Performance Models for Maintenance Activities in Nevada

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ABSTRACT: The Regional Transportation Commission (RTC) of the Washoe County in Nevada uses the information provided by their pavement management system (PMS) to make informed decisions about the maintenance and rehabilitation of their existing pavement network. They use the MicroPAVER® software and the Pavement Condition Index (PCI) to assess the pavement's condition and for predicting its maintenance and rehabilitation needs. Current prediction models for PCI have induced inaccuracy in the prediction of pavement future conditions. Additionally, the current models do not account for changes in PCI whenever maintenance is applied to the pavement. To this end, RTC sponsored this study to re-evaluate their current PCI prediction models. New performance models were also developed. Finally, a benefit-cost analysis was performed to determine the effectiveness of slurry seal application on pavement performance. The main objective behind such analysis was to determine the best timing for applying a slurry seal.

1 INTRODUCTION

The Regional Transportation Commission (RTC) of the Washoe County in Nevada, U.S., uses the information provided by their pavement management system (PMS) to make informed decisions about the maintenance and rehabilitation of their existing pavement network. The Washoe County Engineering Department (WCED) is responsible for the unincorporated roadways portion of Washoe County in the northwest region of the state of Nevada. These roadways include over 1,000 miles of paved and unpaved roads within the county, which generally begins in Lake Tahoe, extends just south of Reno to Fernley then north to the Oregon state border (Washoe County, 2007).

The Washoe County Engineering Department uses the MicroPAVER® software developed by the US Army Corps of Engineers and the Pavement Condition Index (PCI) procedure to assess the pavement's condition and for predicting the network's maintenance and rehabilitation needs (Shahin, 2007). The PCI is a numerical rating index of the pavement's structural and surface operational condition ranging from 0 for a failed pavement to 100 for a pavement in excellent condition. The PCI provides an insight into the causes of distress and relates to load and/or climate. The WCED maintenance and rehabilitation matrix is based on the PCI value.

The accurate prediction of pavement performance is important for efficient management of the transportation infrastructure. A significant budget savings can be obtained by the reduction of the prediction error of pavement deterioration. Such savings will be of a great value especially with the escalating crude oil prices which are leading to significant increase in asphalt binder prices. Currently, WCED uses the PCI models shown in Table 1 to predict pavement performance of roads in Truckee Meadows and Incline Village areas of Washoe County as a function of pavement age. Incline Village is located near Lake Tahoe at an elevation of 7500 feet while the Truckee Meadows represents the rest of the county which is at 3000 feet lower elevation than the lake. These models were developed by the engineering department about 15 years ago and never been revised since then.

Recent changes in asphalt binder properties, traffic volumes, traffic weights and tire pressure, and construction techniques induced inaccuracy in the prediction of pavement future conditions based on the currently used RTC prediction models for PCI. Additionally, the current models do not account for change in PCI whenever a slurry seal maintenance treatment is applied to the pavement.

To this end, and recognizing the importance of the pavement performance prediction models for a complete pavement management system, RTC sponsored this study to re-evaluate the current PCI prediction models for Truckee Meadows and Incline Village. The new developed models were assessed based on the statistical concept of the minimum residual values. Additionally, a cost-benefit analysis was performed to evaluate the impact of slurry seal and time of application on the overall pavement performance as measured by the PCI value.

2 RTC PAVEMENT MANAGEMENT SYSTEM

The MicroPAVER pavement management software system used by the Washoe County Engineering Department was developed by the US Army Corps of Engineers (USACE) in the late 1970's. The system is supported, maintained, and periodically updated by the US Army Engineer Research and Development Center – Construction Engineering Research Laboratories (CERL) (Shahin, 2007).

The program was originally developed as a means for the USACE to inventory and manage the maintenance, rehabilitation, and reconstruction of the extensive number of pavements under their jurisdiction including airfield, roadway, and large pavement surfaces such as parking lots. Current versions of the software include functions to inventory pavement assets, maintain historical records of treatments and performance, monitor pavement performance utilizing visual inspection criteria, as well as predict future performance by utilizing the past performance characteristics as well as mathematical prediction models that can be specifically calibrated to a region or agency (Shahin, 2007).

2.1 *Pavement categorization*

The data used in this study was obtained from the Washoe County Engineering Department's maintenance program, and thus included all of the roadway pavements under their jurisdiction.

Each of the individual Networks were further categorized into Branches, the second most general level in the MicroPAVER system. Each Branch designation generally identified an individual street or roadway. Each Branch is further categorized by a Section number, which is again sequential within the Branch. These sections may be distinguished for several reasons including differences in construction geometry including section thicknesses or materials, construction dates, or traffic patterns.

Each Section is then separated into multiple Sample Units, which are most utilized during the condition survey process as discussed in the following sections. The Sample Units are approximately the same size in terms of square footage of pavement surface area within the Section.

2.2 *Data collection*

Prior to any data collection procedures each portion of the roadways to be included must be uniquely identified with network, branch, section, and sample unit designations. Each level of identification typically provides smaller areas and more specific functional definitions with a single street generally being designated as a branch containing multiple sections and sample units within those.

The data collection portion of the MicroPAVER program is generally comprised of two main functions: historical records and condition surveys. The historical records can be further defined as the chronological assembly of the construction, maintenance, and rehabilitation procedures that have been conducted on a particular section and sample unit.

The condition surveys are usually conducted by performing visual inspections on a given percentage of the available sample units. Typically, ten percent of the sample units are inspected; however there are other methods to determine the number of sections required if historical inspections have been conducted. These alternative methods generally determine the number of sample units or replicates required to obtain a 95% confidence interval for the data collection, based upon information obtained from previously conducted condition surveys for a given network.

The various types of distress, extent and severity used by Washoe County are defined in the Asphalt Distress Manual, Pavement Distress Identification Guide for Asphalt-Surfaced Roads and Parking Lots (Army Corps of Engineers, 1997).

In order to establish the desired historical performance records, the condition surveys are generally conducted on the same sample units each time. The frequency of the inspections often depends upon the rate of pavement deterioration, which can be linked to traffic loading, environmental conditions, and the pavement condition itself. WCED typically conducts condition surveys on the sections used in this analysis approximately every other year.

2.3 *Data processing*

Once the information is accurately gathered, checked, and entered into MicroPAVER, the analyses can be performed by calculating the Pavement Condition Index (PCI). As stated previously, the PCI is a numerical indicator used to describe the condition of the pavement. The PCI values range from 100 for a newly constructed roadway without any distresses to a value of 0 at the extreme low end for a severely distressed and failed pavement. The PCI values are calculated for each section not each individual sample unit. Each PCI value is calculated by the MicroPAVER software. A description of the calculations and the method for performing the calculations manually can be found in Appendix X3 of ASTM D6433 Standard Practice. The treatments analyzed in this paper were based upon the resulting PCI values for the respective test sections.

3 PAVEMENT PERFORMANCE PREDICTION

Currently, WCED uses the PCI models shown in Table 1 to predict pavement performance as a function of pavement age. This research effort re-evaluated the models based on the RTC PMS data and accordingly new models are developed. Selected pavements sections were either a reconstruction or an HMA overlay

3.1 *Evaluation of current PCI prediction models*

First, the current PCI models were checked against the actual PCI values for the reconstructed and the HMA overlayed flexible pavement sections that were not subjected to any maintenance activities during the analysis period. After a general examination of the county's pavement management system, all of the sections shown in Table 1 were utilized in this analysis (a total of 872 pavement sections). The selected roadways were limited to the Truckee Meadows and Incline Village Areas of Washoe County.

Table 1. RTC current PCI prediction models and selected pavement sections.

Area	Road classification	ID	PCI model	Number of sections
Truckee meadows	Arterial	TM-A	100-2.2842*Age*-1.4028*Age*^{2}+0.1676*Age*^{3}-0.0055*Age*^{4}	18
	Collector	TM-B	100-4.1088*Age*-0.5338*Age*^{2}+0.0721*Age*^{3}-0.0022*Age*^{4}	17
	Residential	TM-C	100-4.1088*Age*-0.5338*Age*^{2}+0.0721*Age*^{3}-0.0022*Age*^{4}	555
Incline village	Arterial	INV-A	100-6.34*Age*-0.1888*Age*^{2}+0.04236*Age*^{3}+0.00107*Age*^{4}	--
	Collector	INV-B	100-7.6104*Age*+1.1702*Age*^{2}-0.1169*Age*^{3}+0.00352*Age*^{4}	24
	Residential	INV-C	100-0.5651*Age*-0.0337*Age*^{2}+0.01022*Age*^{3}+0.00093*Age*^{4}	258

3.1.1 *Truckee Meadows*

The current prediction curves over estimate the rate of reduction in the PCI values with time. Similar trend was determined for the other road type. Therefore, similar figures were developed for the other road-types, however due to the space limitations such figures are not shown in this document.

The overall fits of the current PCI models were checked using the calculated residual values. The residual value is the deviation of a particular observed PCI value from the model predicted PCI value. The smaller the variability of the residual values around the prediction line relative to the overall variability, the better the prediction. A perfect fit would have a residual value of zero. Any kind of trend in the shape of the plotted residual values would be the indication of a high variability in the residual values, hence a worse prediction. The discrepancy between the measured PCI values and the prediction models is measured by the sum of squared residuals (SSR) value. An SSR value close to zero indicates that the model has accounted for almost all of the variability with the pavement *Age* variable specified in the model. Equation 1 shows the SSR model. The actual difference in the number of pavement sections in each road class is accounted for by dividing the SSR with the total number of surveyed sample units (SSRR). The SSRR mathematical expression is given by Equation 2.

Similarly to the SSR, the mean square error (MSE) is another way to quantify the amount by which an estimator differs from the true value of the quantity being estimated. The MSE mathematical expression is give by Equation 3. A good fit is revealed by smaller values for both the SSRR and the MSE.

$$SSR = \sum\left(y_i - \hat{y}_i\right)^2 \tag{1}$$

$$SSRR = \frac{\sum\left(y_i - \hat{y}_i\right)^2}{n} \tag{2}$$

$$MSE = \frac{\sum\left(y_i - \hat{y}_i\right)^2}{DFE} \tag{3}$$

where, y_i is the observed response, $\hat{y}_i$ is the predicted response, n is the number of studied sections, and *DFE* is the error degrees of freedom.

Table 2 summarizes the SSR, SSRR, and the MSE values. Table 2 shows that the PCI model for collector roads predicts more accurately the PCI values over the pavement in-service life than the PCI models for arterial and residential roads. The prediction curve for the residential roads was highly inaccurate with large statistic values.

3.1.2 *Incline Village*

The prediction models for the Incline Village (INV) underestimate the rate of reduction in the PCI values. Table 2 summarizes the SSR, the MSE, and the SSRR statistic values. Table 2 shows that the PCI prediction model can predict the PCI values for collector roads more accurately than the model for residential roads.

3.2 *Development of new PCI prediction models*

In this analysis, the measured PCI values are used to generate new pavement performance prediction models for the RTC pavement sections using a best fit polynomial curve. Additionally, the accuracy of the new developed prediction models is compared to that of the currently used RTC prediction models. All the sections used for this part of the study did not have any maintenance activities during their in-service life.

Equations 4-6 show the new polynomial performance prediction models for TM which relate the PCI value to the pavement age for arterials, collectors and residential roads, respectively. Equations 7 and 8 show the new polynomial performance prediction models for INV collectors and residential roads, respectively. The precision of the new performance models in relation to the actual data is described using the R^2 estimate, the mean square error (MSE), the sum of squared residuals (SSR), and the ratio of the SSR to the total number of surveyed sample units (SSRR) for each road class and are summarized in Table 2. R^2 estimates between 0.780 and 0.942 were found for the various model fits. An R^2 close to 1.0 indicates that the model has accounted for almost all of the variability with the pavement age variable specified in the model. Additionally, all three models showed good fits by having SSRR statistic values less than 45.

Table 2. Statistics for the current and new prediction models of the Truckee Meadows and the Incline Village areas.

Area	Road class	ID	Model fit (R^2)	Sum of squared residuals (SSR)	Number of sample units (N)	Mean square error (MSE)	SSRR
Current prediction models							
Truckee meadows	Arterial	TM-A	--	12892	115	3223	112
	Collector	TM-B	--	3262	48	3262	68
	Residential	TM-C	--	17964131	2933	204138	6125
Incline village	Collector	INV-B	--	9534	71	4767	134
	Residential	INV-C	--	200636	1140	2389	176
New prediction models							
Truckee meadows	Arterial	TM-A	0.928	2357	112	589	21
	Collector	TM-B	0.942	754	45	503	17
	Residential	TM-C	0.867	118303	2933	1344	40
Incline village	Collector	INV-B	0.902	1016	71	508	14
	Residential	INV-C	0.780	50923	1140	606	45

$$PCI = 100 - 0.0083Age^4 + 0.2163Age^3 - 1.8468Age^2 + 1.227Age \quad (4)$$

$$PCI = 100 - 0.0031Age^4 + 0.0823Age^3 - 0.912Age^2 - 0.406Age \quad (5)$$

$$PCI = 100 - 0.0101Age^4 + 0.2572Age^3 - 1.9537Age^2 + 0.1584Age \quad (6)$$

$$PCI = 100 + 0.0116Age^3 - 0.03314Age^2 - 2.3432Age \quad (7)$$

$$PCI = 100 - 0.0042Age^4 + 0.1101Age^3 - 0.8329Age^2 - 2.0416Age \quad (8)$$

Table 3 shows the percent of reduction in the SSRR statistic of the current RTC prediction models when compared to the SSRR of the new developed PCI models. It shows that a significant increase in the model prediction accuracy is achieved with the new PCI prediction models compared to the current RTC prediction models. The most improvement was achieved in the PCI prediction of pavement sections from residential roads.

Table 3. Statistics for the Truckee Meadows and Incline Village areas.

Area	Treatment	Road Class	Number of Sections	SSRR		% reduction in SSRR
				RTC	NEW	
Truckee Meadows	Reconstruction or HMA Overlay	Arterial	18	112	21	- 81%
		Collector	17	68	17	- 75%
		Residential	555	6125	40	- 99%
Incline Village	Reconstruction or HMA Overlay	Collector	24	134	14	- 90%
		Residential	258	176	45	- 74%

3.3 *Modeling performance of pavements with slurry seals*

As mentioned before, the new PCI prediction models were developed from a group of pavement sections that have not been subjected to any maintenance treatment during their performance life. In this part of the research, the new developed PCI prediction models are checked against pavement sections that were slurry sealed during their in-service life to assess their applicability and the needs to develop separate models for the performance of slurry seals.

The developed new PCI models were found to be inaccurate in predicting the PCI values of the pavement sections after a slurry seal application. Table 4 shows the precision of the developed PCI models for TM residential roads and INV residential and collector roads without maintenance activities in relation to the actual data before and after slurry seal application in terms of the SSR, MSE, and SSRR. The data in Table 4 show that, before the application of slurry seal, the developed PCI models predict very well the measured PCI values of the analyzed pavement sections (SSRR values less than 12). Additionally, when the PCI values of the pavement sections after slurry seal were included in the analysis, an increase in the SSRR values was observed indicating a reduction in the models' accuracy. Therefore, a separate model needs to be developed to predict the PCI values of the pavement sections after slurry seal application.

Table 4. Statistics for the Truckee Meadows and Incline Village roads with slurry seal application.

Area	Road class	Pavement sections	Number of sections	Time range of analyzed data	SSR	MSE	SSRR
Truckee meadows	Residential	Slurry sealed after 3 years	38	0-2 years	610	1280	12
				0-9 years	5308	11122	58
		Slurry sealed after 5 years	57	0-4 years	906	1993	10
				0-12 years	7258	14211	21
		Slurry sealed after 7 years	142	0-6 years	1421	2700	8
				0-11 years	13376	28758	49
		Slurry sealed after 9 years	87	0-8 years	1978	20064	6
				0-12 years	57307	124929	150
Incline village	Collectors	Slurry sealed after 3 years	7	0-2 years	37	44	1
				0-12 years	6823	14328	94
		Slurry sealed after 5 years	11	0-4 years	1016	119	19
				0-12 years	7192	15823	82
		Slurry sealed after 7 years	18	0-6 years	1954	170	29
				0-12 years	7874	17291	87
		Slurry sealed after 9 years	21	0-8 years	1488	181	18
				0-12 years	14038	29480	135
	Residential	Slurry sealed after 3 years	16	0-2 years	653	1685	10
				0-9 years	3652	7652	33
		Slurry sealed after 5 years	36	0-4 years	1728	3628	21
				0-9 years	6590	12903	47
		Slurry sealed after 7 years	24	0-6 years	1199	2518	12
				0-11 years	14308	30762	68
		Slurry sealed after 9 years	26	0-8 years	5527	12160	23
				0-12 years	7587	16540	28

4 BENEFIT OF SLURRY SEAL APPLICATION

A benefit-cost analysis was performed to determine the effectiveness of slurry seal application on pavement performance. The main objective behind such analysis was to determine the best timing for applying a slurry seal. The overall benefit of the application of the slurry seal was assessed by measuring the area between the performance curve of the slurry seal and the HMA overlay after 3, 5, 7, and 9 years, respectively. Additionally, the benefit area was divided by the number of years between the slurry seal application and the last surveying date. Such value, called Particular Benefit (PB), is a better tool to more accurately assessing the slurry seal contribution to the pavement performance. Finally, the benefit/cost ratio was determined as the PB divided by the cost of a lane mile of slurry seal. This result was multiplied by 1,000 for easier interpretation. Table 5 shows the benefit/cost analysis for the Truckee Meadows and Incline Village slurry sealed pavement sections for the mentioned time of application. The cost per lane mile of a 24' width slurry seal was calculated to be $16,160.

Equations 9-10 show the mathematical model for benefit, particular benefit and the ratio among those parameters, respectively.

Benefit = Area under the curve of the improved model with slurry seal – Area under the curve of the improved model without slurry seal (9)

Particular Benefit =[Benefit / Number of years between the slurry seal application and the end date]*1000 (10)

Particular Benefit/Cost =Particular benefit/Cost of a lane mile of slurry seal (11)

The best timing for applying a slurry seal was related to the highest PB and PB/Cost ratio. Therefore, the slurry seal application with the largest value of both indicators was considered as providing the highest benefit to the pavement performance. In the case of Truckee Meadows, the best PB and PB/Cost was found for the slurry seals applied after three years of construction (PB= 23.5 and PB/Cost = 1.5). In the case of the collector roads in Incline Village the best PB and PB/Cost was found for the slurry seals applied after three years of construction (PB=32.5 and PB/Cost=2.0). In the case of the residential roads in Incline Village, the highest benefit was found for the slurry seals applied after three years of construction (PB = 12.8 and PB/Cost = 0.8). Finally, in both cases, the next timing of slurry seal application that provided the overall largest benefit was found to be after five years of construction. In general, it can be concluded that the slurry seals constructed between three to five years after the HMA overlay placement provided the largest benefit to the pavement performance.

Table 5. Benefit/cost analysis for the Truckee Meadows and Incline Village roads with slurry seal application.

Area	Road class	Year	Area under the curve for the improved model with slurry seal	Area under the curve for the improved model without slurry seal	Benefit	Particular benefit (PB)	Particular benefit/cost
Truckee Meadows	Residential	3	516.8	446.4	70.4	23.5	1.5
		5	577.3	462.30	115.0	23.0	1.4
		7	395.8	315.8	79.9	11.4	0.7
		9	258.5	182.5	76.0	8.4	0.5
Incline Village	Collectors	3	711.2	613.8	97.4	32.5	2.0
		5	529.5	441.8	87.7	17.5	1.1
		7	369.3	288.8	80.4	11.5	0.7
		9	219.8	156.9	62.9	7.0	0.4
	Residential	3	498.8	460.5	38.3	12.8	0.8
		5	312.6	290.7	21.9	4.4	0.3
		7	332.7	266.0	66.7	9.5	0.6
		9	238.8	185.5	53.3	5.9	0.4

5 CONCLUSIONS

The Regional Transportation Commission (RTC) of the Washoe County in Nevada uses the information provided by their pavement management system (PMS) to make informed decisions about the maintenance and rehabilitation of their existing pavement network. Since RTC recognized the importance of keeping its performance models updated, new performance models were developed based on current data from their PMS data. The following conclusions were made:

- The statistical method of the residual value has been shown as a useful tool to assess the goodness of the current and the new RTC performance models.
- In general, the current RTC-prediction curves under estimate the rate of reduction in the PCI values while a better prediction is achieved with the new developed models. Such conclusion was verified with the statistical analysis of the sum of squared residual values.
- The best timing for the slurry seal application was assessed through a benefit-cost ratio. Such analysis showed that the slurry seals applied between 3 and 5 years after the HMA overlay placement provided the largest benefit to the pavement performance.
- The developed models are going to be verified against the PMS data of the cities of Reno and Sparks, Nevada that are in the same area of the RTC-managed roads.

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