Effective Timing for Sequential Applications of Slurry Seal on Asphalt Pavement Performance
(Paper No. 12-4524)

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Word Count: 3842 + 2*250 + 13*250 = 7592
Submission Date: August 1, 2011
Revision Date: November 8, 2011

ABSTRACT

This study evaluated the field performance of asphalt pavements with sequential slurry seal applications, developed performance models for asphalt pavements without slurry seals and asphalt pavements receiving slurry seals at various times following construction, and identified the optimum time for the application of two slurry seals on asphalt pavements within the Washoe County, Nevada region. This is a continuation of a previous study in which only one application of slurry seal was investigated. The long-term pavement performance data collected was evaluated using the MicroPAVER system for the last 15 years and the cost-effectiveness of slurry seals applied to new and existing flexible pavements at years 0, 1, 3, 5, 7 and 9 after construction. The optimum times and highest relative benefit of application of slurry seals for both overlays and new construction pavements was when the first slurry seal was applied at year 3 followed by a second slurry seal at year seven or nine.

Keywords: Slurry seal, asphalt pavement treatment, pavement maintenance, optimum time, benefit cost ratio, performance life, service life

INTRODUCTION

Pavement preservation has been proven to reduce local and state agencies' overall transportation costs. Pavement preservation addresses pavements that are still in good condition. They restore the function of the existing roadway, but not increase its capacity or strength. With timely pavement preservation, the occurrence of more costly, time consuming rehabilitation and reconstruction techniques can be reduced and also provide users with safer and more comfortable rides. Although the selection of the appropriate pavement preservation technique is critical for a long lasting pavement, this study focuses on one of the treatments: the slurry seal.

A slurry seal is a mixture of slow setting emulsified asphalt, well graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavements, to restore a uniform surface texture, to seal the surface to prevent moisture and air intrusion into the pavement, and to improve skid resistance *(1)*.

This report is a continuation of a study conducted by the Pavements/Materials Program at the University of Nevada, Reno (UNR) for the Washoe Regional Transportation Commission (RTC) to evaluate the field performance of slurry seals on asphalt pavements. The optimum time for the application of a single slurry seal has already been determined *(2)*, this study focuses on the optimum time for sequential application of slurry seals on asphalt pavements.

OBJECTIVE

The overall objectives of this study are (1) to evaluate the field performance of asphalt pavements with sequential slurry seal applications, (2) to develop performance models for asphalt pavements without slurry seals and asphalt pavements receiving sequential slurry seals at various times following construction, and (3) to identify the optimum time for the application of sequential slurry seals on asphalt pavements within the Regional Transportation Commission (RTC) region in northern Nevada. This objective was achieved by evaluating the long-term pavement performance and the cost-effectiveness of sequential slurry seals applied to new and existing flexible pavements within the Washoe county, Nevada region with respect to the time of slurry seal application.

BACKGROUND

Pavement performance is defined as the serviceability trend of the pavement over a design period, where serviceability indicates the ability of the pavement to serve the demand of the traffic in the existing condition *(3)*. A pavement performance model can be described as an equation that relates a pavement performance index with time. It serves as a valuable tool to aid in the prediction of the future pavement condition of the pavement based on the current pavement condition data. Additionally, pavement performance models are critical to the pavement management process, as the scheduling of maintenance and rehabilitation (M&R) activities is based on the present pavement serviceability conditions measured in the field and future pavement service conditions predicted with pavement performance models *(4)*.

It has been noted that a valuable method to prioritize and justify transportation infrastructure expenditures is the use of road surface condition ratings such as the pavement condition index (PCI) *(5)*. By utilizing road surface ratings in conjunction with construction and

maintenance histories, pavement condition prediction models can be developed which are imperative for the development of a complete pavement management system.

As mentioned, this project is a continuation of a slurry seal study by Hajj et al. *(2)* in which they determined the optimum time to place a single slurry seal on Nevada roads. From their study, they concluded that the optimum time of application of slurry seal for newly constructed flexible pavements was three years after construction. For pavements subjected to overlays, the optimum time to apply slurry seal was between three and five years after construction. The application of the slurry seal immediately after or one year after construction of the asphalt layer was not effective in terms of both the benefit to the users and the benefit cost ratio for the agency. Similarly, previous work has demonstrated the cost-effectiveness of modified slurry seals *(6)*.

Furthermore, Hajj et al. *(2)* determined for the various single slurry seal applications, the slurry seal performance lives and the extensions in pavement service life. The slurry seal performance life was defined as the number of years for the slurry seal performance curve to reach the PCI of the existing pavement before treatment application. In other words, the slurry seal performance life is the number of years for the treated pavement section that provides a higher user satisfaction before it returns to the serviceability condition before treatment. Whereas, the extension in pavement service life is the number of additional years the pavement will have at the end of its service life (i.e. PCI = 40) due to the application of the slurry seal. In other words, the extension in pavement service life is the number of years a pavement reconstruction is delayed. Typically, the slurry seal performance life ranged from 2.0 to 4.0 years, except when applied in year 0 and 1, it ranged between 0.0 to 1.0 years. Except in very few cases, the pavement service life was not extended by the application of the single slurry seal.

The pavement modeling for this study is utilized for the identification of the effectiveness of a slurry seal application to a flexible pavement with respect to time within the Washoe county region. To document pavement performance, the Washoe County Engineering Department (WCED) uses the MicroPAVER pavement management software system that is supported, maintained, and periodically updated by the Construction Engineering Research Laboratories (CERL) of the US Army Engineer Research and Development Center *(7)*.

The MicroPAVER system works in conjunction with the ASTM D6433 inspection standard to determine and monitor the pavement condition index (PCI) of a given roadway section. The PCI rating of a roadway is based on the observed surface distresses. The PCI rating is not a direct measure of structural capacity, skid resistance or road roughness; however, it is an objective tool for assessing the M&R needs of roadway section with respect to an entire pavement system.

The environmental conditions of the Washoe county region can be characterized as a high desert, which generally indicates relatively low annual precipitation rates, generally around 10 inches, but nearly all locations in the county below 20 inches, except for the mountainous regions surrounding Lake Tahoe *(8)*. Being a high desert, the area is subjected to relatively high summer temperatures, periodically over 100°F, and generally mild winters, usually not below 0°F. However, the region is subjected to significant daily temperature fluctuations varying by 30 to 40°F, but may exceed 45°F, between consecutive day and night temperatures throughout the year *(9)*.

EVALUATED PAVEMENT SECTIONS

All asphalt pavement sections identified for this study were within the jurisdictions of: Washoe County, City of Reno and City of Sparks. The evaluation covered two pavement types: newly constructed pavements and pavements that received overlays. Asphalt mixtures were generally dense graded HMA with a 0.50 or 0.75 inch nominal maximum aggregate size with AC-20, AR4000 or PG64-22 unmodified asphalt binders. Slurry seals were designed in accordance with guidelines contained in International Slurry Surfacing Association (ISSA) Publication A105 *(10)*. Emulsion asphalts consisted of latex modified cationic quick set with a minimum of 3 percent latex rubber by weight of the binder following agencies requirements. Only residential roads within the three jurisdictions experienced sequential slurry seal applications. There were no projects found for arterial or collector roads. The Washoe county regional functional classification for residential roads is defined as having an approximate average daily traffic (ADT) of less than 6,000 with a high percentage of trucks (>4%), and lower volume roads that provide direct access to commercial and industrial lands.

A total of 2373 pavement sections were evaluated for the do nothing condition (pavements without any slurry seal applications throughout its pavement life) with 525 pavement sections being newly constructed and 1,848 pavement sections that received overlays. Furthermore, a total of 321 pavement sections that only had one slurry seal for their whole entire pavement life applied at year 0 were evaluated with 85 pavements sections being newly constructed and 236 pavement sections that received overlays.

A total of 172 pavement sections were evaluated in this study that experienced sequential slurry seal applications with 82 pavement sections being newly constructed and 90 pavement sections that received overlays. These pavement sections were broken into the following two categories:

- First slurry seal applied either immediately after construction (0 years after construction), 1, 3, or 5 years after construction
- Second slurry seal applied at 7 or 9 years after construction

The performance of the various pavement sections were measured in terms of the PCI that the agencies collect using the MicroPAVER system. All three local agencies use the same pavement evaluation procedures and score their pavements on the same cycle (i.e. every other year). A joint refresher meeting is held every year to ensure that all pavement survey teams are conducting similar survey results. Additionally, a portion of the network is periodically cross-scored by an independent rating source to make sure that ratings between each agency are comparable *(11)*.

MicroPAVER divides the road network into sections based on uniform properties of the pavement and traffic conditions. Each pavement section is further divided into units and the units to be surveyed within a given section are identified randomly. The average PCI value of the surveyed units within each section is used to represent the condition of the entire section for the specific survey date.

PERFORMANCE MODELS

The PCI data collected by the owner agencies were used to develop the performance prediction models. Figure 1a and 1b present individual PCI measurements as well as the developed fourth-

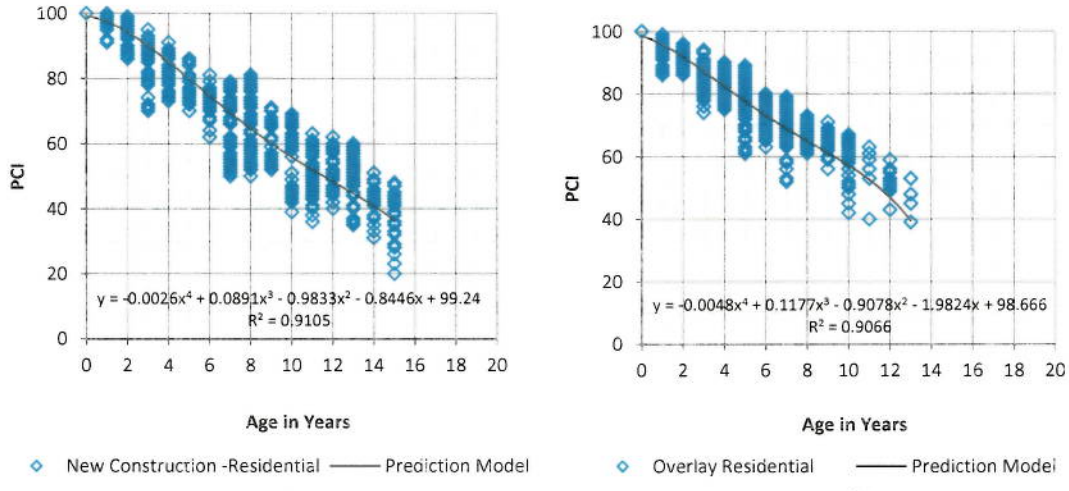
degree polynomial family performance prediction model for the do-nothing condition for both new construction and overlay sections. Only data that have been processed through a filtering and outlier analysis were used to develop the performance prediction models. Performance prediction models for the various sequential slurry seal conditions were developed in a similar fashion.

The do-nothing performance prediction model as well as the performance prediction model for sections that only had one slurry seal applied at year 0 throughout their pavement life were used to help determine the improvement in performance of the various sequential slurry application conditions. In order to forecast the performance prediction model after a first or second slurry seal is applied, they need to be shifted to a present PCI-age point. Once this shift is applied, it is assumed that the deterioration of all pavement sections in a family is similar and is a function of only their present condition, regardless of age (7). It must be noted that the performance prediction models were not shifted farther than 1.2 years.

Table 1 presents all the various performance prediction models used for project. The number of sections reported in Table 1 represents the number of sections identified by the MicroPAVER system. This indicates that multiple sections may have been located on the same road. The sections identification nomenclature was organized as follows: for example, OL-0-7 would indicate **overlay** pavements that received the first slurry seal at year **0** and the second slurry seal at year **7**. Similarly, NC-0-7 would indicate **newly constructed** pavements that received the first slurry seal at year **0** and the second slurry seal at year **7**.

As indicated in the column indicating age range in Table 1, the performance models are only valid over certain pavement age ranges. For example, the performance model for OL-0-9 for treatment year of 9 years can only be used to predict PCI values when the pavement is 9 years or older.

The R^2 value indicates the coefficient of determination between the model and the actual data. An R^2 value of 1.00 indicates a perfect fit between the model and the data and an R^2 value of 0.00 indicates a very poor fit.



(a) (b)

Figure 1 Developed performance curves for the do nothing condition for a) new construction and b) overlay sections.

Table 1 Performance models for newly-constructed and overlay pavements.

ID	Number of Sections	Trt Year of Application	Age Range (years)	Performance Model	R^2
Do nothing, Overlays – OL			$Age \geq 0$	$PCI = -0.0048Age^4 + 0.1177Age^3 - 0.9078Age^2 - 1.9824Age + 98.666$	0.907
Slurry Seal @ Year 0 - OL			$Age \geq 0$	$PCI = -0.0041Age^4 + 0.1056Age^3 - 0.8448Age^2 - 2.2707Age + 99.849$	0.973
Do nothing, New Construction – NC			$Age \geq 0$	$PCI = -0.0026Age^4 + 0.0891Age^3 - 0.9853Age^2 - 0.8446Age + 99.24$	0.911
Surry Seal @ Year 0 - NC			$Age \geq 0$	$PCI = -0.0023Age^4 + 0.0805Age^3 - 0.8721Age^2 - 1.4712Age + 99.924$	0.977
OL-0-7	15	0	$0 \leq Age \leq 7$	$PCI = -0.0165Age^4 + 0.2949Age^3 - 1.7736Age^2 - 1.5027Age + 100.03$	0.989
		7	$Age \geq 7$	$PCI = -0.0395Age^4 + 1.6286Age^3 - 24.513Age^2 + 153.73Age - 260.28$	0.959
OL-0-9	17	0	$0 \leq Age \leq 9$	$PCI = -0.0244Age^4 + 0.4825Age^3 - 3.0234Age^2 + 1.4635Age + 98.752$	0.976
		9	$Age \geq 9$	$PCI = -0.0853Age^4 + 3.6414Age^3 - 56.628Age^2 + 371.11Age - 772.95$	0.936
OL-1-7	13	1	$1 \leq Age \leq 7$	$PCI = 0.0025Age^4 - 0.0636Age^3 - 0.3471Age^2 - 4.8768Age + 104.34$	0.992
		7	$Age \geq 7$	$PCI = -0.0318Age^4 + 1.285Age^3 - 19.169Age^2 + 120.21Age - 187.49$	0.951
OL-1-9	10	1	$1 \leq Age \leq 9$	$PCI = -0.0046Age^4 + 0.131Age^3 - 1.1386Age^2 - 1.176Age + 101.9$	0.993
		9	$Age \geq 9$	$PCI = -0.0119Age^4 + 0.4477Age^3 - 5.5291Age^2 + 14.536Age + 150.44$	0.983
OL-3-7	17	3	$3 \leq Age \leq 7$	$PCI = -0.0625Age^4 + 1.375Age^3 - 11.688Age^2 + 38.875Age + 56.5$	0.944
		7	$Age \geq 7$	$PCI = 0.0076Age^4 - 0.4031Age^3 + 7.3648Age^2 - 59.809Age + 267.21$	0.988
OL-3-9	12	3	$3 \leq Age \leq 9$	$PCI = -0.0457Age^4 + 1.1416Age^3 - 10.54Age^2 + 37.202Age + 55.974$	0.990
		9	$Age \geq 9$	$PCI = -0.0095Age^4 - 0.0233Age^3 + 1.2645Age^2 - 21.495Age + 193.05$	0.988
OL-5-9	6	5	$5 \leq Age \leq 9$	$PCI = 0.1167Age^4 - 2.925Age^3 + 26.158Age^2 - 104.8Age + 262.5$	0.979
		9	$Age \geq 9$	$PCI = -0.0308Age^4 + 1.5823Age^3 - 30.31Age^2 + 249.14Age - 654.22$	0.983
NC-0-7	10	0	$0 \leq Age \leq 7$	$PCI = -0.0248Age^4 + 0.3615Age^3 - 1.9867Age^2 - 0.5081Age + 100.09$	0.990
		7	$Age \geq 7$	$PCI = -0.0401Age^4 + 1.8221Age^3 - 30.014Age^2 + 204.81Age - 402.3$	0.991
NC-0-9	12	0	$0 \leq Age \leq 9$	$PCI = -0.0145Age^4 + 0.3004Age^3 - 2.0051Age^2 - 0.4084Age + 99.452$	0.979
		9	$Age \geq 9$	$PCI = -0.2215Age^4 + 10.258Age^3 - 176.82Age^2 + 1335.5Age - 3637.3$	0.980
NC-1-7	15	1	$1 \leq Age \leq 7$	$PCI = 0.0025Age^4 - 0.0636Age^3 + 0.3471Age^2 - 4.8768Age + 104.34$	0.992
		7	$Age \geq 7$	$PCI = -0.0214Age^4 + 0.9241Age^3 - 14.652Age^2 + 95.982Age - 140.61$	0.956
NC-1-9	12	1	$1 \leq Age \leq 9$	$PCI = 0.0166Age^4 - 0.3062Age^3 + 1.7789Age^2 - 7.9927Age + 106.32$	0.977
		9	$Age \geq 9$	$PCI = -0.1279Age^4 + 6.0189Age^3 - 105.95Age^2 + 819.19Age - 2257.7$	0.995
NC-3-7	15	3	$3 \leq Age \leq 7$	$PCI = 0.1597Age^4 - 3.1528Age^3 + 22.59Age^2 - 72.931Age + 187.67$	0.948
		7	$Age \geq 7$	$PCI = -0.0032Age^4 + 0.1351Age^3 - 2.4789Age^2 - 17.543Age + 56.59$	0.983
NC-3-9	11	3	$3 \leq Age \leq 9$	$PCI = -0.0519Age^4 + 1.2266Age^3 - 10.574Age^2 + 36.15Age + 57.839$	0.856
		9	$Age \geq 9$	$PCI = 0.0224Age^4 - 1.2347Age^3 + 24.577Age^2 - 215.9Age + 799.08$	0.993
NC-5-9	7	5	$5 \leq Age \leq 9$	$PCI = 0.3417Age^4 - 9.4083Age^3 + 95.133Age^2 - 424.12Age + 804.5$	0.989
		9	$Age \geq 9$	$PCI = -0.0308Age^4 + 1.5823Age^3 - 30.31Age^2 + 249.16Age - 654.22$	0.990

Figure 2 shows a typical performance curve for the do nothing condition, the first slurry seal, and the second slurry seal superimposed on a PCI versus time plot. The slurry seal performance lives and extensions in pavement service life can be determined for the various slurry seal applications. As defined before, the slurry seal performance life is defined as the number of years for the slurry seal performance curve to reach the PCI of the existing pavement before treatment application. Whereas, the extension in pavement service life is the number of additional years the pavement will have at the end of its service life (i.e. PCI = 40) due to the application of the slurry seal. For example, it took 4.3 years for the first slurry seal applied on year 3 of service to the newly constructed residential road to deteriorate from a PCI of 100 right after treatment to the pre-treatment PCI of 88 (ΔPCI = 12) (Figure 2). Furthermore, it took 2.5 years for the second slurry seal applied on year 9 of service to deteriorate from a PCI of 93 right after treatment to the pre-treatment PCI of 80 (ΔPCI = 13). Therefore, the performance life for the first slurry seal is 4.3 years, whereas the performance life for the second slurry seal is 2.5 years. For the same example, the two treatments of slurry seal extended the pavement service life and delayed the time until a PCI of 40 was reached by 3.2 years (see Figure 2).

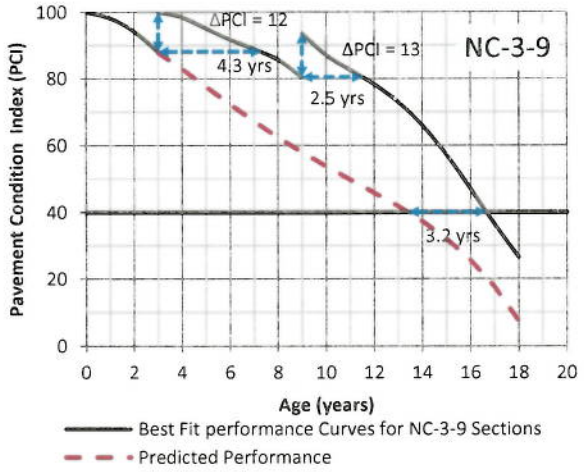
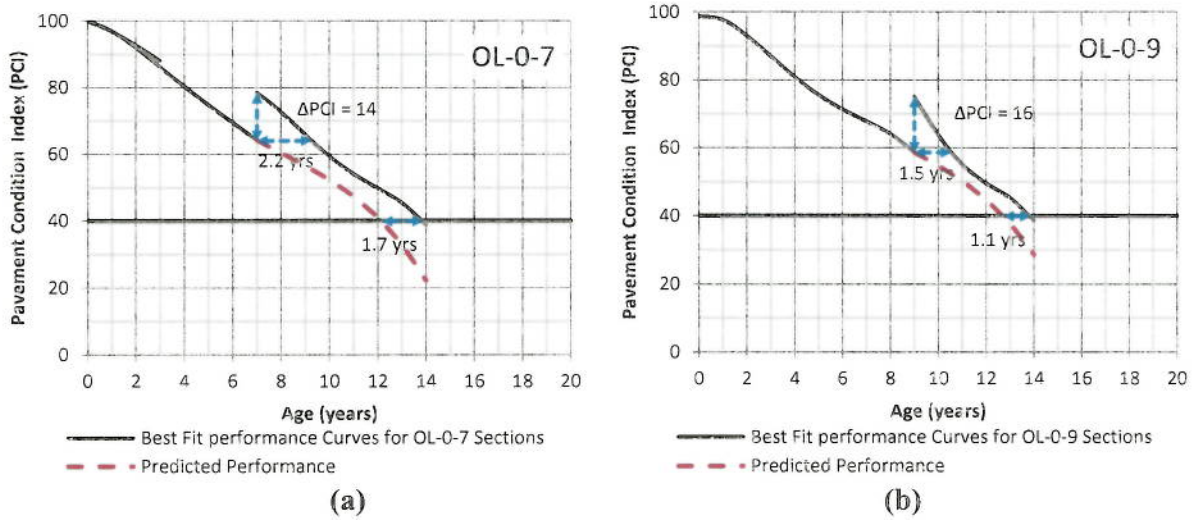


Figure 2 Performance curves for a newly constructed residential section for the do-nothing condition and slurry seals applied in year 3 and 9.

Figures 3 to 10 presents all the various cases of sequential application of slurry seals for overlays and newly constructed pavements. The performance model for pavements without slurry seals (do nothing case) is superimposed with the performance models for the first slurry seal application and the performance models for the second slurry seal application. From the figures, the following general trends can be observed:

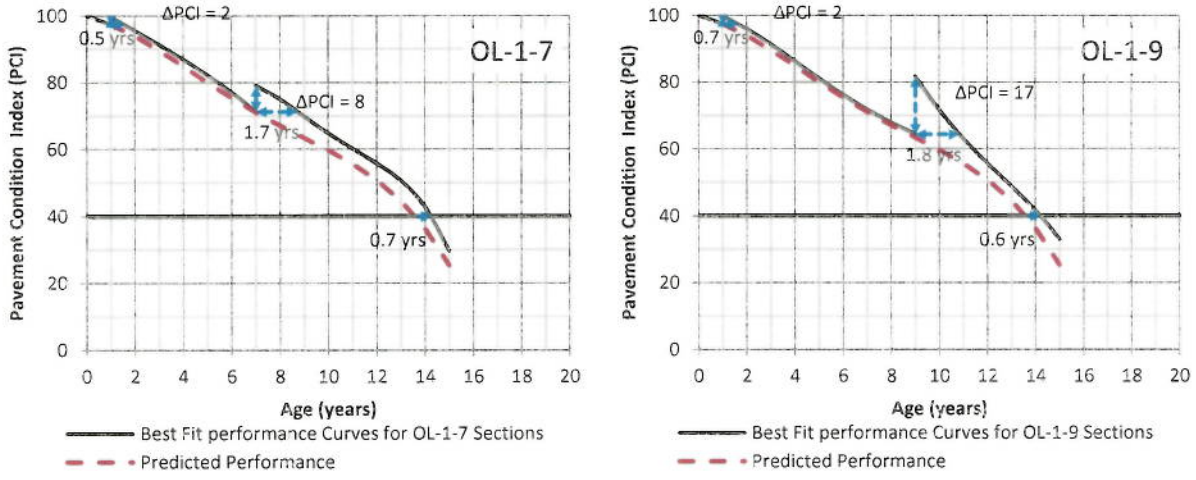
- The application of the first slurry seal at years 0 and 1 neither shows a significant change in the shape of the performance curve nor in the initial PCI value for both overlays and newly-constructed pavements (Figures 3, 4, 7, and 8)
- The application of the first slurry seal at years 3 and 5 show significant jumps in the PCI value at the time of application and in the shape of the performance curve for future years. In fact, the PCI value jumps back up to nearly 100.
- The shape of the performance curve of the second slurry seal as well as the magnitude in the jump of the PCI values are greatly affected by time of application of the first slurry seal. For both overlay and newly constructed pavements, the second slurry seal extends the serviceability life of the pavements most when the first slurry seal is applied in year 3 or 5.

From the performance models in Figures 3 to 10, the slurry seal performance lives and extensions in pavement service life can be determined. Figure 11 summarizes the various performance lives and extensions for all pavement types. Figure 11 shows clearly that the highest performance life for the first slurry seal is when it is applied in years 3 and 5. This does not necessarily mean that this higher performance life for the first slurry seal carries over to the second slurry seal. In fact, the performance life of the second slurry seal for NC-0-9 is higher than both NC-3-9 and NC-5-9. Regardless of this fact, the extension in pavements lives was found to be the highest with the first slurry seal applied in years, 3 or 5 and the second slurry seal in either year 7 or 9.



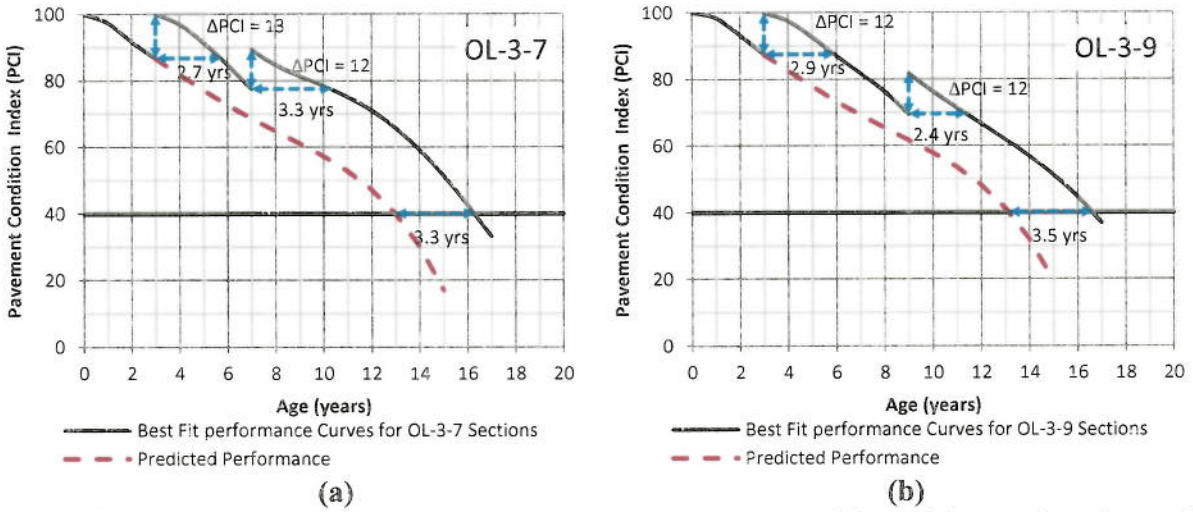
(a) (b)

Figure 3 Overlay: do-nothing and slurry seal performance models at (a) year 0 and year 7 and (b) year 0 and 9.



(a) (b)

Figure 4 Overlay: do-nothing and slurry seal performance models at (a) year 1 and year 7 and (b) year 1 and 9.



(a) (b)

Figure 5 Overlay: do-nothing and slurry seal performance models at (a) year 3 and year 7 and (b) year 3 and 9.

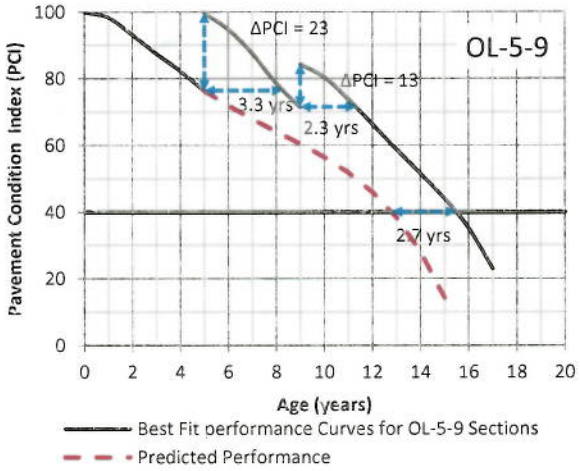
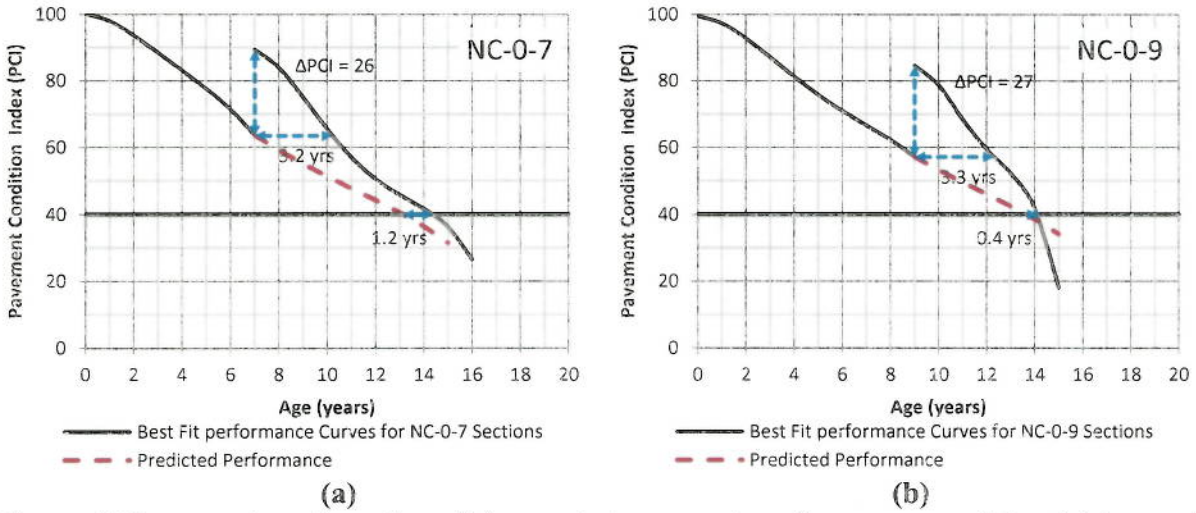
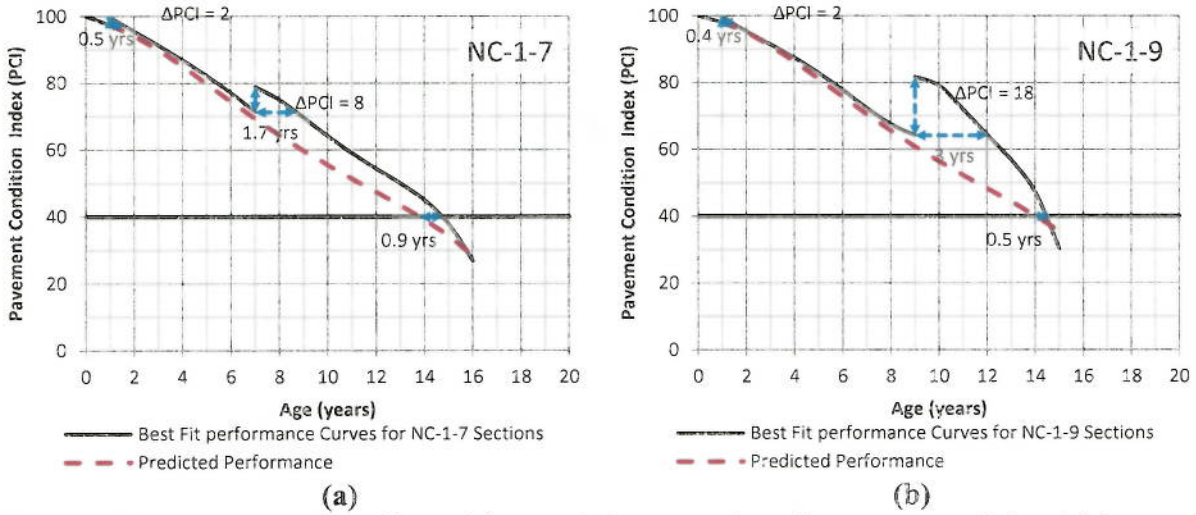


Figure 6 Overlay: do-nothing and slurry seal performance models at year 5 and 9.



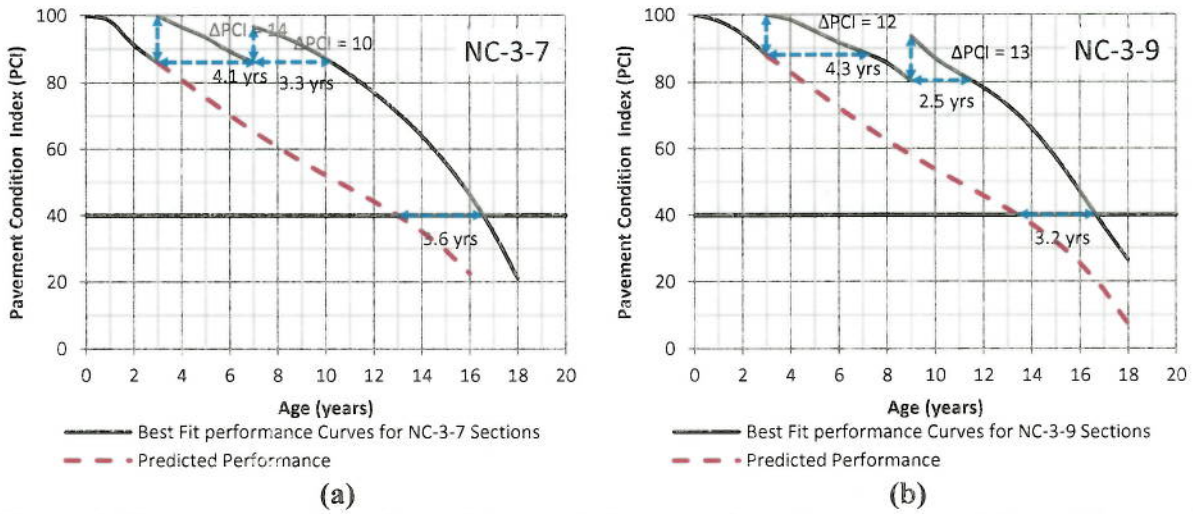
(a) (b)

Figure 7 New construction: do-nothing and slurry seal performance models at (a) year 0 and year 7 and (b) year 0 and 9.



(a) (b)

Figure 8 New construction: do-nothing and slurry seal performance models at (a) year 1 and year 7 and (b) year 1 and 9.



(a) (b)

Figure 9 New construction: do-nothing and slurry seal performance models at (a) year 3 and year 7 and (b) year 3 and 9.

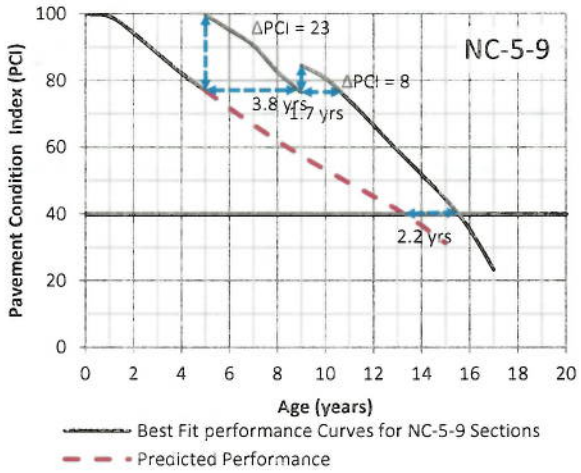


Figure 10 New construction: do-nothing and slurry seal performance models at year 5 and 9.

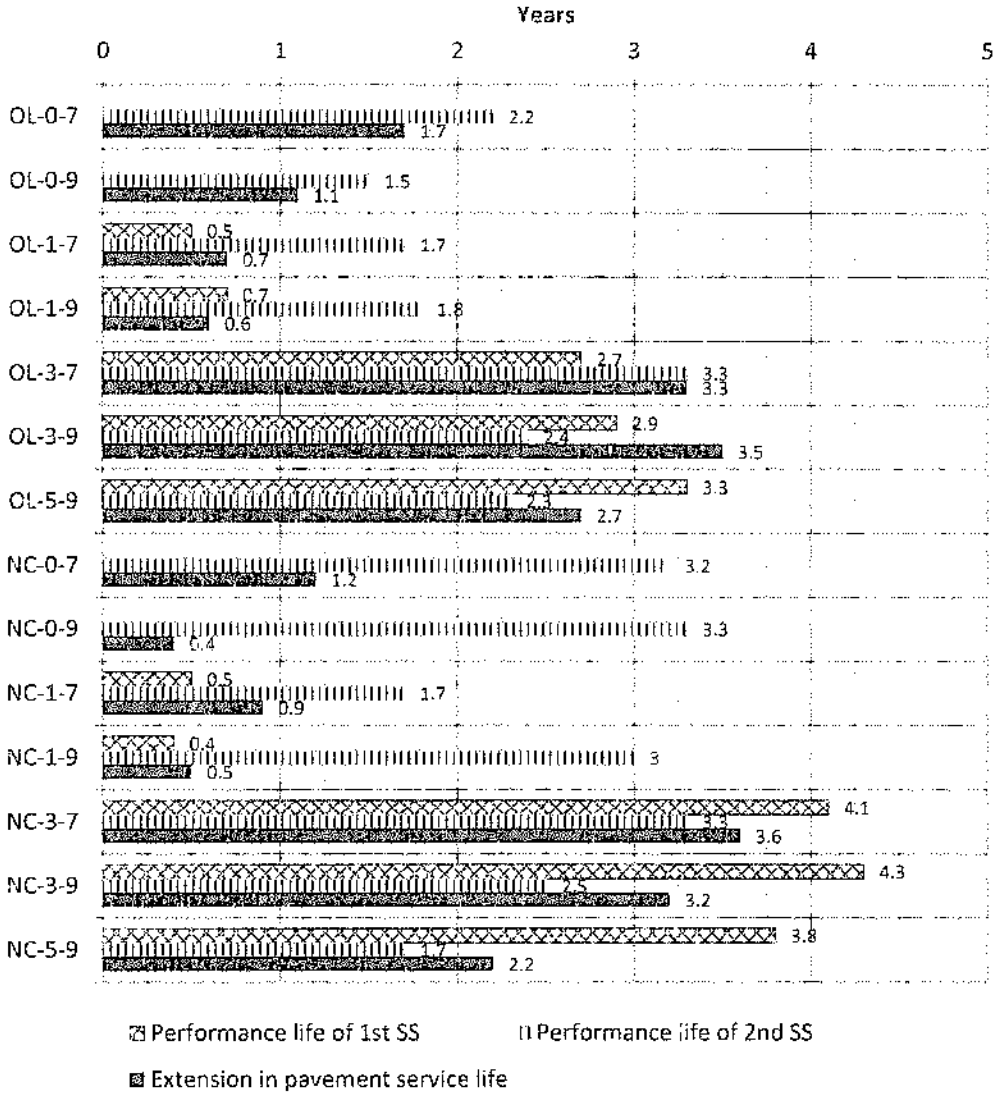


Figure 11 Performance lives of the first and second slurry seals and the extension in pavement service life for both newly constructed pavements and pavements with overlays.

BENEFIT COST ANALYSIS

The relative benefit is defined as the ratio of the slurry seals performance benefit (B) over the area under the performance curve of the pavement without slurry seal (A) up to the terminal PCI of 40 (i.e. B/A x100) (Figure 12). The relative benefit can thus be viewed as the percent improvement in the serviceability of the pavement which is directly related to users' satisfaction.

Figure 13 graphically presents relative benefit values for sequential slurry seals applied at various combinations for both newly constructed and overlay pavements. For both pavement types, it is clear that the pavements that received the highest relative benefit were those that had the first slurry seal applied in year 3, and the second slurry seal is applied in year 7 or 9. The

highest relative benefit is achieved when both pavement types had the first slurry seal applied in year 3 and the second slurry seal applied in year 7.

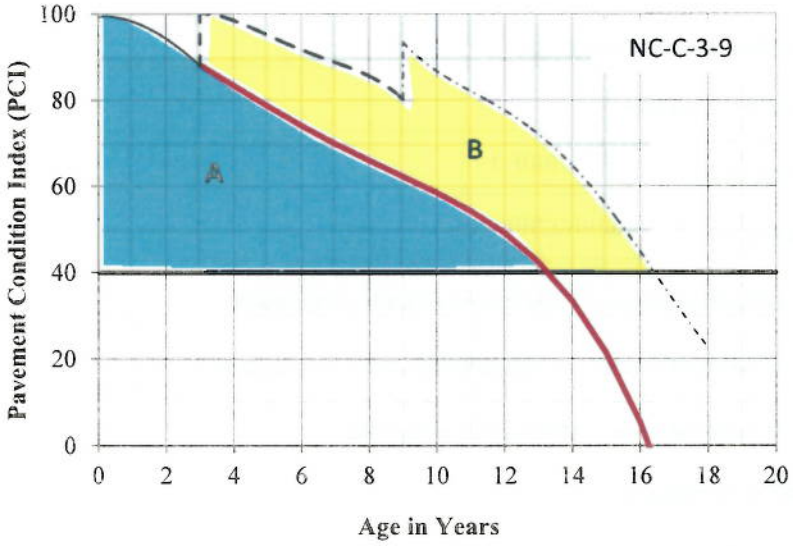


Figure 12 Benefit determination of do-nothing condition and sequential slurry seal application.

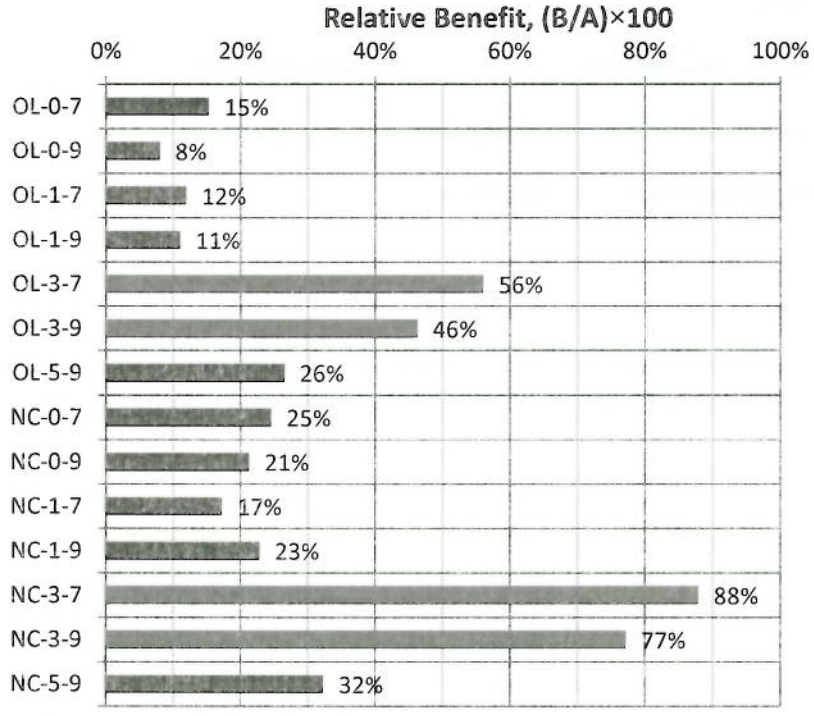


Figure 13 Relative benefit for newly constructed pavements and pavements that received overlays.

The cost of the slurry seal (C) was estimated based on the cost figures of 2009 (i.e. 0 year after construction) at $11,070/lane-mile. A discount rate of three percent was determined based on historical 15-year records (1991 – 2005) for the region and was used to estimate the cost figures for the various years of slurry seal applications. For example, the cost of slurry seal applied at year 3 after construction will be: $11,070(1 + 0.03)^4 = $12,459/lane-mile. In general, the longer a slurry seal is postponed the higher the present cost of the slurry seal will become. The costs presented in Table 2 are total costs of both the first and second slurry seals.

The benefit cost ratio is defined as the ratio of the benefit (B) divided by the cost (C) of the application of the slurry seal. The benefit cost ratio was used to determine the relative cost-effectiveness of the slurry seal treatment with respect to various times of application. Table 2 summarizes the benefit and cost figures for the application of slurry seals at various years after construction for the new construction and overlay.

For overlays, the highest benefit cost ratio from a sequential slurry seal application occur when the first slurry seal is applied in year 3 followed by the second slurry seal in year 7 at 7.7. The second highest for overlays occurs when the first slurry seal is applied in year 3 followed by the second slurry seal in year 9 at 7.3. Similarly for new construction, the highest benefit cost ratio from a sequential slurry seal application occurs when the first and second slurry seals are applied in years 3 and 7, respectively at 13.0. The second highest for new construction occurs when the first slurry seal is applied in year 3 followed by a second slurry seal in year 7 at 11.7.

Table 2 Cost effectiveness of Sequential Slurry Seals for Newly Constructed and Overlay Asphalt Pavements.

Sample ID	Benefit, B (Area)	Cost, C ($/lane-mile)	Benefit-Cost Ratio, (B/C x 1000)
OL-0-7	56.7	24,685	2.3
OL-0-9	31.6	25,514	1.2
OL-1-7	52.7	25,017	2.1
OL-1-9	48.7	25,846	1.9
OL-3-7	229.6	29,871	7.7
OL-3-9	194.5	26,540	7.3
OL-5-9	124.4	27,277	4.6
NC-0-7	94.2	24,685	3.8
NC-0-9	83.5	25,514	3.3
NC-1-7	72.5	25,017	2.9
NC-1-9	99.2	25,846	3.8
NC-3-7	333.4	25,711	13.0
NC-3-9	310.4	26,540	11.7
NC-5-9	148.2	27,277	5.4

CONCLUSIONS AND RECOMMENDATIONS

Review of the pavement performance data and benefit cost ratio of two slurry seal applications as a function of the years of applications lead to the following conclusions:

- The application of the first slurry seal immediately after or one year after construction of the asphalt layer is not effective in terms of both the benefit to the users and the benefit cost ratio for the agency.
- Regardless of construction activity, optimum time for a sequential slurry seal is when the first slurry seal is applied in year 3 and the second slurry seal is applied in year 7.
- The pavement service life was extended by 2.0 to nearly 4.0 years when the first slurry seal was applied in years, 3 or 5 and the second slurry seal in either year 7 or 9. For those application conditions, the sequential slurry seal was effective in delaying the time for reconstruction.

In summary, for both new and overlay constructions, it is recommended that the agency applies the first slurry seal three years after the construction of the asphalt layer and the second slurry seal seven years after the construction. It should be noted that the above conclusions and recommendations were based on the analysis of asphalt pavement sections that received a sequential application of slurry seal during their intended performance life. The optimum time for a single slurry seal application has already been conducted for this region and was consistently found to be three years after construction.

ACKNOWLEDGEMENTS

The contents of this paper are part of the overall effort between the Regional Transportation Commission of Washoe County (RTC) and the Pavements/Materials Program at the University of Nevada, Reno (UNR). However, the contents of this report reflect the views of the authors and do not necessarily reflect the official views and policies of the RTC. The authors would like to thank the RTC for their support as well as City of Reno, City of Sparks and Washoe County Engineering Department for providing access to their pavement management data. Further gratitude is also expressed to Jose Pablo Vargas of National Laboratory of Materials at University of Costa Rica for the help in the study.

REFERENCES

1. Peshkin, D. G., Hoerner, T. E., and Zimmerman, K. A. *Optimal Timing of Pavement Preventive Maintenance Treatment Applications*. NCHRP Report 523, Transportation Research Board of the National Academies, Washington, D.C., 2004.
2. Hajj, E., Loria, L., Sebaaly, P., Borroel, C., Leiva, P., "Optimum Time for Application of Slurry Seal," Tranportation Research Record, in press, Transportation Research Board, Washington, D.C., 2011.
3. *Special Report 61E: The AASHO Road Test Report 5, Pavement Research*. HRB, National Research Council, Washington, D.C., 1962.
4. Li, Z., and Zhang, Z. Using Ordered Probit Model to Predict Pavement Performance from Experimental Data. In *Pavement Management, Design, & Testing*. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C., 2004.
5. Hein, D., and Watt, D. *Municipal Pavement Performance Prediction based on Pavement Condition Data*. Presented at the Very Long-term Life-Cycle Analysis of Pavements – Determining the True Value of Our Investment Session at the Annual Conference of the Transportation Association of Canada, Calgary, Alberta, 2005.

6. Liu, L., Manepalli, V.S., Gedafa, D.S., and Hossain, M. 2010. Cost Effectiveness of Ultrathin Bonded Bituminous Surface and Slurry Seal. In *Compendium of Papers from the First International Conference on Pavement Preservation.* New Port Beach, California, 2010, pp. 317-329.
7. Shahin, M.Y. *MicroPAVER Homepage.* US Army Engineer, Research and Development Center – Construction Engineering Research Laboratories – Department of Defense. http://www.cecer.army.mil/paver. Accessed July 29, 2010.
8. *Washoe County Quality of Life Webpage.* Economic Development, NV Energy, Las Vegas, Nevada. http://www.nvenergy.com/economicdevelopment/county/washoe/quality.cfm. Accessed July 29, 2010.
9. *Climate Description Webpage.* US Department of Commerce, National Oceanic & Atmospheric Administration. National Weather Service, Reno Weather Forecast Office. Reno, NV. http://www.wrh.noaa.gov/rev/climate/description_reno.php. Accessed July 29, 2010.
10. *Recommended Performance Guidelines for Emulsified Asphalt Slurry Seal.* International Slurry Surfacing Association, Publication A105, January 2001.
11. Washoe RTC's Regional Preventive Maintenance Program Manual, April 2004, Revised June 2004. http://www.rtcwashoe.com/streets-highways-32. Accessed November 12, 2010.