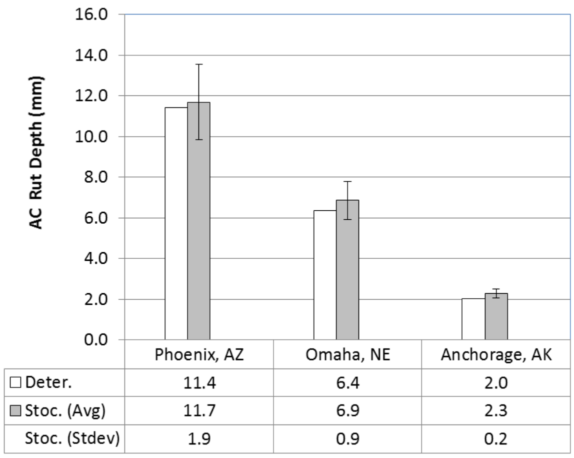
$$f_{eff} = \frac{17.6v}{2\left(a + h_{eq}\right)} \qquad \text{(Equation 2)}$$

The bottom portion of Table III lists the SPT effective temperatures for the distresses at the three locations. They were calculated at a fixed frequency of 25 Hz. One major advantage of using the effective temperature and frequency is that they could simplify the process of an asphalt material characterization. However, if the calculated effective frequency is more than 25 Hz, then it may not be suitable to conduct the test due to the limitations of lab equipment. For this reason, it is necessary to define a new (suitable) frequency and the corresponding equivalent temperature, commonly known as SPT-recommended frequency and temperature. These values can be calculated by using the time-temperature superposition principle for a given asphalt mixture dynamic modulus master curve.

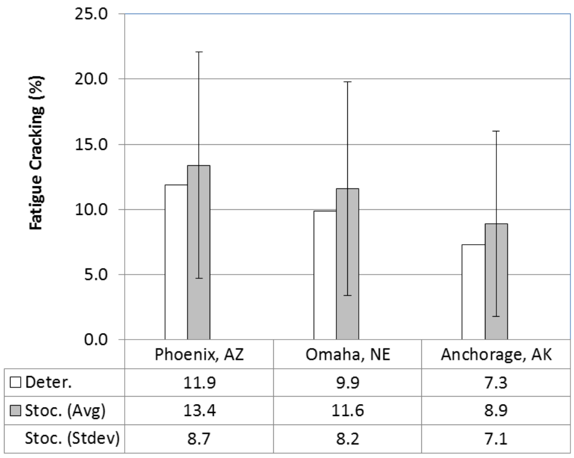
TABLE III
EFFECTIVE TEMPERATURES AND FREQUENCIES FOR EACH LOCATION: BEFORE AND AFTER ADJUSTMENT

Distress	Unit	Before Adjustment		
		Phoenix, AZ	Omaha, NE	Anchorage, AK
Rutting	Temp. (°C)	40.1	30.0	13.4
	Freq. (Hz)	50.0	44.1	35.8
Fatigue	Temp. (°C)	26.5	15.4	-0.7
	Freq. (Hz)	57.2	57.2	57.2
Distress	Unit	After Adjustment		
		Phoenix, AZ	Omaha, NE	Anchorage, AK
Rutting	Temp. (°C)	42.9	32.0	14.8
	Freq. (Hz)	25.0	25.0	25.0
Fatigue	Temp. (°C)	29.3	17.8	1.1
	Freq. (Hz)	25.0	25.0	25.0

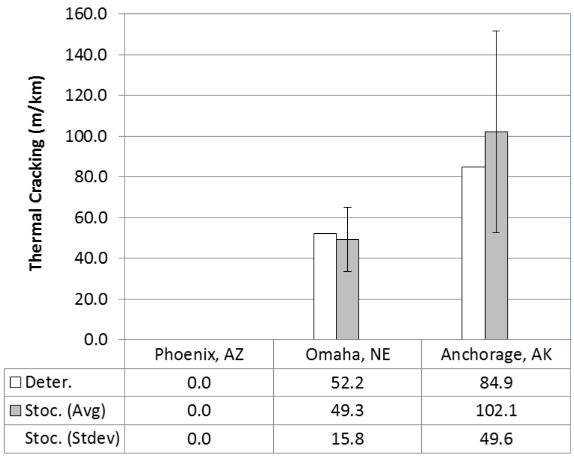
2) Design Mix Result: The deterministic and stochastic solutions of predicted distresses in three locations resulted from the QRSS are presented in Figure IV. The trend of distress predictions against climate was found to be valid, as evident in Figure IV(a). The rut depth prediction was quite small in a cold location (AK), and obviously the rut depth went up in a warm location (AZ). For the thermal cracking, it occurred in the opposite way which was correct, as shown in Figure IV(c). No thermal cracking occurred in AZ. It may be due to the warm climate in the southwest region in America. Figure IV(b) shows the trend of fatigue cracking prediction over the climate change. It is widely known that the fatigue cracking is more dependent upon the pavement structure such as AC thickness and unbound material stiffness. With the given AC thickness used in this case study (h_{ac} = 130 mm (5.12 in.)), the fatigue distress increased with going to warmer climatic location, which is not always the case.



(a)



(b)



(c)

FIGURE IV
DESIGN MIX DETERMINISTIC RESULTS: (a) RUT DEPTH, (b) FATIGUE CRACKING, AND (c) THERMAL CRACKING

The stochastic solution results for the as-design mix were also obtained by simulating the design JMF mix data for the selected climatic regions. The average and standard deviation of all three distresses for the as-design mix was calculated from the statistical applications: Monte Carlo simulation for the rutting and fatigue distresses and Rosenblueth method for thermal fracture. The results showed the fairly similar trend as described in the deterministic solution results with respect to the fact that the average amount of distress was rationally predicted for each distress by location. The standard deviation values also followed the rational trend as expected, too where the standard deviation values increases with the increase of the corresponding average distress.

The average distress level of rutting and fatigue distresses decreases with the decrease of air temperature (i.e., warm region to cold region). As explained in the deterministic solution part, this is rational because a strong AC mix is more resistible against those distresses (i.e., an AC mix having lower stiffness is more vulnerable to the distresses).

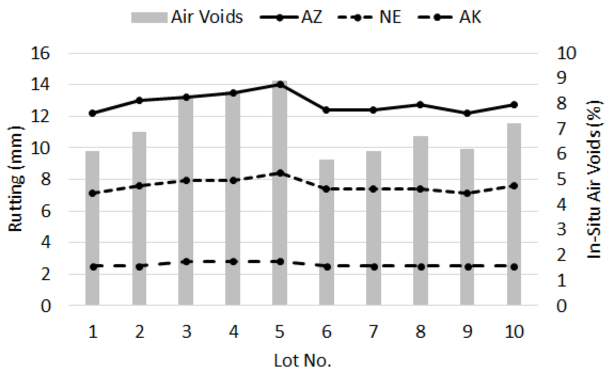
3) As-Built Mix Stochastic Results: The stochastic solution results of the as-built mix are presented in Table IV for each lot and location. It needs to be recalled that the material quality of each lot greatly varies dependent upon how the material properties of each lot are consistent with the specified JMF. Similarly to the as-design stochastic results, the trend of average predicted distress with the climatic locations was found to be rational for all three distress types as illustrated in Figure V. For instance, the rut depth predicted in AK is noticeably smaller than that in AZ. This fact is observed throughout the entire lots. The similarity was also found with respect to the thermal cracking (i.e., TC increases with the decrease of air temperature).

The average predicted distress was also found to reasonably reflect the mix quality. As it is widely known that the in-place air voids act as a key player in causing distresses, the resulting distresses of each lot was compared with the respective lot air voids level. The air voids gradually increases from Lot 1 to Lot 5 and there is a sharp drop in Lot 6. The rut depth predicted by the QRSS captures the effect of air voids for all three locations. A similar result is observed for the fatigue cracking as shown in Figure V(b). The fatigue cracking reaches the peak at Lot 5 where the highest air voids level is found. As for the thermal fracture prediction, the impact of air voids is significant in the intermediate climatic region (NE). Note that the low temperature cracking does not occur in AZ.

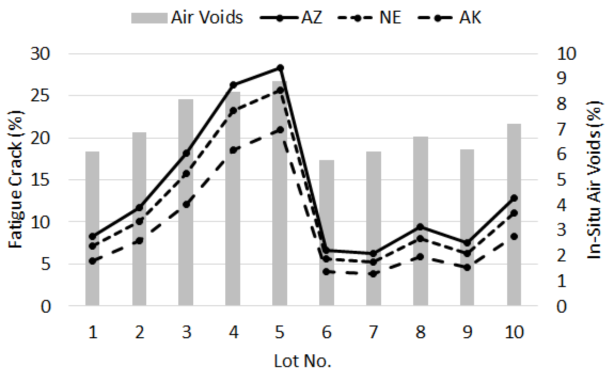
Overall, it was found that the QRSS correctly caught the effect of the major material property and reflected in predicting distresses.

TABLE IV
AS-BUILT MIX AVERAGE DISTRESS PREDICTION RESULTS

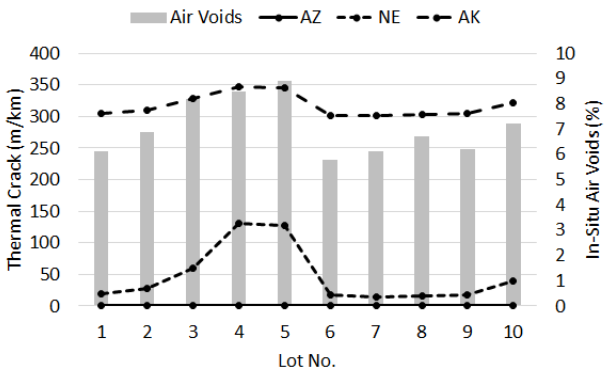
Distress	Region	LOT NO. (1 - 5)				
		1	2	3	4	5
Rutting (mm)	AZ	12.2	13.0	13.2	13.5	14.0
	NE	7.1	7.6	7.9	7.9	8.4
	AK	2.5	2.5	2.8	2.8	2.8
Fatigue (%)	AZ	8.3	11.7	18.2	26.3	28.3
	NE	7.1	10.1	15.8	23.3	25.6
	AK	5.4	7.8	12.1	18.5	21.0
Thermal (m/km)	AZ	0	0	0	0	0
	NE	18.7	27.3	60.6	131.6	127.1
	AK	305.5	310.2	328.0	347.5	345.8
Distress	Region	LOT NO. (6 - 10)				
		6	7	8	9	10
Rutting (mm)	AZ	12.4	12.4	12.7	12.2	12.7
	NE	7.4	7.4	7.4	7.1	7.6
	AK	2.5	2.5	2.5	2.5	2.5
Fatigue (%)	AZ	6.6	6.3	9.4	7.5	12.9
	NE	5.6	5.3	8.0	6.2	11.1
	AK	4.1	3.9	5.9	4.6	8.3
Thermal (m/km)	AZ	0	0	0	0	0
	NE	16.9	14.4	16.7	18.2	39.4
	AK	301.9	301.9	302.8	305.5	321.8



(a)



(b)



(c)

FIGURE V
AS-BUILT MIX DISTRESS VERSUS AIR VOIDS: (A) RUT DEPTH, (B) FATIGUE CRACKING, AND (C) THERMAL CRACKING

V. CONCLUSIONS AND RECOMMENDATIONS

This paper evaluates the validity of the quality assurance tool with respect to asphalt pavement performance using a case study. The following conclusions can be drawn from the case study:

- The QRSS has a convenient and user friendly input and output system for an asphalt pavement quality assurance tool. The performance results computed from the program seem reasonable and valid.
- The QRSS reasonably reflects the climatic effect in the distress computation. The warmer the site location, the more rutting and the less thermal cracking occur. For the fatigue cracking, it's difficult to determine whether the QRSS is accurate enough. With the given case study, however, the results seem valid. More case studies are recommended for further evaluations.
- The deterministic solution and the average of the stochastic solution are very close proving the computation process for both modes is effective. It also supports that the stochastic modules of Monte Carlo Simulation and Rosenbleuth method work well with no serious issue.
- The QRSS reasonably addresses the effect of the in-place air voids on the distress prediction for the as-built mix.

Although the study presented in this paper drew several important findings from the case study, a more rigorous validation study is necessary to further evaluate the QRSS. The ideal method will be to use the AASHTO ME Design Software since the QRSS distress prediction models are inherently originated from the AASHTO program. Also, as described in Section II, the users of the QRSS needs to understand that the QRSS has quite a few limitations and they may cause inaccurate calculations and the distress predictions. Eventually, the error will affect the final pay adjustment system (i.e., incentive / disincentive determinations) to the contractors. The limitations needs to be addressed when the QRSS are upgraded to be a new version.

REFERENCES

[1] Fugro Consultant Inc., Arizona State University, NCHRP Report 704. "A Performance-Related Specification for Hot-Mixed Asphalt." Transportation Research Board of the National Academies, Washington, D.C., 2011.
[2] M. El-Basyouny, M.G. Jeong, "Probabilistic Performance-Related Specifications Methodology Based on Mechastic-Empirical Pavement Design Guide", In *Transportation Res. Record: J. of the Transportation Res. Board*, 2151, pp. 93-102, 2010.
[3] M. El-Basyouny, M.G. Jeong, "Prediction of the MEPDG Asphalt Concrete Permanent Deformation Using Closed Form Solution", *Int. J. Pavement Res. Technol.* 7 (6), pp. 397-404, 2014.
[4] S.M. El-Badawy, M.G. Jeong, M. El-Basyouny, "Methodology to Predict Alligator Fatigue Cracking Distress Based on Asphalt Concrete Dynamic Modulus", In *Transportation Res. Record: J. of the Transportation Res. Board*, 2025, pp. 115-124, 2009.
[5] M.G. Jeong, "Stochastic Analysis of Thermal Cracking Distress of Asphalt Pavements Using the MEPDG Thermal Cracking Model", *Int. J. Pavement Res. Technol.* 7 (6), pp. 425-433, 2014.
[6] M. El-Basyouny, M. G. Jeong, "Effective Temperature for Permanent Deformation and Fatigue Distress Analysis on Asphalt Mixtures", In *Transportation Res. Record: J. of the Transportation Res. Board*, 2127, pp. 155-163, 2009.
[7] M.G. Jeong, M. El-Basyouny, "Statistical Applications and Stochastic Analysis for Performance Related Specification of Asphalt Pavement Quality Assurance", In *Transportation Res. Record: J. of the Transportation Res. Board*, 2151, pp. 84-92, 2010.
[8] Applied Research Associates, Inc., "Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures", Final Report, National Cooperative Highway Research Program Project 1-37A, National Research Council, Washington, D.C., 2004.