Effectiveness of preventive maintenance of asphalt pavements

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ABSTRACT

In light of shrinking agency budgets, pressure is being placed on agencies to become more cost-effective in their delivery of services to the public. Unfortunately, transportation infrastructure, by nature, begins to deteriorate as soon as it is placed. Roadway preventative maintenance provides users with safer and more comfortable rides and has been shown to reduce overall transportation costs when maintenance treatments are properly selected and timed. As such, infrastructure agencies have expressed an increasing interest in the selection and timing of maintenance activities for their existing transportation infrastructure.

The paper presents the evaluation of field performance of asphalt pavements with sequential slurry seal applications. the study 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 slurry seals on asphalt pavements. This was achieved by evaluating the long-term pavement performance data collected 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. This study found that the application of the slurry seal immediately after or 1 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. The optimum time of application of slurry seal depended on the type of the construction activity. For newly constructed pavements, the optimum time to apply slurry seal 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. However, for uniformity purposes, it was recommended that the agency applies slurry seal three years after the construction of the asphalt layer for both new and overlay constructions.

Keywords: Maintenance, Slurry seals, Urban application

1. INTRODUCTION

It has been well established 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) *(1)*. 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.

The performance life of a slurry seal is 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.

The pavement modeling for this study is utilized for the identification of the effectiveness of a slurry seal applications to a flexible pavement with respect to time. Pavement performance was documented through the MicroPAVER pavement management software system that is developed and maintained by the Construction Engineering Research Laboratories (CERL) of the US Army Engineer Research and Development Center *(2)*.

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 maintenance and rehabilitation (M&R) needs of roadway section with respect to an entire pavement system.

2. EVALUATED PAVEMENT SECTIONS

All asphalt pavement sections identified and evaluated in this study were within the jurisdictions of: Washoe County, City of Reno, and City of Sparks, located in the northern part of the State of Nevada, USA. The evaluation covered two pavement types: newly constructed pavements and pavements that received overlays. Asphalt mixtures were generally dense graded with a 12.5 or 19 mm 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 *(3)*. 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.

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. 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. 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 pavement section is used to represent the condition of the entire section for the specific survey date.

3. PERFORMANCE MODELS

Table 1 presents the various performance prediction models developed and used in this effort. 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**.

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 determine the improvement in performance of the various sequential slurry application conditions. As indicated in the "Age Range" column 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 9” can only be used to predict PCI values when the pavement is 9 years or older.

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			$Age \geq 0$	$PCI = -0.0026Age^4 + 0.0891Age^3 - 0.9833Age^2 - 0.8446Age + 99.24$	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	$1 \leq Age \leq 7$	$PCI = 0.0025 Age^4 - 0.0636Age^3 + 0.3471Age^2 - 4.8768Age + 104.34$	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	$Age \geq 9$	$PCI = -0.0005Age^4 - 0.0233Age^3 + 1.2645Age^2 - 21.495Age + 193.06$	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	$0 \leq Age \leq 7$	$PCI = -0.0248 Age^4 + 0.3615Age^3 - 1.9867Age^2 - 0.5081Age + 100.09$	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	$0 \leq Age \leq 9$	$PCI = -0.0145 Age^4 + 0.3004 Age^3 - 2.0051Age^2 - 0.4084Age + 99.452$	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	$Age \geq 7$	$PCI = -0.0214 Age^4 + 0.9241Age^3 - 14.652Age^2 + 95.982Age - 140.61$	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	$Age \geq 9$	$PCI = -0.1279 Age^4 + 6.0189Age^3 - 105.95Age^2 + 819.19Age - 2257.7$	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	$Age \geq 7$	$PCI = -0.0032 Age^4 + 0.1351Age^3 - 2.4789 Age^2 + 17.543Age + 56.59$	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	$5 \leq Age \leq 9$	$PCI = 0.3417 Age^4 - 9.4083Age^3 + 95.133Age^2 - 424.12Age + 804.5$	0.989
		9	$Age \geq 9$	$PCI = -0.0308Age^4 + 1.5823Age^3 - 30.31Age^2 + 249.16Age - 654.22$	0.990

Figure 1 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. For example, it took 4.3 years for the first slurry seal applied on year 3 of service to the newly constructed pavement to deteriorate from a PCI of 100 right after treatment to the pre-treatment PCI of 88 ($\Delta PCI = 12$) (Figure 1). 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 ($\Delta PCI = 13$). 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 1).

Figures 2 to 9 present the various cases of sequential application of slurry seals for overlays and newly constructed pavements. In each case, 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 2, 3, 6, and 7).
- 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.

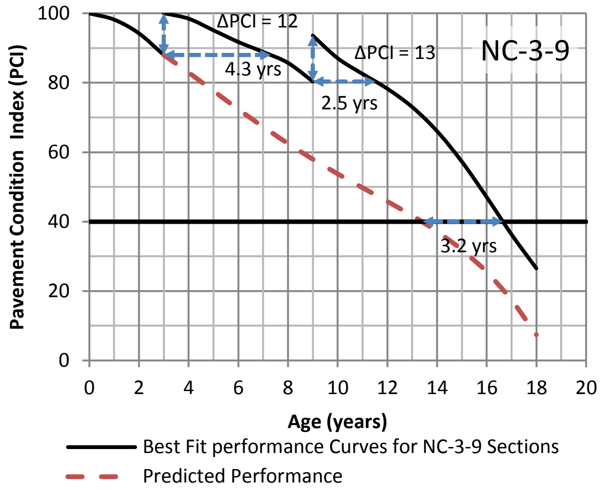

Figure 1. Performance curves for a newly constructed pavement section

From the performance models in Figures 2 to 9, the slurry seal performance lives and extensions in pavement service life can be determined following the technique presented in Figure 1. Figure 10 summarizes the various performance lives and extensions for all pavement types. Figure 10 shows clearly that the highest performance life for the first slurry seal is when it is applied in years 3 and 5. However, 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 year 3 or 5 and the second slurry seal in either year 7 or 9.

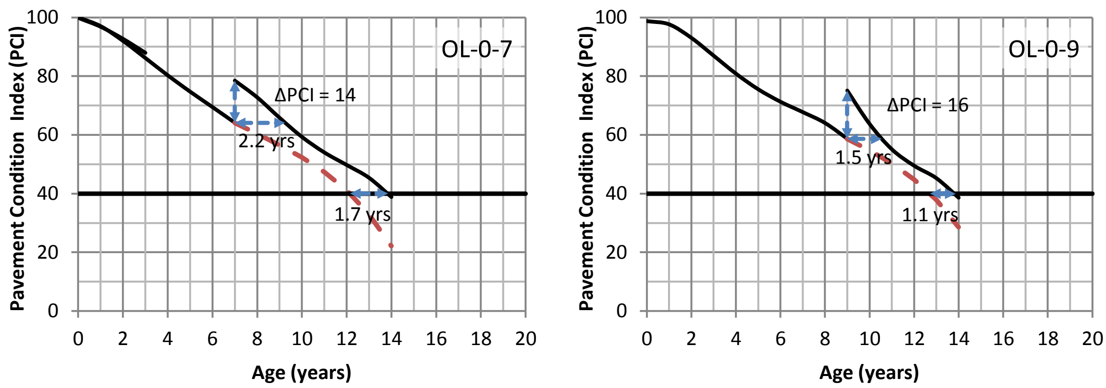

Figure 2. Performance models for pavements with overlays, slurry 0/7 and 0/9 years

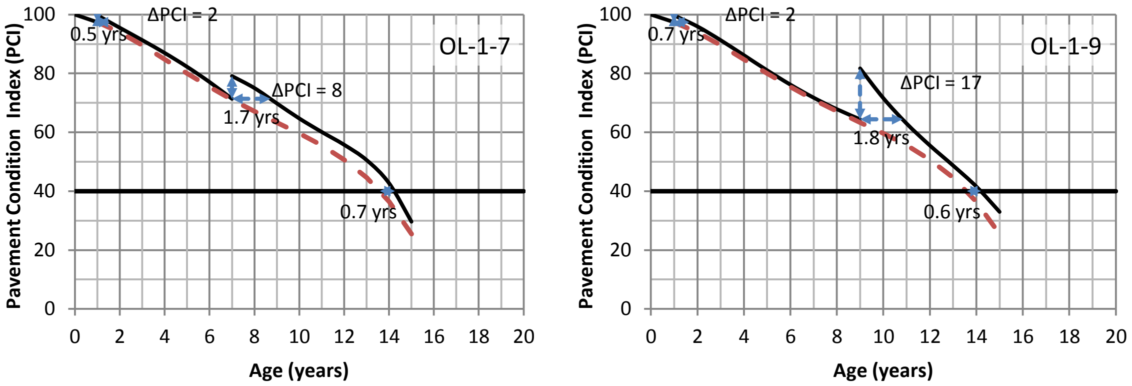

Figure 3. Performance models for pavements with overlays, slurry 1/7 and 1/9 years

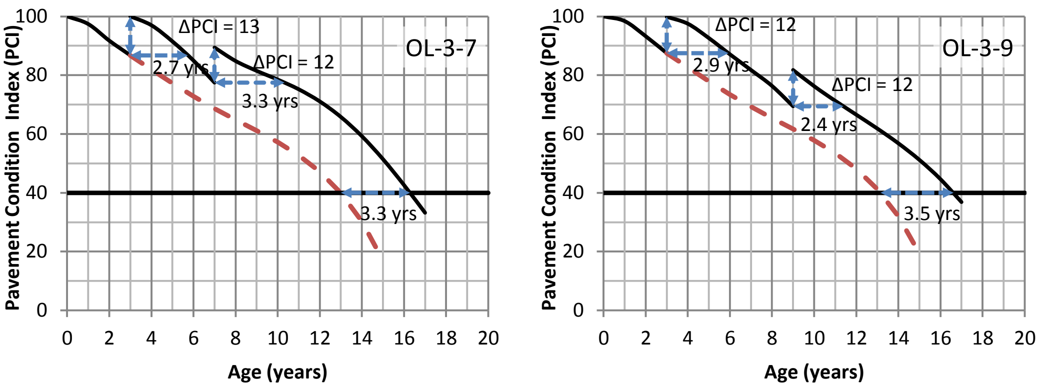

Figure 4. Performance models for pavements with overlays, slurry at 3/7 and 3/9 years

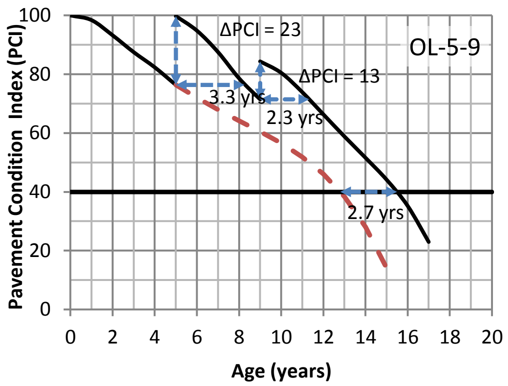

Figure 5. Performance models for pavements with overlays, slurry at 5/9 years

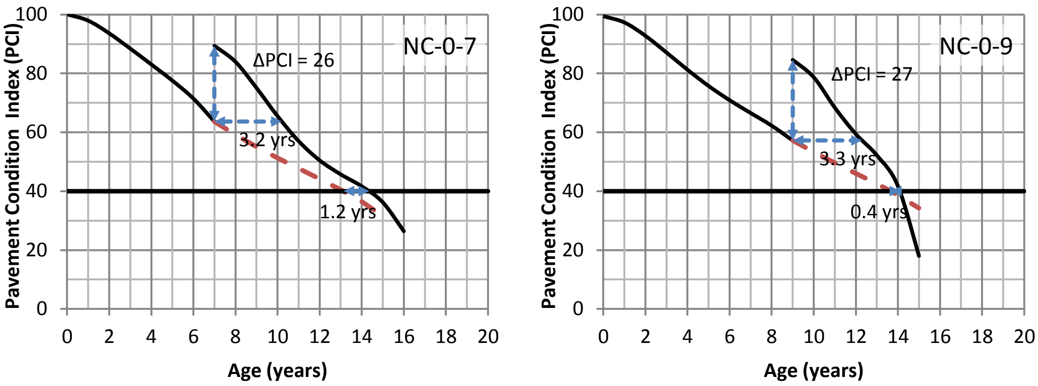

Figure 6. Performance models for new pavements, slurry at 0/7 and 0/9 years

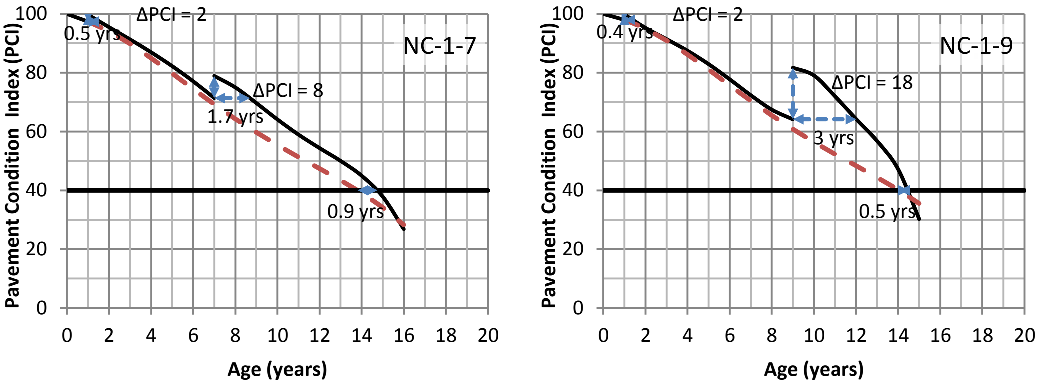

Figure 7. Performance models for new pavements, slurry at 1/7 and 1/9 years

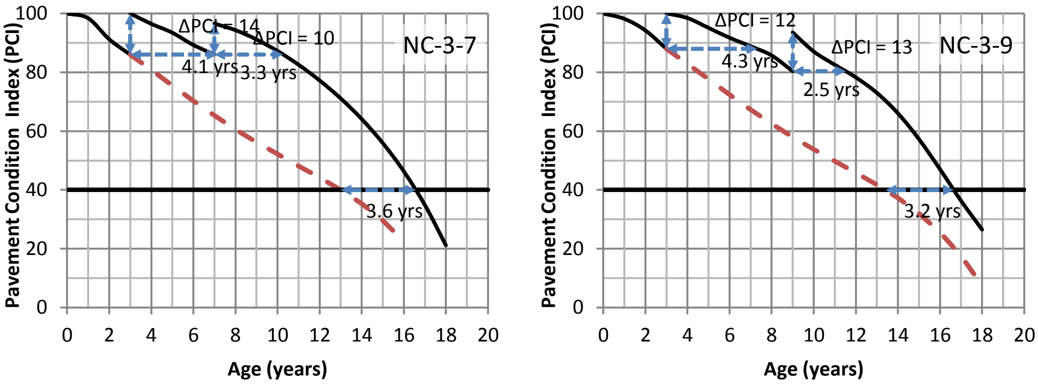

Figure 8. Performance models for new pavements, slurry at 3/7 and 3/9 years

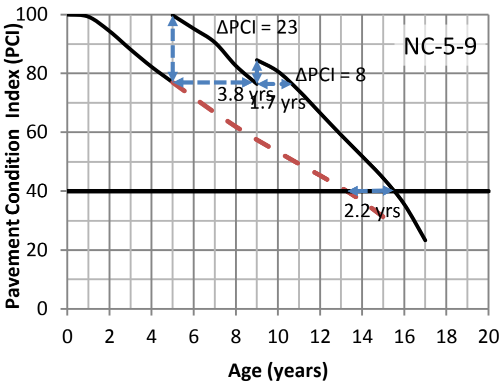

Figure 9. Performance models for new pavements, slurry at 5/9 years

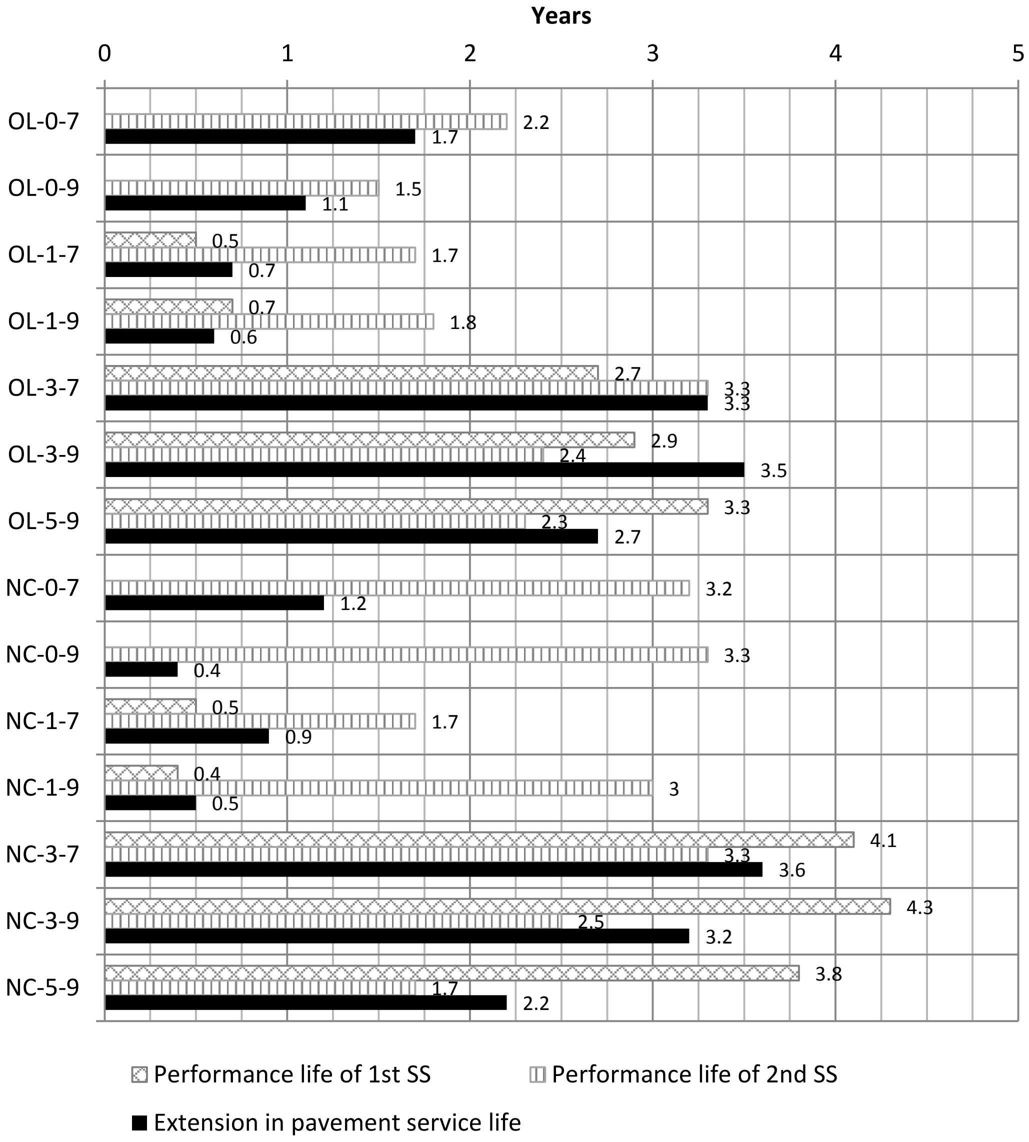

Figure 10. Performance lives of the first and second slurry seals and the extension in pavement service life for both newly constructed pavements and pavements with overlays

4. BENEFIT COST ANALYSIS

Figure 11 defines the parameters used in the determination of the benefit of slurry seal treatment relative to the pavement without the slurry seal. 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 11). 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 12 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 most relative benefits were those that had the first slurry seal applied in year 3, and the second slurry seal 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. It is also clear that higher benefits are realized on the newly constructed pavements as compared to the pavements that received overlays. This can be due to the propagation of some distresses in the existing old pavement through the overlay (i.e. reflective cracking) which reduces the overall performance of the slurry seal treatment.

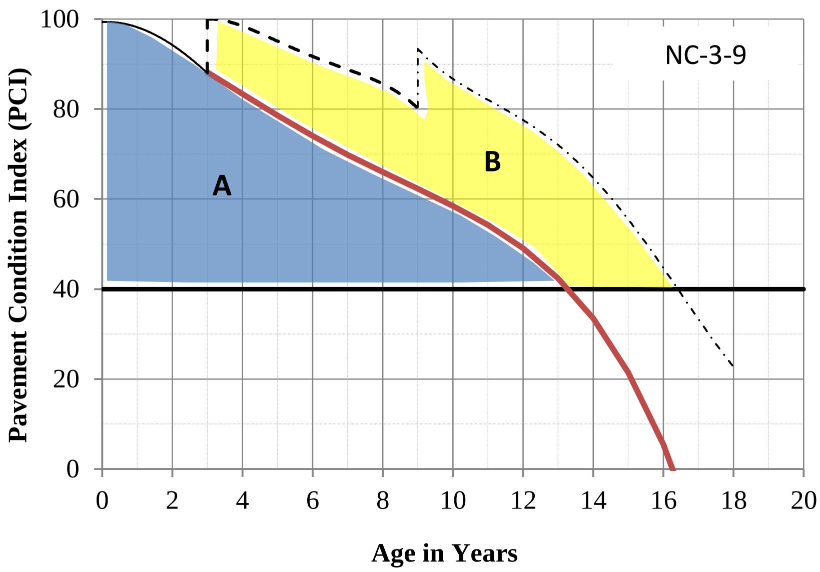

Figure 11. Benefit determination of do-nothing condition and sequential slurry seal application

The cost of the slurry seal (C) was estimated based on the agencies most recent cost figures (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 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 of 7.7 from a sequential slurry seal application occurs when the first slurry seal is applied in year 3 followed by the second slurry seal in year 7. The second highest benefit cost ration of 7.3 for overlays occurs when the first slurry seal is applied in year 3 followed by the second slurry seal in year 9. Similarly for new construction, the highest benefit cost ratio of 13.0 from a sequential slurry seal application occurs when the first and second slurry seals are applied in years 3 and 7. The second highest benefit cost ratio of 11.7 for new construction occurs when the first slurry seal is applied in year 3 followed by a second slurry seal in year 7. Again, it is clear that the new construction pavements are experiencing significantly higher benefit cost ratios due to the application of sequential slurry seals as compared to pavements that received overlays.

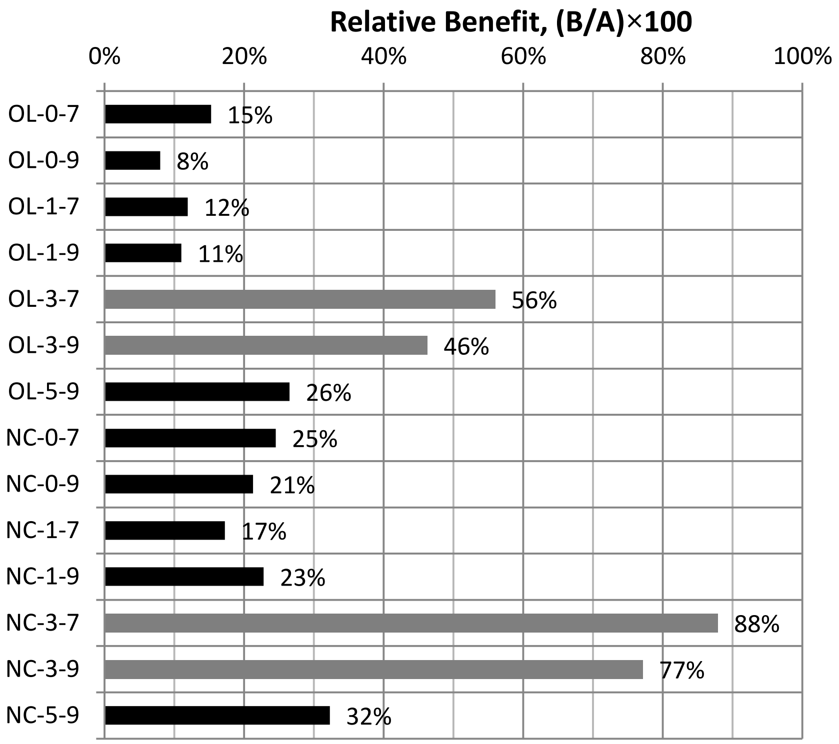

Figure 12. Relative benefit for newly constructed pavements and pavements that received overlays

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

5. CONCLUSIONS AND RECOMMENDATIONS

Review of the pavement performance data and benefit cost ratio of sequential 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 concrete 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 (i.e. new or overlay), 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 concrete 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 *(4)*.
It is well recognized that the long-term performance of an asphalt concrete pavement is significantly impacted by the conditions at the specific location; materials, construction, traffic, and environment. Therefore, it is more practical to express the optimum timing of the sequential slurry seals in terms of PCI level instead of years after construction. This conversion will make the results of this research applicable to asphalt concrete pavements at various locations significantly outside the conditions of the pavements analyzed in this study. Table 3 summarizes the recommended threshold PCI values to apply the first and second of the sequential slurry seal applications. For example, a first slurry seal is recommended to be applied on a newly constructed pavement when it reaches a PCI level between 87 and 90 and a second slurry when its PCI level, after the application of the first slurry seal, reaches 86. It is anticipated that under normal conditions the recommended PCI levels will coincide well the time-based recommendations for the application of sequential slurry seals. However, under certain extreme conditions such as; severe climate, extra heavy loads, or severely distressed pavements, the agreement may not be as good, in such cases the PCI-based criteria recommended in Table 3 should be used.

Table 3. Recommended Threshold PCI Values for Slurry Seal Applications

Construction Type	Recommended Threshold PCI Values	
	1st Application of Slurry Seal	2nd Application of Slurry Seal
New Construction	87-90	86
Overlay	85-87	77

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