Effectiveness of Rehabilitation Options on Roughness Using LTPP Pavement Section Data for Arizona

Pedro Zavagna[1], Mena Souliman[2], Francisco Thiago Sacramento Aragão[3]
[1]Graduate Research Assistant, University of Texas at Tyler, Department of Civil Engineering, RBS 1008, 3900 University Blvd. Tyler, TX 75701, USA; pzavagna@patriots.uttyler.edu
[2]Assistant Professor, University of Texas at Tyler, Department of Civil Engineering, RBS 1008, 3900 University Blvd. Tyler, TX 75701, USA; msouliman@uttyler.edu
[3]Assistant Professor, Federal University of Rio de Janeiro/COPPE, Rio de Janeiro, Brazil, 21941-596; fthiago@coc.ufrj.br

ABSTRACT

The decrease of pavement service life associated to the increase in traffic load has been studied by several researchers in the last years. Several indices and test methods have been developed to evaluate that performance reduction and to serve as basis for the decision about the need for maintenance and rehabilitation of damaged sections. Among these, the International Roughness Index (IRI) has been well accepted and adopted by the pavement community. This study compares different rehabilitation techniques employed in 31 Asphalt Concrete (AC) sections of the state of Arizona. For that, short-term IRI reduction was evaluated based on historical data collected from the Long-Term Pavement Performance (LTPP) InfoPave website. An additional analysis was also performed to assess the long-term effectiveness of the rehabilitation techniques by analyzing their estimated service lives and the area bounded by treatment performance curve (AOC). The results showed that pavements with higher $IRI_{initial}$ experienced a higher IRI_{drop}, while pavements with low $IRI_{initial}$ had a smaller IRI_{drop}. Results also showed that roughness has a relatively gradual increase over the initial life of the treatment that is accelerated in its later stages. No difference in roughness was found when comparing shallow-depth overlays and deeper overlays. Treatment effectiveness models were also developed for predicting the expected effectiveness for future treatments on the basis of all the evaluated conditions in this study.

Keywords: Roughness, IRI, AC, LTPP, effectiveness

1. INTRODUCTION

The massive increase in traffic in the past decade resulted in a decrease in the pavement service life. For this reason, different methods of rehabilitation and maintenance are being studied in order to increase the pavement quality and consequently its service life. In 1984, the Long-Term Pavement Performance (LTPP) [1] program was started with the objective to assess different pavement and traffic data collection from over 2000 pavement test sections. Roughness data is one of the available data at the InfoPave website.

Analyzing how the road roughness values change year by year is very important, since this provides important insights on how a particular pavement behaves up to a certain level of traffic and weather conditions. Understanding this information is a key effort that may lead to the improvement of pavement designs by selecting specific pavement types that can have slower deterioration rates. This would decrease the maintenance or rehabilitation needs over the pavement life and reduce the associated costs for state and federal transportation agencies.

There are different methods to quantify the maintenance and rehabilitation effectiveness by prolonging the pavement life or increasing the ride quality. Short-term effectiveness is the performance jump or sudden boost of the pavement condition after treatment, resulting in a roughness drop (IRI_{drop}). However, for long-term effectiveness, Khurshid et al. [2] used two methods, the time necessary for the pavement to reach a specified failure point, and the area bounded by the treatment performance curve. For this study, 31 sections from the State of Arizona were analyzed from data obtained directly from the InfoPave LTPP database.

2. OBJECTIVES

The main objective of this study is to:

- Analyze the effectiveness of different rehabilitation treatments on the roughness of asphalt concrete (AC) pavement, considering different overlay depths, level of surface preparation, material type, and $IRI_{initial}$, by collecting the measured IRI data from the InfoPave database.
- Analyze short-term and long-term effectiveness for flexible pavement rehabilitation.
- Develop a predictive model for effectiveness of future pavement treatments.

3. LITERATURE REVIEW

Bumpy road caused by a rough road are experienced every day. Among the different parameters used to quantify the riding quality of the roads, roughness is probably the best correlated with the subjective evaluation made by drivers and/or by transportation engineers in technical surveys. Sayers et al. [3] defined roughness as “the variation in surface elevation that induces vibrations in traversing vehicles”. In simple words, this indicates how smooth or bumpy and consequently how comfortable the road is. In addition, the road roughness level is also frequently used to assess the rehabilitation needs of the road [4].

In 1980, in a cooperative highway research program, Gillespie et al. [5] published roughness measuring guidelines. Later in 1982, in a research funded by the World Bank, Sayers et al. developed the International Roughness Index (IRI) in Brazil. The main goal of the research was to standardize the characterization of road conditions. IRI is a scale based on the response of a vehicle to the road roughness in a single wheel path, using the RARS at 80 km/h recommendation as the best numerical index [3]. In 2002, Hall et al. [6] studied different rehabilitation treatments and demonstrated a significant correlation between $IRI_{initial}$ and post-treatment IRI. Two different types of effectiveness can be measured for pavement when analyzing overall roughness: short-term effectiveness and long-term effectiveness.

3.1 Short-Term Effectiveness

In order to provide a better pavement assessment, estimating the short-term effectiveness is very important, since it provides a fast comparison between different pavement rehabilitation techniques. Labi et al. [7] quantified the short-term effectiveness by comparing IRI_{drop} or performance jump after the rehabilitation work has finished. It can be easily calculated by subtracting the $IRI_{initial}$ (pre-treatment roughness) value by the IRI_0 (post-treatment roughness). However, in order to increase the calculation accuracy, it is important to measure the IRI value just before and just after the application of the of the rehabilitation treatment, as seen in Eq. (1):

$$IRI_{drop} = IRI_{initial} - IRI_0 \tag{1}$$

3.2 Long-Term Effectiveness

Long-term analysis can be considered more effective while analyzing roughness than short-term analysis since it includes a longer span of pavement performance observed after the pavement treatment [8]. However, long-term effectiveness can be measured by two different parameters: 1) Pavement Condition Index (PCI) that can be calculated by evaluating the treatment service life, and 2) calculating the area under the performance curve [9].

Estimation of treatment service life is a direct measurement of time elapsed between the pavement treatment and the pavement failure time. Treatment service life is given by Eq. (2):

$$IRI = e^{(A + \beta t)} \tag{2}$$

Where IRI represents the treated pavement section performance in a given year, A is a constant term, β is a coefficient for models explanatory variable, and t is the time elapsed from the application of the treatment.

An additional variable related to the pavement age can be calculated using Eq. (3):

$$t^* = \frac{\ln IRI_{critical} - A}{\beta} \tag{3}$$

Where t^* is the pavement age when the pavement performance reaches the threshold value or critical, $IRI_{critical}$ is the threshold value of IRI that is basically same as the $IRI_{Initial}$.

Another method to analyze the long-term effectiveness of pavement rehabilitation treatments for roughness is by considering the Areas Bounded by the Treatment Performance Curve (AOC) [10]. The use of AOC is advantageous because it includes the pavement performance life and the increase of pavement roughness over the service life in the analyses. AOC can be calculated by using the pavement performance curve and the treatment service life as indicated in Eq. (4):

$$\mathrm{AOC} = IRI_{critical} \times t - \int_0^t e^{(A + \beta * t)} dt \tag{4}$$

Where t is the treatment service life in years. Coefficients A and β can be found by using Eq. (2). Ahmed et al. [8] investigated a significant correlation between the rate of pavement deterioration after the treatment, analyzing the impact of pre-treatment IRI conditions on the pavement long-term effectiveness. In 2016, Souliman et al. [11] indicated that thicker overlays were on average more effective in terms of the estimated service life, while AOC had a higher correlation with the level of surface preparation, material type, and initial pavement condition.

4. DATA COLLECTION AND DATA ANALYSIS

The only source of data used on this research was the LTPP's website InfoPave. The State of Arizona has a total of 146 sections, 95 from flexible pavements and 31 sections with valid rehabilitation data for asphalt concrete pavements. The database includes the station location, pavement roughness condition, rehabilitation year, and rehabilitation strategy.

As indicated in Table 1, IRI data was collected for the roughness analysis considering three stages: pre-treatment IRI conditions (IRI value before treatment), post-treatment IRI condition (IRI value after treatment), and in a year-to-year IRI values during service life of the treatment.

4.1 Short-Term Effectiveness Data Analysis

Since it is easier to analyze the short-term effectiveness of pavements, due to the fact that it requires only initial roughness and after treatment roughness measurements. Short-term effectiveness can be a good indicator of greater long-term effectiveness when comparing pavement sections with similar rehabilitation techniques used, similar environmental conditions, and similar traffic configurations. If the conditions are not similar, each material can behave in a different way, not indicating a greater long-term effectiveness correlation.

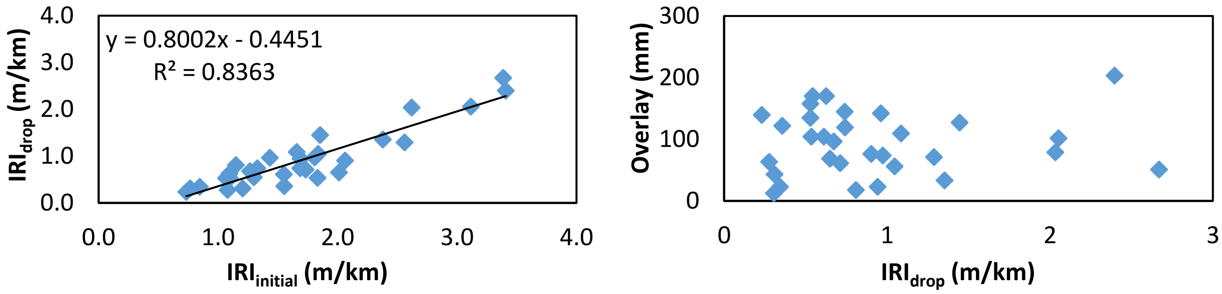
TABLE 1 Short-term Effectiveness

Overlay Type	**Section**	**$IRI_{initial}$ (m/km)**	**IRI_{final} (m/km)**	**IRI_{drop} (m/km)**	**Overlay Thickness (mm)**
Open Graded AC	04-6060	0.85	0.50	0.34	22.9
	04-6055	0.76	0.46	0.31	12.7
	04-1065	1.15	0.34	0.81	17.8
Dense Graded AC	04-D310	1.21	0.90	0.31	43.2
	04-1062	1.85	0.41	1.45	127.0
	04-1034	1.69	0.75	0.94	22.9
	04-1025	1.27	0.59	0.67	96.5
	04-1024	1.43	0.47	0.96	142.2
	04-1022	0.73	0.50	0.23	139.7
	04-1021	1.30	0.75	0.54	170.2
	04-1018	1.07	0.54	0.53	134.6
	04-1017	1.33	0.59	0.74	144.8
	04-1016	1.66	0.57	1.09	109.2
	04-1015	1.10	0.47	0.63	170.2
	04-1007	1.81	0.83	0.97	73.7
	04-1006	1.08	0.80	0.28	63.5
	04-1003	1.10	0.57	0.53	157.5
	04-1002	2.62	0.59	2.03	78.7
	04-0661	3.39	0.71	2.67	50.8
	04-0660	3.41	1.01	2.40	203.2
	04-0659	3.12	1.06	2.05	101.6
	04-0560	1.84	0.79	1.05	55.9
	04-0507	1.83	1.30	0.54	104.1
	04-0506	1.73	1.02	0.71	61.0
	04-0505	2.56	1.27	1.29	71.1
	04-0504	1.55	1.20	0.36	121.9
Recycled AC	04-0559	2.06	1.16	0.90	76.2
	04-0509	2.38	1.03	1.35	33.0
	04-0508	1.55	0.94	0.61	104.1
	04-0503	1.69	0.95	0.74	119.4
	04-0502	2.01	1.36	0.65	68.6

Table 1 shows a significantly higher range of IRI_{drop} values for Dense Graded AC sections, which ranged between 0.23 and 2.67 m/km. For Open Graded AC sections, the IRI_{drop} value ranged only between 0.31 and 0.81 m/km, with the IRI_{final} value being smaller than 0.50 for all three sections. The IRI_{drop} values for the Recycled AC sections ranged between 0.61 and 1.35 m/km, with the IRI_{final} ranging between 0.94 and 1.36 m/km. These values indicate that for Open Graded AC sections, the IRI_{final} is low, showing a higher reliability. For Dense Graded AC sections nothing can be predicted since IRI final values can range from very low to very high.

For the 31 Arizona sections analyzed in this article, the average IRI_{drop} ranged between 0.23 and 2.67. By analyzing and comparing the values in Table 1, it is possible to notice that sections 04-0661, 04-0660, and 04-0659 yielded the highest short-term effectiveness, due to the fact that the sections had a high pre-treatment IRI (3.31, 3.41, and 3.12 m/km, respectively). Sections 04-D310, 04-6055, 04-1022 and 04-1006 yielded the lowest short-term effectiveness values as a consequence of their lower pre-treatment IRI (1.21, 0.76, 0.73, and 1.08 m/km, respectively).

$IRI_{initial}$ (or pre-treatment IRI values) were plotted versus IRI_{drop} for all 31 sections, as shown in Figure 1a. The results showed a good correlation (R^2= 0.8363) between $IRI_{initial}$ and IRI_{drop}, indicating that pavements with poor initial roughness condition will have a larger IRI_{drop}, while pavements with greater initial roughness condition will have a smaller IRI_{drop}. Suggesting that these variables are directly proportional.



(a) **(b)**

FIGURE 1 (a) $IRI_{initial}$ vs. IRI_{drop}, (b) IRI_{drop} vs Overlay thickness

Different materials, techniques and overlay thickness were used on the rehabilitation process. However, as seen in Figure 1b, there is not a clear correlation between the overlay depth and the IRI_{drop}. This is mostly because the sections analyzed in this study were in good conditions. IRI pre-treatment values were lower and did not cause a great difference on the performance jump, and since the IRI_{drop} will be higher for sections that present higher roughness values, this analysis can be useful to identify sections that were subjected to unnecessary roughness rehabilitation processes.

4.2 Long-Term Effectiveness Data Analysis

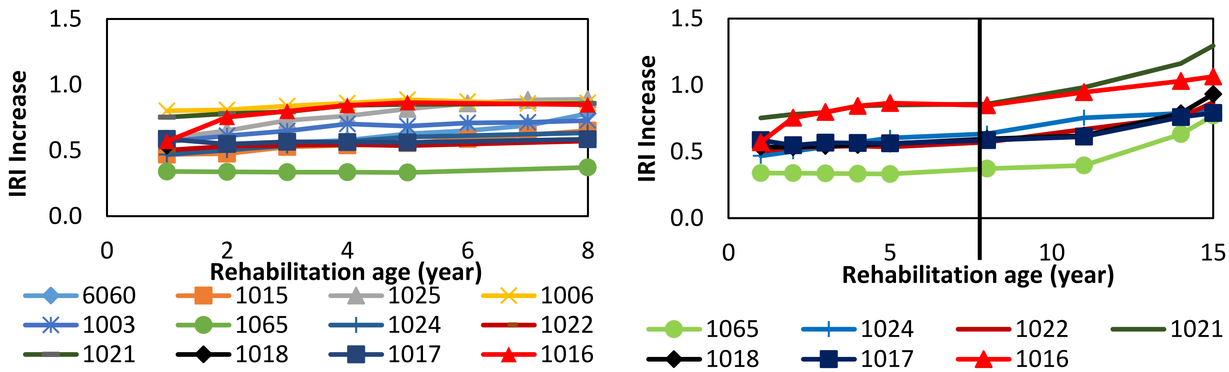
In order to analyze long-term effectiveness for the 31 sections located in the Arizona State, year-to-year roughness measurements were evaluated for a period of eight consecutive years. In most cases, the sections only had one or two roughness measurements after the rehabilitation process. For this reason, only 12 sections had their data analyzed, as shown in Table 2 and Figure 2a.

Figure 2a shows that roughness usually increases slightly with time, with the total IRI increase ranging between 0.06 and 0.30. It was also noticeable that sections with higher IRI pre-treatment had a higher IRI increase over time.

Figure 2b shows the roughness data for a period of 15 years. Only seven sections had data collected for a consecutive period of 15 or more years. Analyzed data indicated that roughness increases significantly after a period of 8 to 10 years, as seen on Figure 2b. It was observed that sections with higher IRI pre-treatment had a higher IRI increase over time, suggesting that pavement sections with poor initial condition will exhibit higher rates of deterioration over the treatment life. This would result in shorter service lives.

TABLE 2 Long-Term Effectiveness

Section	$IRI_{critical}$ (m/km)	Years	A	β	AOC (m*years/ km)	$IRI_{8\ Years}$ (m/km)	$IRI_{15\ Years}$ (m/km)	Overlay (mm)
04-6060	0.8690	9	-0.3622	0.02463	0.8072	0.7800	-	22.9
04-1065	0.7700	15	-0.3622	0.00676	0.5606	0.8900	0.7700	17.8
04-1025	0.8900	8	-0.3622	0.03070	0.8074	0.6510	-	96.5
04-1024	0.8180	15	-0.3622	0.01076	0.9382	0.8633	0.8180	142.2
04-1022	0.7580	14	-0.3622	0.00600	0.4460	0.7277	0.8703	139.7
04-1021	1.3630	19	-0.3622	0.03538	7.0368	0.3711	1.2959	170.2
04-1018	0.9320	15	-0.3622	0.01945	1.8548	0.6340	0.9320	134.6
04-1017	0.7910	15	-0.3622	0.00851	0.7281	0.5720	0.7910	144.8
04-1016	1.3079	18	-0.3622	0.03504	6.0812	0.8570	1.0641	109.2
04-1015	1.0791	17	-0.3622	0.02576	3.4947	0.5950	-	170.2
04-1006	0.9601	18	-0.3622	0.01786	2.5023	0.5851	-	63.5
04-1003	0.7689	18	-0.3622	0.00553	0.6655	0.8471	-	157.5



(a) **(b)**

FIGURE 2 (a) IRI increase after Treatment for 8 years, (b) IRI increase after Treatment for 15 years

5. CONCLUSIONS

This study addressed the effectiveness of flexible pavement rehabilitation treatments using the Long-Term Pavement Performance InfoPave website for pavement roughness data for the State of Arizona. The data analyzed indicated that for rehabilitation with Open Graded AC, the IRI_{final} is lower and more reliable than the Dense Graded AC and Recycled AC rehabilitation techniques. In addition, pavements with higher $IRI_{initial}$ (poor initial condition) also had a larger IRI_{drop}, while pavements with low $IRI_{initial}$ (great initial condition) had a smaller IRI_{drop}. Results also indicated that roughness slightly increases during the initial life of the treatment, however, after a period of 8 to 10 years (later stage of treatment life), it tends to increase rapidly. No difference in roughness was found when comparing shallow-depth overlays and deeper overlays.

Since roughness is an important indicator of the road health, roughness provides a standard platform when comparing road networks in Arizona, dictating the road roughness needs for maintenance.

REFERENCES

[1] Long-Term Pavement Performance (LTPP). LTPP Infopave [online]. Available from www.infopave.com. Accessed April 2017.

[2] Khurshid, M.B., Irfan, M. and Labi, S. An Analysis of the Cost-Effectiveness of Rigid Pavement Rehabilitation Treatments. 2009.

[3] Sayers, M. W., Gillespie, T. D., and Queiroz, C. A. V. The International Roughness Experiment. World Bank Technical Paper Number 45. 1986.

[4] Greene, S., Akbarian, M., Ulm, F-J., and Gregory, J. Pavement Roughness and Fuel Consumption. Concrete Sustainability Hub. 2013

[5] Gillespie, T. D., Sayers, M.W., and Segel, L. Calibration of Response-Type Road Roughness Measuring Systems. 1980.

[6] Hall, K.T., Correa, C.E., and Simpson, A.L. LTPP data analysis: effectiveness of maintenance and rehabilitation options. Publication NCHRP Project 20-50(3/4): Final Report. Washington, DC: National Cooperative Highway Research Program Transportation Research Board, National Research Council. 2002.

[7] Labi, S. and Sinha, K.C. Measure of short-term effectiveness of highway pavement maintenance. Journal of Transportation engineering, 129 (6), 673-683. 2003.

[8] Ahmed, A., Labi, S., Lee, Z. and Shields, T. Aggregate and disaggregate statistical evaluation of the performance-based effectiveness of long-term pavement performance specific pavement study-5 (LTPP SPS-5) flexible pavement rehabilitation treatments. USA. 2013.

[9] Labi, S. et al. An analysis of long-term effectiveness of thin hot mix asphaltic concrete overlay treatments. Transportation Research Board, 1840, 3-12. 2005

[10] Geoffrey, D.N. Cost-effective preventive pavement maintenance. NCHRP Synthesis of Highway Practice 223. Washington, DC: Transportation Research Board, National Research Council. 1996.

[11] Souliman, M., Shankar, K., and Walubita, L. F. Effectiveness of Rehabilitation Options on Roughness Using LTPP Section Data for New Mexico. 4th GeoChina International Conference 2016. China. 2016.