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SMOOTHNESS EFFECTIVENESS OF FLEXIBLE PAVEMENTS

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EXECUTIVE SUMMARY

Some State Highway Agencies in the United States use smoothness specifications to insure that they are providing the public with quality roads. For asphalt pavements, these specifications are usually written for the use of a straightedge, a profilograph, or a road profiler. Monetary incentive/disincentive policies based on the initial Profilograph Index are currently being used by some State Highway Agencies to encourage contractors to build smoother roads. Very little work has been done to determine the need for such smoothness specifications, especially on asphalt pavements. This research study was conducted on representative pavement sections in the state of Florida to determine if the initial roughness of a pavement section has any effects on its long-term performance. The statistical tests performed indicate that flexible pavements with low initial smoothness do stay smooth over time. These findings justified the implementation of new smoothness specifications for asphalt pavements in the state of Florida.

INTRODUCTION AND BACKGROUND

Pavement roughness contributes a major portion of road serviceability or riding quality. During the AASHO Road Test, several studies were conducted which indicated that 95 percent of a user's perception of a road result from the roughness of its surface profile [1].

Road roughness can be defined as "the distortion of the road surface that imparts undesirable vertical accelerations and forces to the vehicle or to the riders and thus contributes to an undesirable, uneconomical, unsafe, or uncomfortable ride" [2]. Surface variations less than one-half inch in length do not significantly affect ride quality and are called surface texture rather than roughness [3]. The normal practice today is to limit the measurement of roughness qualities to those related to the longitudinal profile of the road surface which cause vibrations in road-using vehicles.

In general, road roughness can be caused by any of the following factors[4]:

a. Construction techniques which allow some variation from the design profile.

b. Repeated loads, particularly in channelized areas, can cause pavement distortion by plastic deformation in one or more of the pavement components.

c. Frost heave and volume changes due to shrinkage and swell of the subgrade.

d. Non-uniform initial compaction.

A recent study performed at the University of Wyoming indicates that straightedges and profilographs are currently the most widely used devices to accept new asphalt pavements [5].

There are sixteen State Highway Agencies (SHAs) using a straightedge for acceptance and fifteen SHAs using the California-type profilograph [5]. When a straightedge is used to accept a pavement, it is placed on the pavement surface and the distance between the bottom of the straightedge and the surface is measured. If this measured distance is less than the specified tolerance limit, the pavement is accepted. Profilographs measure the profile of a pavement section and give a Profilograph Index (PI). AASHTO recommends two methods for smoothness specifications based on PI for asphalt pavements. Method 1 of the AASHTO specifications has only disincentives (penalties) while method 2 offers both incentives and disincentives. Tables 1 and 2 show the recommended payment plan for methods 1 and 2, respectively [6].

Due to the importance of pavement roughness, many SHAs have implemented or are examining smoothness specifications to insure good ride quality. The Federal Highway Administration has been encouraging SHAs to implement smoothness policies for asphalt pavements. Today, only eighteen SHAs have roughness incentive/disincentive policies for asphalt pavements [5]. These policies are made based on the assumption that lower initial pavement roughness will result in better pavement performance. Most SHAs require contractors to perform corrective work on extremely rough sections [5].

The Florida Department of Transportation (FDOT) has recently implemented smoothness specifications for asphalt pavements. These newly developed specifications will utilize roughness measurements obtained with a laser road profiler to assess incentive payments for exceptionally smooth pavements. In order to justify paying incentives for smoother asphalt pavements, the roughness variations of a large number of test sections in the state of Florida were analyzed over a six-year analysis period. The main objective of the analysis was to determine if asphalt pavements constructed smoother will stay smooth over time.

DESIGN OF EXPERIMENT

FDOT has been utilizing ultrasonic road profilers in collecting pavement roughness measurements since 1992. The pavement network in Florida is divided into segments and the roughness measurements of these segments are normally measured every year. All roughness measurements are saved in computer files on FDOT's mainframe. FDOT does not normally apply any maintenance to asphalt pavements. It is the normal practice to wait for pavement sections until they have deteriorated enough to mill the existing sections and apply new overlays. This practice is ideal for monitoring the roughness of pavement sections over the years since there is no need to account for any maintenance.

In this study, roughness measurements in the form of International Roughness Index (IRI) were obtained on all asphalt sections which were constructed in 1992. The objective was to monitor the roughness fluctuations of these sections over a six-year analysis period between 1992 and 1997. This search resulted in 228 asphalt test sections with variable lengths. All sections that received another overlay prior to 1997 were eliminated from the study. Furthermore, all sections with no roughness measurements in 1997 were also eliminated from the study. This process resulted in 123 asphalt pavement sections with adequate data for the analysis.

DATA ANALYSIS

Roughness data between 1992 and 1997 for the 123 test sections were summarized in computerized spreadsheets. As shown in Table 3, the test sections were divided into five different categories based on their initial roughness in 1992. The range of each category was 10 inches per mile except for the rough sections (above 101) which were all included in one category. Around 10 percent of the sections fell within the smoothest category while 43 percent of the sections fell in the roughest category.

A comprehensive data analysis was performed on the roughness data of test sections included in the experiment. This analysis consisted of first performing regression analysis and then conducting the Mann-Whitney test to provide reliable and conclusive results on the relationships between initial and future roughness measurements of asphalt pavements.

a. Regression Analysis

Initially, the analysis concentrated on roughness data from the individual sections. However, due to the relatively low accuracy level of the ultrasonic sensors used to collect the roughness measurements, the data showed significant scatter. Next, roughness measurements for sections within each category were averaged and then summarized in Table 4. These average values were later used to perform a simple linear regression analysis to correlate roughness measurements between 1992 and 1997 for each roughness category. Table 5 summarizes the results from the regression analysis. The same data is presented graphically in Figure 1. It is clear from both figure 1 and table 5 that sections with lower initial smoothness are staying smoother over time. Rougher sections, up to 100 inches per mile, do get rougher over time. Pavement sections with roughness higher than 101 inches per mile are already rough and due to the pounding of traffic they will not get rougher over time. This trend is shown graphically in Figure 2 which clearly supports the above findings. It is important to emphasis here that not every pavement section will follow this trend but on the average, this is the expected performance of typical pavement sections in the state of Florida. It is also important to mention that roughness data of smooth sections show less scatter than rough sections as indicated by the R-Square values shown in Table 5.

b. Results from Statistical Analysis

The Mann-Whitney test [7] was performed on the data collected in this research study. The Mann-Whitney test is a non-parametric test based on the ranks of the observations. The test sections in this study were ranked based on their roughness for the year being tested, with the smoothest section being one and the roughest section being N (where N is the number of test sections). Then the sections were separated into two roughness categories based on their initial roughness. The two roughness categories are shown below:

Smooth (category x): IRI $\leq$ 90 in/mile

Rough (category y): IRI > 90 in/mile

The rank sums (R_x and R_y) for each category were then determined. These sums were used to calculate U_x and U_y, where:

$$U_x = R_x - N_x(N_x + 1)/2$$

$$U_y = R_y - N_y(N_y + 1)/2$$

Where:

U_x=number of times an x value is larger than a y value

U_y=number of times a y value is larger than an x value

N_x=the number of test sections in group one

N_y=the number of test sections in group two

The test statistic Z was then determined based on the formula shown below:

$$Z = \frac{U[(N_x * N_y)/2]}{\sqrt{[N_x * N_y * (N_x + N_y + 1)]/12}}$$

Where:

U = the lower of U_x and U_y

N_x =the number of test sections in the smooth category

N_y =the number of test sections in the rough category

When the test statistic Z was less than the critical value from the standard normal tables, the null hypothesis that the populations were identical was rejected [7].

In this evaluation, the initial IRI measurements were tested against future IRI values to determine if smoother pavements remained smoother over the years. When the Mann-Whitney test indicated that the two groups were different, it meant that the smoother sections were performing better than rougher sections. In this study, the 1992 roughness data set was compared to 1993, 1994, 1995, 1996, and 1997 data sets. As shown in Table 6, in all cases the data sets were statistically different. This supports the findings from the regression relationships and demonstrates that those sections with lower initial roughness will remain smoother throughout their service lives. This indicates that initial IRI values do affect future roughness values for asphalt pavements.

CONCLUSIONS AND RECOMMENDATIONS

A large number of asphalt test sections in the state of Florida were included in this research study. Initial and later IRI measurements over a six-year analysis period were obtained for each one of those test sections. A comprehensive statistical analysis was performed on the data and the following conclusions were drawn:

1. The regression relationships developed indicate that initial IRI measurements correlate with future IRI values for asphalt pavements.
2. Relationships developed for smooth pavements have better correlation coefficients and show less scatter than the relationships of the rough sections.

3. The Mann-Whitney statistical tests strongly support the fact that asphalt pavements constructed with low initial roughness do remain smooth over time.

The results of this research emphasize the importance of low initial roughness and support the need for smoothness specifications for asphalt pavements. Pavements that have low initial roughness will stay smooth and result in a higher level of satisfaction of the driving public.

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REFERENCES

1. Carey, W. N., and Irick, P. E., "The Pavement Serviceability- Performance Concept", HRB, Bull. 250, 1960, pp. 40-58.

2. Hudson, W. R., "Road Roughness: Its Elements and Measurements", Transportation Research Record 836, Transportation Research Board, Washington, D. C., 1981.

3. Scrivner, F., and Hudson, W., "A Modification of the AASHO Road Test Serviceability Index Formula," Highway Research Record 46, 1964.

4. Yoder, E. J., Hampton D., "Pavement Profile and Roughness Measurements; A Review of Method", Purdue University, January, 1958.

5. Ksaibati, K., Staigle, R., and Adkins, T., "Pavement Construction Smoothness Specifications in the United States," Transportation Research Board, Washington, D.C., 1995.

6. "Guide Specifications for Highway Construction," American Association of State Highway and Transportation Officials, Washington, D. C., 1993.

7. Owen. D. B., "Handbook of Statistical Tables", Addison-Wesley Publishing Company, Inc., 1962.

Table 1. Method 1 of the AASHTO Smoothness Specifications.

Profilograph Index Inches per Mile	Price Adjustment % of Pavement Unit Bid Price
PI < 7	100
7 < PI < 8	98
8 < PI < 9	96
9 < PI < 10	94
10 < PI < 11	92
11 < PI < 12	90
PI > 12	Corrective work required

Table 2. Method 2 of the AASHTO Smoothness Specifications.

Profilograph Index Inches per Mile	Price Adjustment % of Pavement Unit Bid Price
PI < 1	105
1 < PI < 2	103
2 < PI < 3	102
3 < PI < 4	101
4 < PI < 7	100
7 < PI < 8	98
8 < PI < 9	96
9 < PI < 10	94
10 < PI < 11	92
11 < PI < 12	90
PI > 12	Corrective work required

Table 3. Sections Included in The Experiment.

Roughness Range	# of Sections	Percent
60-70	12	10
71-80	20	16
81-90	14	11
91-100	24	20
101-140	53	43

Table 4. Changes in Roughness Measurements between 1992 and 1997.

	Roughness Range				
Year	60-70	71-80	81-90	91-100	101-140
1992	65.7	75.5	85.4	96	120.5
1993	67.6	81.6	86.5	99.4	101.1
1994	73.5	82.5	96.9	98.1	100.7
1995	78.4	81.9	83.9	100.4	105.2
1996	80.7	88.5	96.5	110.2	106.7
1997	83.4	89.8	95	99	99.6

Table 5. Results from The Regression Analysis Performed on The Data.

Range	Intercept	Slope	R-Square
60-70	-7483	3.789	.98
71-80	-5146	2.622	.88
81-90	-3624	1.863	.33
91-100	-2739	1.424	.29
101-140	4840	-2.374	.33

Table 6. Results of Mann-Whitney Tests Based on Initial IRI Measurements for Asphalt Test Sections.

Years	Statistic Analysis Value	Standard Value	Conclusion
1992 versus 1993	-4.7	-1.645	Different
1992 versus 1994	-3.5	-1.645	Different
1992 versus 1995	-5.8	-1.645	Different
1992 versus 1996	-3.89	-1.645	Different
1992 versus 1997	-2.37	-1.645	Different

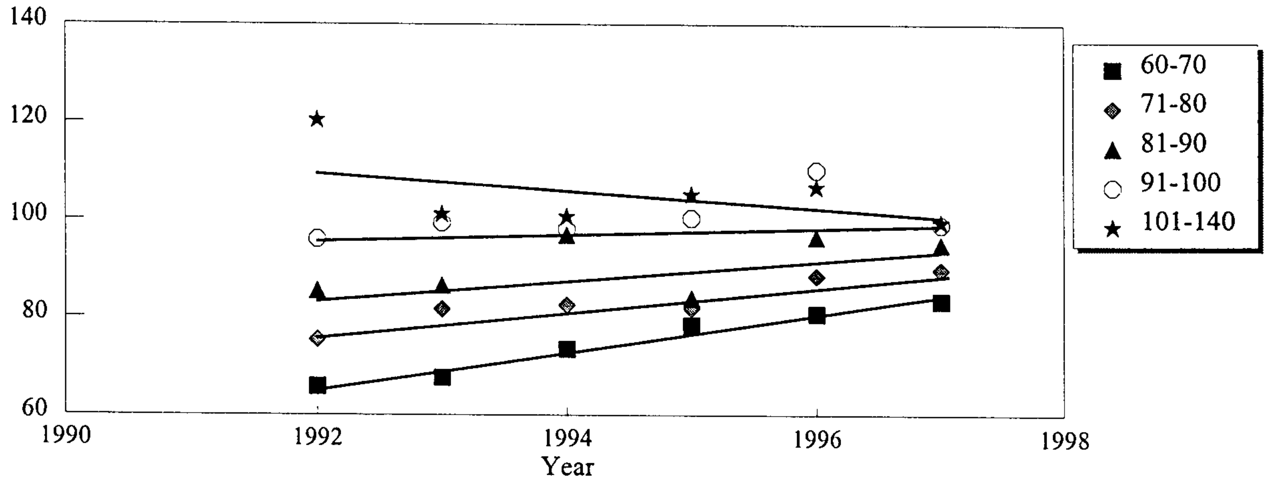

Figure 1. Roughness Fluctuation Due To Aging

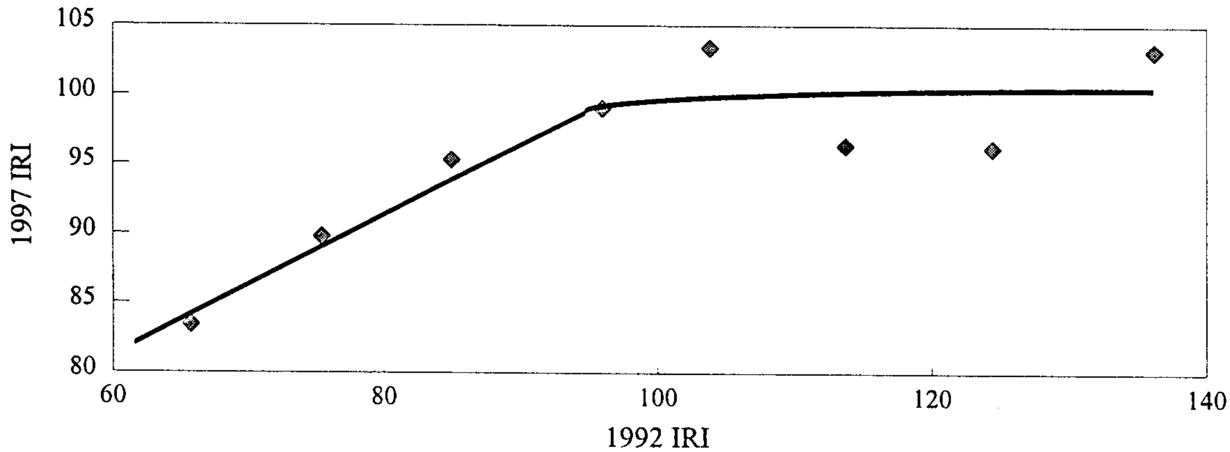

Figure 2. Relationship between 1992 and 1997 Roughness