

THE EFFECT OF INITIAL PAVEMENT SMOOTHNESS ON LONG-TERM ROUGHNESS PROGRESSION: SOME FINDINGS FROM C-LTPP AND US-LTPP STUDIES

This brief provides findings on the observed effect of initial pavement smoothness (also known as initial roughness, or as-constructed roughness) on the long-term pavement roughness progression of asphalt overlays. The relationship can be used as a measure for estimating the long-term effect of pavement smoothness and for consideration when developing smoothness specifications and/or payment adjustments within a smoothness specification. This brief summarizes research completed by the University of Waterloo through the C-SHRP Graduate Research Program and is intended to complement C-SHRP Technical Brief #16 entitled Summary of Pavement Smoothness Specifications in Canada and Around the World.

BACKGROUND

Smoothness specifications are an essential part of a transportation agency's quality assurance program. Road user surveys identify pavement smoothness as the most important measure of pavement quality. Furthermore, the construction of smoother pavements leads to increased pavement service life, increased safety and decreased vehicle operating costs. Smoothness specifications are developed to encourage the construction of smoother pavements, typically through payment adjustment clauses within the construction contract. The concept is simple - full contract payment is provided for pavements constructed to a standard level of smoothness as specified by the agency. Bonuses are provided for pavements constructed with higher smoothness (lower initial roughness) and penalties are imposed for pavements constructed with lower smoothness (higher initial roughness). Determining the level of smoothness that constitutes the "standard level" and the appropriate payment adjustments for a specification are not as simple. The "standard level" of smoothness should represent an achievable quality benchmark that warrants full payment. Payment adjustments should be related to the increased or reduced costs (usually determined from increased or decreased pavement life) that will occur from the initial pavement smoothness.

Previous Studies

A previous study for the National Asphalt Pavement Association (NAPA) examined the relationship between initial roughness and roughness after 8 to 10 years of service. The study reported that pavements constructed with a lower initial roughness had lower roughness, lower cracking levels and required lower average maintenance costs after 8 to 10 years of service. The findings indicated that approximately 110 percent of initial roughness is present after 8-10 years of service. The study is based on roughness measurements from Arizona and Pennsylvania obtained with a Mays Ride Meter. Mays Ride Meter measurements have been shown to have a linear relationship with International Roughness Index (IRI), therefore the same relationship should be present for IRI measurements.

Another measure of the long-term effect of initial roughness is the pavement roughness prediction model based on the Road Deterioration and Maintenance submodel of the World Bank's Highway Design and Maintenance Standards Model HDM-III. The model is intended for use when a pavement has less than 5% cracking over its total area. The model estimates that 113 percent of the initial roughness will be present after 8 years of service. The model was recalibrated for the province of New Brunswick in 2000 and the resulting provincial model estimates that 107 percent of the effect of initial

roughness remains after 5 years of service. These models measure roughness (and smoothness) in terms of IRI.

Methodology

Although previous reports have identified that initial roughness affects long-term pavement roughness progression, there is limited long-term data quantifying this effect. The underlying question for this investigation was – “If a pavement is constructed with a lower (or higher) initial roughness than a standard benchmark, how much of this roughness difference will remain after several years of service?” Consider the following scenario:

Two asphalt pavements are constructed using the same materials and at the same time. However, the first pavement is constructed with an initial IRI of 0.9 m/km (very smooth), while the second is constructed with an initial IRI of 1.2 m/km (fairly standard). With time, the roughness of each pavement will increase under traffic and environmental loading. Assume that the progression of roughness is linear with time. At some future date, the roughness values of each pavement are compared. There are three possible outcomes of this comparison as follows.

- i) The difference in IRI remains constant (at 0.3 m/km in our example). This indicates that the progression of roughness (i.e. the slope of the roughness versus time graph) has been constant for both pavements. In other words, 100% of the difference in initial IRI has remained. If the second pavement has reached the critical roughness value at the selected date, then smoother pavement will require an additional time interval “X” to reach the critical point according to the following equation derived from trigonometry:

$$X = \sqrt{\text{Slope}^2 - \text{Difference}^2}$$

This outcome is good (the smoother pavement is still smoother), but there is no additional benefit of constructing the pavement smoother.

- ii) The difference in IRI increases. This indicates that the roughness progression for the smoother pavement has been less than the second pavement and that more than 100% of the initial IRI difference has remained. This outcome is excellent as it indicates that constructing smoother pavements not only produces longer lasting pavements, but also retards the progression of roughness so that the pavement stays smoother for a longer period of time.
- iii) The difference in IRI decreases. This outcome indicates that the progression of roughness for the smoother pavement has been greater with time than the second pavement (i.e. it is catching up to the second pavement). In other words, less than 100% of the initial IRI difference has remained. In this case, there still may be some benefit to constructing smoother pavements since the smoother pavement may still have lower overall roughness. However, the benefit is reduced with time.

This technical brief summarizes the findings from an analysis of the C-LTPP and US-LTPP test sites. Instead of completing comparisons between pairs of pavements, an overall analysis was completed for all of the pavement sections by plotting the IRI value after 8 years in service versus the initial IRI (i.e. smoothness). For each of the graphs, a linear regression was completed to best fit the data points. The intercept for each regression equation represents the (fictitious) roughness expected after 8 years in

service if the pavement was constructed with an initial IRI of zero (perfectly smooth). The slope of the regression equation is the percentage of the initial IRI difference that has remained after 8 years in service and indicates whether or not the construction of smoother pavements is beneficial.

TEST ROAD PERFORMANCE

The Canadian Long Term Pavement Performance (C-LTPP) program administered by C-SHRP and the Long Term Pavement Performance (US-LTPP) program administered by the Federal Highway Administration were investigated to determine the observed effect of initial roughness on long-term roughness progression in asphalt overlays placed over existing asphalt pavements. This consisted of data from the US-LTPP Specific Pavement Study Project 5 (SPS-5), US-LTPP General Pavement Study Project 6 (GPS-6) and the C-LTPP sites. Eight years of service was selected as the measure of long-term performance because it was representative of the available roughness measurements from the test sites. The eight-year time frame is also comparable with previous studies.

Observations for the C-LTPP Sites

The C-LTPP experiment consists of 65 sections located at 24 test sites across Canada. The pavement sections were constructed between 1989 and 1990 as asphalt overlays placed over existing flexible pavement structures. Each site consists of two, three or four adjacent sections. Roughness measurements for each site were determined from the average of the various sections. Of the 24 sites, the three sites located in British Columbia were removed from the analysis because roughness measurements were only available for the first five years of service. The relationship between initial roughness and pavement roughness after eight years of service is provided in Figure 1. The plot has a regression line with a slope of 0.68, which indicates that 68 percent of the initial roughness remains after 8 years of service. Therefore, two pavements with a 1.0 m/km difference in initial IRI would have a predicted difference in IRI after 8 years of 0.68 m/km.

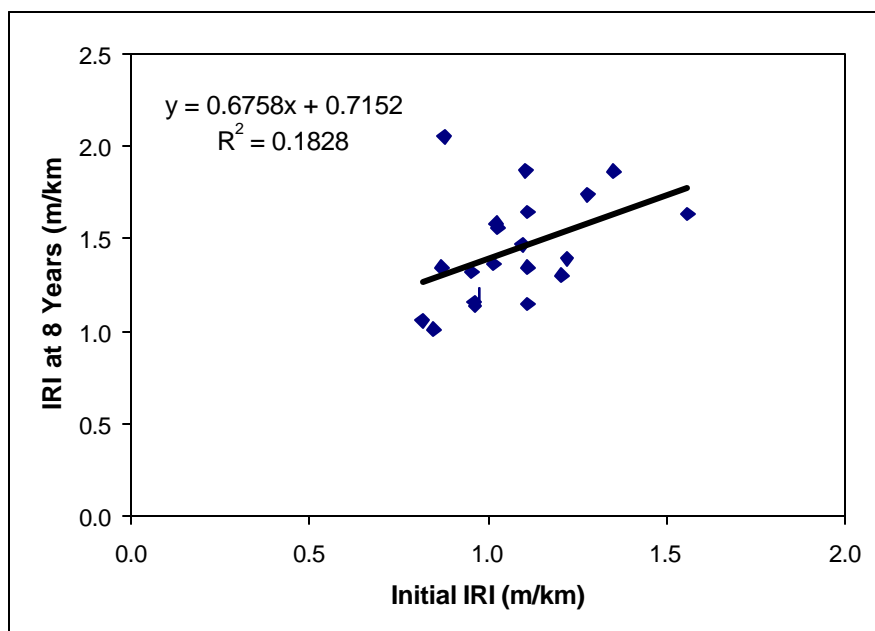


Figure 1 – C-LTPP Site Comparison of IRI at 8 Years and Initial IRI

Observations for US-LTPP SPS-5 Sites

SPS-5 sites are located across the United States and Canada. The sites were constructed with eight asphalt overlay sections consisting of different treatments of surface preparation, overlay thickness and overlay material. Roughness levels for each site were determined based on the average roughness of the eight sections. The relationship between initial roughness and pavement roughness after 8 years of service has a regression slope of 0.57 percent, which indicates that 57 percent of the initial roughness remains after 8 years of service.

Observations for US-LTPP GPS-6 Sites

GPS-6 sites are located across the United States and Canada. Twenty-nine sites from the GPS-6 experiment were examined. The objective of the GPS-6 study is to examine the performance of an asphalt overlay treatment over an existing asphalt concrete pavement. The relationship between initial roughness and pavement roughness after 8 years of service has a regression slope of 0.85 percent, which indicates that 85 percent of the initial roughness remains after 8 years of service.

Observations for the Combined Data

Combining the data from the C-LTPP, US-LTPP SPS-5 and US-LTPP GPS-6 sites enabled a more extensive analysis of the effect of initial roughness on long-term roughness. Combining the three databases resulted in a total of 61 sites representing both freeze and no-freeze environments. The relationship for initial roughness is shown in Figure 2. The slope of the regression line is 0.84, which indicates that 84 percent of the initial roughness remains after 8 years of service.

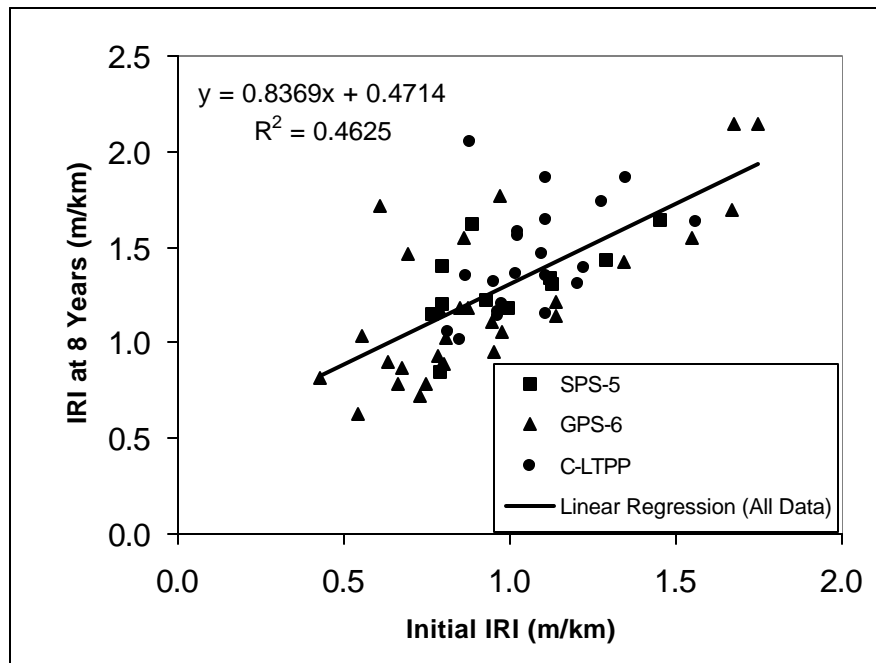


Figure 2 – C-LTPP, SPS-5 and GPS-6 Site Comparisons of IRI at 8 Years and Initial IRI

Examination of Freeze Environments

The previous analyses have been representative of the environmental conditions found across Canada and the United States. To investigate the specific performance of northern climates, the analyses were repeated with sites located in a no freeze environment removed. No additional sites were removed from the C-LTPP data (as the BC sites were previously removed from the analysis), while four sites were removed from the SPS-5 data and seven sites were removed from the GPS-6 data. The examination of sites located in a freeze environment produced similar results to the previous analyses with a slightly more pronounced effect of initial roughness. The relationship for initial roughness with data located in a freeze environment is shown in Figure 3. The slope of the regression line is 0.88, which indicates that 88 percent of the initial roughness remains after 8 years of service.

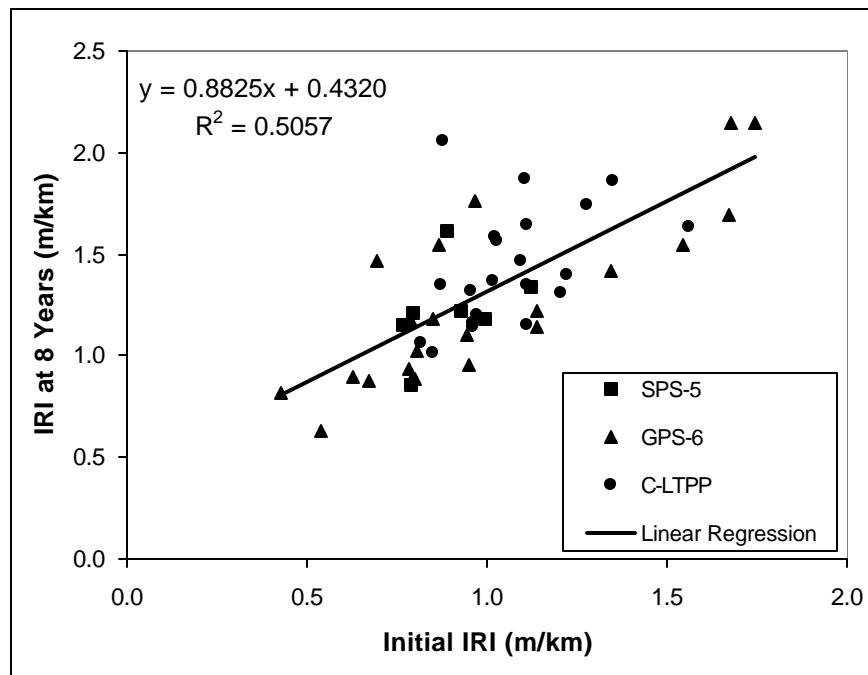


Figure 3 – C-LTPP, SPS-5 and GPS-6 Site Comparisons of IRI at 8 Years and Initial IRI for Freeze Conditions

Examination of Outlier Values

The data was examined for individual points located outside the 95 percent confidence intervals of the regression analyses. Outlier values were identified for all of the data sets except for the SPS-5 sites, which had the fewest number of data points. Outliers were identified for the combined data (all environments) as shown in Figure 4. One trend observed in the outlier values was that they were all located above the regression trend line. The outliers therefore represent pavements that are deteriorating faster than would be expected for a given initial roughness. The reason for this trend is not known, however, it could be a result of a construction deficiency or the pavement being under designed. The removal of the outlier values from the analyses causes the slopes of the regression lines to increase. The relationship of initial roughness and long-term roughness for the combined data (all environments) with outliers removed is shown in Figure 4. The regression slope is 0.98, which is very close to a value of one and indicates that essentially all of the initial roughness remains after 8 years of service.

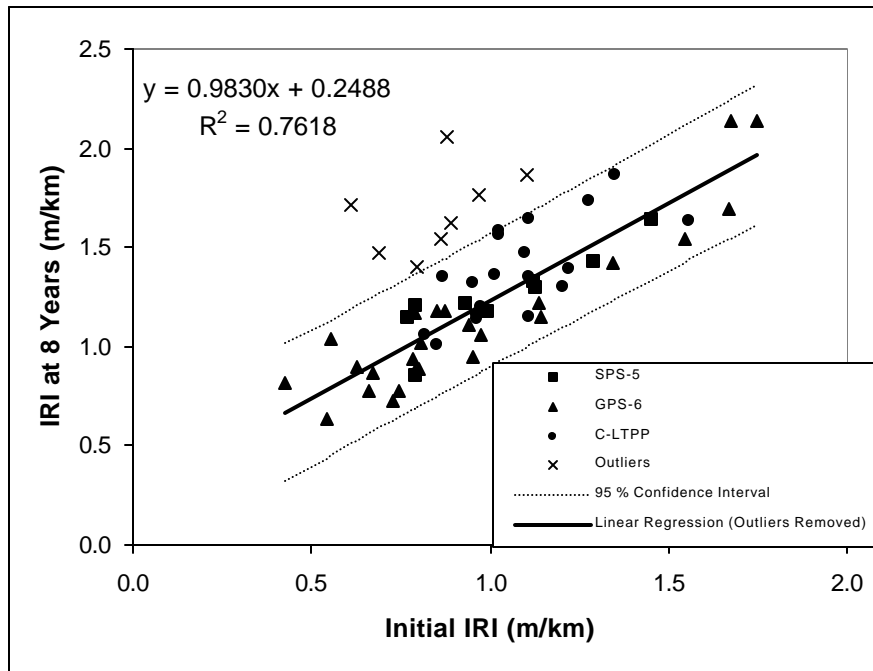


Figure 4 – C-LTPP, SPS-5 and GPS-6 Site Comparisons of IRI at 8 Years and Initial IRI with Outlier Values Removed

APPLICATION TO SPECIFICATION DEVELOPMENT

Selecting the level of smoothness that represents full payment in a smoothness specification typically involves reviewing historical measurements and determining the appropriate level of roughness that should represent full payment. If this level is set very smooth, it will lead to difficulties in achieving full payment for contractors that undertake a reasonable commitment to quality. Consequently, setting the level too rough will result in bonuses being paid for pavements that are not of superior quality.

Payment of bonuses and penalties should be based on the increased or reduced costs resulting from the constructed pavement smoothness. These costs are typically quantified as the increased or reduced pavement life of a pavement, although safety and vehicle operating costs are also impacted by pavement smoothness. If the premise that approximately 100 percent of the effect of initial roughness remains after 8 years is extrapolated for the service life of a pavement, it is possible to perform a life cycle cost analysis and determine the increase or decrease in costs resulting from initial pavement smoothness. These costs can then be represented in the specification bonuses and penalties.

SUMMARY

The data from three research projects, the C-LTPP, LTPP SPS-5 and LTPP GPS-6 were examined both individually and in combination to investigate the effect of smoothness (i.e. initial roughness) on long-term roughness progression. Separate analyses were also performed for data located in a freeze environment and the removal of outlier values that did not fit a 95 percent confidence interval. The results of these analyses are summarized in Table 1 (outlier values included) and Table 2 (outlier values removed). The slope represents the slope of the regression line for a plot of roughness after 8 years of service versus initial roughness. This slope can also be explained as the amount of initial roughness that remains after 8 years of service. The lower and upper bounds that represent the 95 percent confidence interval for the slope are also presented along with their statistical significance level.

The slope determined from the combined data of the three research projects is 0.84 (both environmental zones) and 0.88 when only the data from sites located in freeze conditions is considered. When outlier values were removed, both slopes increased to 0.98. All four analyses indicated a statistically significant long-term effect for initial roughness.

When the outlier values identified in the various data sets were examined, there was an apparent trend that every outlier value removed from a data set was located above the regression line. The removal of the outlier values from the data sets caused the slope to increase in all cases. The analyses presented in Table 10 with outlier values removed generally indicated a slope that is close to a value of one. All of the slopes are between 0.90 and 0.98 except for the two SPS-5 analyses, which have slopes of 0.57 and 0.68.

When only the data located in freeze conditions was examined, the effect of initial roughness (i.e. the slope) increased for most data sets. The largest difference in slopes is 0.11 for the SPS-5 study, which has the smallest data set. Smaller differences are observed for the combined data sets and data sets with outlier values removed. This convergence of slopes for larger data sets and the removal of outliers indicated that the effect of initial roughness for freeze conditions is similar to the effect for all environments.

Table 1 – Summary of Effect of Initial Roughness Regression Analyses

Analysis	Slope	95% Confidence Interval		Significance (p-value)
		Lower Bound	Upper Bound	
SPS-5	0.57	0.33	1.17	0.06
SPS-5 Freeze Conditions	0.68	-1.19	2.56	0.39
GPS-6	0.85	0.54	1.15	0.00
GPS-6 Freeze Conditions	0.90	0.60	1.20	0.00
C-LTPP	0.68	-0.01	1.36	0.05
SPS-5, GPS-6 and C-LTPP	0.84	0.60	1.07	0.00
SPS-5, GPS-6, C-LTPP Freeze Conditions	0.88	0.63	1.14	0.00

Table 2 – Summary of Effect of Initial Roughness Regression Analyses with Outlier Values Removed

Analysis	Slope	95% Confidence Interval		Significance (p-value)
		Lower Bound	Upper Bound	
SPS-5 (no outliers identified)	0.57	0.33	1.17	0.06
SPS-5 Freeze Conditions (no outliers)	0.68	-1.19	2.56	0.39
GPS-6	0.97	0.79	1.15	0.00
GPS-6 Freeze Conditions	0.98	0.79	1.17	0.00
C-LTPP	0.90	0.43	1.37	0.00
SPS-5, GPS-6, C-LTPP	0.98	0.83	1.14	0.00
SPS-5, GPS-6, C-LTPP Freeze Conditions	0.98	0.81	1.15	0.00

Based on the results, the best estimate of the relationship slope is 0.98, derived from the analyses of the combined data from the SPS-5, GPS-6 and C-LTPP studies. This estimate is essentially the same as a slope of 1.0, indicating that approximately 100 percent of the effect of initial pavement roughness remains after eight years of service for asphalt overlay pavements. In essence, if a pavement is constructed with a high initial roughness, it should maintain its high roughness for at least eight years. Whether this will continue beyond eight years can only be determined with continuing field observations.

MORE INFORMATION

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