Automated Versus Manual Profilograph Correlation

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The Texas Department of Transportation (TxDOT) has attempted to correlate the outputs of the automated Cox profilograph, the automated McCracken profilograph and a TxDOT manual McCracken profilograph. The evaluation process was precipitated by calls from construction engineers within the TxDOT highway agency and paving contractors working within Texas. Both the state and contractor personnel were requesting the use of the automated profilograph. The results of the evaluation process were as follows. The Cox automated profilograph used a filter setting number of 5, which represents the attenuation of 2.2 ft (0.067 m) and less, whereas the McCracken model used a data filter cutoff frequency of 2.5 ft (0.76 m). The profilograms from the TxDOT manual profilograph were reduced by two different interpreters. Both of the automated versions of the profilograph were slightly more repeatable than the interpretation of the manual profilograph. The automated profilographs showed very close correlation with the manual profilograph on the smooth, medium, and rough sections of asphalt concrete pavement and on the rough sections of continuously reinforced concrete (CRC) pavement. The automated profilographs deviated from the manual profilograph output on the smooth-section CRC pavement. This deviation was from 0.5 to 2.0 (0.789 to 3.16 cm) PI counts smoother (lower) than the output of the manual profilograph

During the past few years several state highway authorities have reported problems when an automated California type of profilograph was used to determine contractor payment on pavement construction projects (*1*). The state highway authorities owned a manual California-type profilograph, whereas the contractor was allowed to use an automated (computerized) California-type profilograph. The contractor's automated profilograph was used daily to determine the bonus or penalty payments for the paving operation. When the state authority came back to verify the results with their manual profilograph, the resulting profile index (PI) was significantly different. The difference was always in the contractor's favor—for example, lower PI values. This situation led FHWA to restrict the use of automated California-type profilographs for use in determining contractor payment on federally funded paving projects in FHWA Region 6 (*2*). Automated profilographs can be used only after it has been demonstrated and documented that they yield PIs within 0.5 in./mi (0.789 cm/km) of a standard manual profilograph.

This paper details an attempt by TxDOT to correlate the outputs of the automated Cox profilograph, the automated McCracken profilograph, and a TxDOT manual McCracken profilograph. The evaluation process was precipitated by calls from construction engineers within TxDOT and paving contractors working in Texas. Both the state and contractor personnel were requesting the use of the automated profilograph.

This correlation effort was not an attempt to evaluate the various filter settings on the automated versions of the profilographs. Some of the problems with the software filter settings (*1,3*) as well as the frequency response of the 12-wheel profilographs (*4*) have been studied and well documented. The manufacturers, Cox and Sons and McCracken Pipe Co., were asked to provide instruments and software with the suggested filter settings. The filter settings were supposed to provide the best correlation with the manual interpretation of a profilogram. These manufacturers suggested filter settings that were maintained throughout the testing process. Also, each automated profilograph manufacturer provided a representative who was present during the testing process and operated their individual profilographs.

SCOPE

A series of comparative tests was performed using an automated Cox, an automated McCracken, and a TxDOT manual McCracken California-type profilograph. The goal of this correlation process was to determine whether the manufacturers' suggested filter settings used for the reduction of automated profilograph data yields the same results as the filter settings on the manual profilograms collected on the same pavement sections. Recently several states have reported that the use of the automated version of the profilograph has given significantly lower PI values than did the manual version of the profilograph data.

The testing procedures used for this correlation effort are presented along with descriptions of the selected test sites. The correlations presented in this paper represent only the resulting PI values from the test sections. The bump responses and bump locations from the various instruments on the test sections were not compared.

A brief description of the automated profilograph software settings is presented. The manual profilograph data reduction procedures followed by TxDOT personnel are described. A description of the correlation analysis used for this comparison testing is presented. Finally, a set of conclusions with the associated recommendations is presented.

TESTING PROCEDURE

The following testing procedure was used to determine the correlation between the Cox and McCracken automated pro-

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filographs and the TxDOT standard, the McCracken manual profilograph. This testing procedure was modeled after the procedures of FHWA's *Highway Performance Monitoring System Field Manual* (*5*). These procedures were intended to obtain correlations between high-resolution profiling devices (Class 1 or 2 instruments) and response-type road roughness measuring systems (Class 3 instruments).

The two automated profilograph manufacturers provided TxDOT personnel with their suggested filter values. Representatives of each manufacturer were present during the comparison testing and operated their individual profilographs. The representatives were asked to verify that their machines were in horizontal and vertical calibration before testing. Personnel from TxDOT Maintenance and Operations Division, Pavement Management Section (D-18PM), measured a 500-ft (0.153-km) horizontal calibration site that was used by all three instruments to check and adjust, if necessary, the distance calibration. A set of gauge blocks shipped with the automated Cox profilograph were used in the vertical calibration determination. The profiling tire inflation pressure was checked daily and adjusted if necessary. The horizontal calibration was performed once before the collection of any data. Each instrument was disassembled and taken by trailer to each of the three pavement-type locations. The vertical calibration was checked before data collection after the instruments were transported to a new test location. D-18PM personnel verified that all three instruments were in calibration.

The TxDOT manual profilograph was operated by several different TxDOT D-18PM personnel during the testing sequence. All operators were experienced in the proper use of the profilograph before the testing. A single operator pushed the manual profilograph on all three runs of an individual test site. All testing was accomplished in the span of 2 days. The profilographs were pushed one after the other on all sections. Each profilograph completed the required three runs on each test section before moving to the next section. Variations as a result of multiple operators of the manual profilographs were not statistically considered in this effort. These variations have been documented in other studies (*3,6*). At the end of each day's testing, the profilograms from all three instruments were collected by D-18PM personnel. The data reduction and comparisons were accomplished after all of the testing was completed.

TEST SITE DESCRIPTION

Before the arrival of the automated profilographs, D-18PM personnel located several test sections that were used in the correlation effort. All selected test sites were on in-service pavements. An attempt was made to locate both continuous reinforced concrete (CRC) pavement and jointed concrete pavement (JCP) sections within close proximity to D-18PM headquarters in Austin, Texas. Unfortunately, the locations of the JCP sites were all city streets and exhibited very large PI values. Therefore, only one JCP section, Harris Branch Parkway, was used in this correlation effort. Four CRC pavement test sections were located on the State Highway 71 bypass built around the city of La Grange, Texas. Six asphaltic concrete pavement (ACP) sections were located on Southwest Parkway within the Austin, Texas, city limits.

Each test site was 0.1 mi (0.1609 km) long. Only one wheelpath in each travel lane was profiled.The outside wheelpath of the outside travel lane was used on the ACP and JCP sections, whereas the inside most wheelpath of the inside travel lane was used on the CRC pavement sections. The decision about which wheelpath and travel lane to use on each group of test sections was driven by safety concerns, because sections were on in-service pavements. The beginning and end and each section's identification were marked with traffic paint. A series of painted dots along each selected wheelpath was used as a guide for each instrument operator to follow. Each instrument was to make three runs on each test site.

TxDOT's surface dynamics (SD) profilometer and a profilograph simulation program developed by Roger Walker of the University of Texas at Arlington (*7*) were used to determine candidate sections with the appropriate ranges of roughness. Three roughness levels in PI terms were targeted for the correlations. Smooth sections ranged from PIs of 0 to 7 in./mi (0 to 11.06 cm/km); medium sections ranged from PIs of greater than 7 to 15 in./mi (11.06 to 23.7 cm/km); and rough sections had PIs greater than 15 in./mi (>23.7 cm/km). There were four smooth, three medium, and three rough sections in the test matrix. The JCP section exhibited an estimated PI of over 80 in./mi (126.38 cm/km).

Each test site was given a unique designation code to prevent mistakes during data reduction and site misidentification by the operators during data collection. The designation code for each test site was painted on the pavement surface at the beginning of each section. The ACP sections on Southwest Parkway were designated SWP01 through SWP06. The CRC pavement sections on State Highway 71 outside of La Grange were designated LAG01 through LAG04, and the JCP site on Harris Branch Parkway was designated HBR01. The operators of each profilograph were instructed to identify each profilogram, in the case of the manual profilograph, and each header name, in the case of the automated profilograph, with the appropriate site designation followed by a 01, 02, or 03. These numerics designate the run number for each of the three required runs for each section. The test date and the test operator's name were also recorded on each run.

AUTOMATED PROFILOGRAPH SOFTWARE DESCRIPTION

The software in both the automated profilographs was set to use a 0.2-in. (0.508-cm) blanking band, a 0.3-in. (0.76-cm) bump height, and a 25.0-ft (7.62-m) bump width. These parameters were used to reduce the manual profilograph data and are specified in the Texas Test Method Tex-1000-S (*8*) procedures for reducing profilograms. The automated Cox profilograph used Filter Setting 5, which represents the attenuation of wavelengths of up to 2.2 ft (0.67 m). The automated McCracken profilograph used a data filter cutoff frequency setting of 2.5 ft (0.76 m). Both of these filter settings were used throughout the comparison testing sequence. These were the filter settings that the manufacturers suggested using for the correlations. Both manufacturers use a third-order

Butterworth filter. In addition, a null band filter setting on the automated Cox profilograph is used to help reduce data through short radius curves and super elevations. The null band filter can be used only by setting the null band filter switch to the filter position. The fixed-distance position eliminates the use of the null band filter in the data reduction. The fixed distance position was used throughout the testing sequence.

MANUAL DATA REDUCTION

The data from the TxDOT manual McCracken profilograph were reduced by two experienced interpreters. The profilograms were separated into two rolls. The three runs on each of the six ACP sections were reduced by Interpreter 1, whereas the runs from the four CRC pavement sections and the one JCP section were reduced by Interpreter 2. After interpreters completed their respective sections and calculated the resulting PIs, they switched rolls. Both interpreters were told to disregard the other person's markings on the profilograms, independently align the blanking band scale, and calculate the resulting PI values.

RESULTS

All the raw data from both interpreters of the manual profilographs and the two automated profilographs were entered into a spread sheet. Table 1 presents the spread sheet that contains the raw data along with a few preliminary statistics. The run number column is used to identify individual runs (1–3) on each test section for the manual interpreters and each automated profilograph. The post number column is used as the *x*-axis on several subsequent graphs and is continuously numbered 1 through 33. This represents the total number of runs made for the comparison testing. The section identification (ID) column indicates the location of the test section, as well as the individual test sections within each location. The four CRC pavement sections are designated as LAG01 through LAG04 and correspond to Sections 1 through 4, respectively. The six ACP sections are designated as SWP01 through SWP06 and correspond to Sections 5 through 10, respectively. The JCP section is designated HBR01 and corresponds to Section 11.

Repeatability

The repeatability of the individual instruments was determined using the standard deviations of the three runs on each test section. Figure 1 illustrates the standard deviations by test section for both manual interpreters and for both of the automated profilographs. Figure 1 also indicates the sections by pavement type. Figures 2 through 5 present four graphs of the standard deviations for the two interpreters and the two automated instruments. From the standard deviations it can be generally stated that both automated profilographs are more repeatable than the manual interpretation of the same profilogram. This might have been expected because one of the advantages of using the automated profilograph is the elimination of the subjectivity in the data reduction process.

General Observations

Figure 6 shows the plots of the PI values from each run on each test section for all instruments. The large PI values obtained on the JCP section cause the scale of the *y*-axis to be rather large. The range of the *y*-axis scale causes the automated and manual profilographs to appear to correlate well. Because the scale used in Texas for the bonus and penalty payments of newly constructed pavements sets PIs greater than 15.0 in./mi (23.7 cm/km) as the cutoff for accepting a pavement, it was decided to eliminate the JCP section from most of the following statistical and graphical comparisons. Another reason to eliminate the JCP section is that the test matrix has no data points between PIs of approximately 25 in./mi (39.49 cm/km) and the JCP PIs of 80 to 100 in./mi (126.38 to 157.98 cm/km). It would not be acceptable to assume that the response of the instruments or their data filters are linear through this region. Looking at the automated McCracken data for the JCP section it would appear that its data filter may not be linear through this range of roughness. This can be observed by looking at the close agreement on the JCP section between both interpreters and the automated Cox. The automated McCracken yields PI values that are 10 in./mi (15.8 cm/km) less than the other instruments.

Figures 7 through 9 provide three bar charts that represent the raw data differences between the manual interpreters and the automated profilographs. The PI values from the automated instruments were always subtracted from those from the manual instruments. This process indicates that for the majority of the test runs, the manual interpreters were higher than the automated profilographs, hence the positive differences. Figure 7 shows the differences between the manual interpreters and indicates that Interpreter 1 is consistently higher than Interpreter 2. In general, it can be seen that Interpreter 2 is closer to the automated profilograph PI values.

Reduced *Y*-Axis Scale Observations

Figure 10 demonstrates a plot for all the PI data from the instruments with the JCP section data eliminated from the data set. This plot yields a more accurate representation of the correlation between the interpreters and the automated instruments over the region of interest. As can be observed from Figure 10, the automated profilographs correlate with the interpreters at least as well as the interpreters correlate with themselves. This observation is generally true except on the three smoothest sections of the CRC pavement represented by Posts 1 through 6 and 10 through 12. The differences between the automated profilographs and the manual interpreters on these sections vary with the interpreter. It can be seen that the automated profilographs are reading between 0.5 (0.789 cm/km) and 2 (3.16 cm/km) PI values less than either interpreter. The automated McCracken profilograph did have a negative difference from both of the interpreters on the first two runs of section LAG01. This difference was

TABLE 1 Summary of Profilograph Correlation Data

SECTION INFORMATION				MANUAL		DIFF	%DIFF
SECT ID	RUN #	POST #	PVT TYPE	INTER #1	INTER #2	(#1-#2)	DIFF/#1
LAG01	1	1	CRC	5.75 (9.08)	4.50 (7.11)	1.25	21.74
	2	2		5.25 (8.29)	4.50 (7.11)	0.75	14.29
	3	3		6.50 (10.27)	5.75 (9.08)	0.75	11.54
	AVE			5.83 (9.22)	4.92 (7.77)	0.92	15.85
	STD DEV			0.51	0.59		
LAG02	1	4	CRC	7.00 (11.06)	7.00 (11.06)	0.00	0.00
	2	5		9.00 (14.22)	8.25 (13.03)	0.75	8.33
	3	6		7.75 (12.24)	7.75 (12.24)	0.00	0.00
	AVE			7.92 (12.51)	7.67 (12.11)	0.25	3.16
	STD DEV			0.82	0.51		
LAG03	1	7	CRC	23.75 (37.52)	21.25 (33.57)	2.50	10.53
	2	8		19.75 (31.20)	21.00 (33.18)	-1.25	-6.33
	3	9		26.45 (41.79)	22.25 (35.15)	4.20	15.88
	AVE			23.32 (36.84)	21.50 (33.97)	1.82	7.79
	STD DEV			2.75	0.54		
LAG04	1	10	CRC	8.75 (13.82)	8.25 (13.03)	0.50	5.71
	2	11		9.00 (14.22)	8.75 (13.82)	0.25	2.78
	3	12		11.25 (17.77)	7.50 (11.85)	3.75	33.33
	AVE			9.67 (15.27)	8.17 (12.90)	1.50	15.52
	STD DEV			1.12	0.51		
SWP01	1	13	ACP	23.50 (37.12)	24.50 (38.70)	-1.00	-4.26
	2	14		21.50 (33.97)	26.25 (41.47)	-4.75	-22.09
	3	15		23.50 (37.12)	25.25 (39.89)	-1.75	-7.45
	AVE			22.83 (36.07)	25.33 (40.02)	-2.50	-10.95
	STD DEV			0.94	0.72		
SWP02	1	16	ACP	3.00 (4.74)	3.25 (5.13)	-0.25	-8.33
	2	17		3.00 (4.74)	2.50 (3.95)	0.50	16.67
	3	18		2.75 (4.34)	2.75 (4.34)	0.00	0.00
	AVE			2.92 (4.61)	2.83 (4.48)	0.08	2.86
	STD DEV			0.12	0.31		
SWP03	1	19	ACP	5.25 (8.29)	4.50 (7.11)	0.75	14.29
	2	20		6.00 (9.48)	4.75 (7.50)	1.25	20.83
	3	21		5.25 (8.29)	6.75 (10.66)	-1.50	-28.57
	AVE			5.50 (8.69)	5.33 (8.43)	0.17	3.03
	STD DEV			0.35	1.01		
SWP04	1	22	ACP	10.75 (16.98)	11.75 (18.56)	-1.00	-9.30
	2	23		13.00 (20.54)	14.00 (22.12)	-1.00	-7.69
	3	24		14.00 (22.12)	12.75 (20.14)	1.25	8.93
	AVE			12.58 (19.88)	12.83 (20.27)	-0.25	-1.99
	STD DEV			1.36	0.92		
SWP05	1	25	ACP	2.25 (3.55)	1.50 (2.37)	0.75	33.33
	2	26		1.50 (2.37)	1.25 (1.97)	0.25	16.67
	3	27		2.50 (3.95)	2.00 (3.16)	0.50	20.00
	AVE			2.08 (3.29)	1.58 (2.50)	0.50	24.00
	STD DEV			0.42	0.31		
SWP06	1	28	ACP	10.00 (15.80)	9.00 (14.22)	1.00	10.00
	2	29		10.50 (16.59)	10.25 (16.19)	0.25	2.38
	3	30		11.25 (17.77)	10.50 (16.59)	0.75	6.67
	AVE			10.58 (16.72)	9.92 (15.67)	0.67	6.30
	STD DEV			0.51	0.66		
HBR01	1	31	JCP	99.00 (156.40)	91.50 (144.55)	7.50	7.58
	2	32		94.50 (149.29)	96.00 (151.66)	-1.50	-1.59
	3	33		100.5 (158.77)	94.50 (149.29)	6.00	5.97
	AVE			98.00 (154.82)	94.00 (148.50)	4.00	4.08
	STD DEV			2.55	1.87		

(continued on next page)

TABLE 1 (*continued*)

SECTION INFORMATION				AUTO	DIFF	%DIFF	DIFF	%DIFF
SECT ID	RUN #	POST #	PVT TYPE	MCCRACK	(#1-MCC)	DIFF/#1	(#2-MCC)	DIFF/#2
LAG01	1	1	CRC	6.00 (9.48)	-0.25	-4.35	-1.50	-33.33
	2	2		5.50 (8.69)	-0.25	-4.76	-1.00	-22.22
	3	3		4.00 (6.32)	2.50	38.46	1.75	30.43
	AVE			5.17 (8.16)	0.67	9.78	-0.25	-8.37
	STD DEV			0.85				
LAG02	1	4	CRC	4.00 (6.32)	3.00	42.86	3.00	42.86
	2	5		5.50 (8.69)	3.50	38.89	2.75	33.33
	3	6		7.50 (11.85)	0.25	3.23	0.25	3.23
	AVE			5.67 (8.95)	2.25	28.32	2.00	26.47
	STD DEV			1.43				
LAG03	1	7	CRC	20.00 (31.60)	3.75	15.79	1.25	5.88
	2	8		20.50 (32.39)	-0.75	-3.80	0.50	2.38
	3	9						0.00
	AVE			20.25 (31.99)	1.50	6.00	0.88	2.75
	STD DEV			0.25				
LAG04	1	10	CRC	7.00 (11.06)	1.75	20.00	1.25	15.15
	2	11		6.50 (10.27)	2.50	27.78	2.25	25.71
	3	12		7.00 (11.06)	4.25	37.78	0.50	6.67
	AVE			6.83 (10.80)	2.83	28.52	1.33	15.84
	STD DEV			0.24				
SWP01	1	13	ACP	24.00 (37.91)	-0.50	-2.13	0.50	2.04
	2	14		24.00 (37.91)	-2.50	-11.63	2.25	8.57
	3	15		22.50 (35.55)	1.00	4.26	2.75	10.89
	AVE			23.50 (37.12)	-0.67	-3.17	1.83	7.17
	STD DEV			0.71				
SWP02	1	16	ACP	2.50 (3.95)	0.50	16.67	0.75	23.08
	2	17		1.50 (2.37)	1.50	50.00	1.00	40.00
	3	18		2.50 (3.95)	0.25	9.09	0.25	9.09
	AVE			2.17 (3.42)	0.75	25.25	0.67	24.06
	STD DEV			0.47				
SWP03	1	19	ACP	6.50 (10.27)	-1.25	-23.81	-2.00	-44.44
	2	20		4.50 (7.11)	1.50	25.00	0.25	5.26
	3	21		6.50 (10.27)	-1.25	-23.81	0.25	3.70
	AVE			5.83 (9.22)	-0.33	-7.54	-0.50	-11.83
	STD DEV			0.94				
SWP04	1	22	ACP	12.50 (19.75)	-1.75	-16.28	-0.75	-6.38
	2	23		12.50 (19.75)	0.50	3.85	1.50	10.71
	3	24		11.50 (18.17)	2.50	17.86	1.25	9.80
	AVE			12.17 (19.22)	0.42	1.81	0.67	4.71
	STD DEV			0.47				
SWP05	1	25	ACP	1.50 (2.37)	0.75	33.33	0.00	0.00
	2	26		2.00 (3.16)	-0.50	-33.33	-0.75	-60.00
	3	27		2.50 (3.95)	0.00	0.00	-0.50	-25.00
	AVE			2.00 (3.16)	0.08	0.00	-0.42	-28.33
	STD DEV			0.41				
SWP06	1	28	ACP	10.00 (15.80)	0.00	0.00	-1.00	-11.11
	2	29		10.00 (15.80)	0.50	4.76	0.25	2.44
	3	30		9.00 (14.22)	2.25	20.00	1.50	14.29
	AVE			9.67 (15.27)	0.92	8.25	0.25	1.87
	STD DEV			0.47				
HBR01	1	31	JCP	80.50 (127.17)	18.50	18.69	11.00	12.02
	2	32		82.50 (130.33)	12.00	12.70	13.50	14.06
	3	33		83.00 (131.12)	17.50	17.41	11.50	12.17
	AVE			82.00 (129.54)	16.00	16.27	12.00	12.75
	STD DEV			1.08				

(*continued on next page*)

TABLE 1 (*continued*)

SECTION INFORMATION				AUTO	DIFF	% DIFF	DIFF	%DIFF
SECT ID	RUN #	POST #	PVT TYPE	COX	(#1-COX)	DIFF/#1	(#2-COX)	DIFF/#2
LAG01	1	1	CRC	4.50 (7.11)	1.25	21.74	0.00	0.00
	2	2		3.50 (5.53)	1.75	33.33	1.00	22.22
	3	3		4.00 (6.32)	2.50	38.46	1.75	30.43
	AVE			4.00 (6.32)	1.83	31.43	0.92	18.64
	STD DEV			0.41				
LAG02	1	4	CRC	5.50 (8.69)	1.50	21.43	1.50	21.43
	2	5		7.00 (11.06)	2.00	22.22	1.25	15.15
	3	6		6.50 (10.27)	1.25	16.13	1.25	16.13
	AVE			6.33 (10.01)	1.58	20.00	1.33	17.39
	STD DEV			0.62				
LAG03	1	7	CRC	20.90 (33.02)	2.85	12.00	0.35	1.65
	2	8		19.90 (31.44)	-0.15	-0.76	1.10	5.24
	3	9		18.90 (29.86)	7.55	28.54	3.35	15.06
	AVE			19.90 (31.44)	3.42	14.65	1.60	7.44
	STD DEV			0.82				
LAG04	1	10	CRC	6.00 (9.48)	2.75	31.43	2.25	27.27
	2	11		7.50 (11.85)	1.50	16.67	1.25	14.29
	3	12		6.50 (10.27)	4.75	42.22	1.00	13.33
	AVE			6.67 (10.53)	3.00	31.03	1.50	18.37
	STD DEV			0.62				
SWP01	1	13	ACP	25.00 (39.49)	-1.50	-6.38	-0.50	-2.04
	2	14		25.00 (39.49)	-3.50	-16.28	1.25	4.76
	3	15		24.50 (38.70)	-1.00	-4.26	0.75	2.97
	AVE			24.83 (39.23)	-2.00	-8.76	0.50	1.97
	STD DEV			0.24				
SWP02	1	16	ACP	2.00 (3.16)	1.00	33.33	1.25	38.46
	2	17		2.00 (3.16)	1.00	33.33	0.50	20.00
	3	18		2.00 (3.16)	0.75	27.27	0.75	27.27
	AVE			2.00 (3.16)	0.92	31.43	0.83	29.41
	STD DEV			0.00				
SWP03	1	19	ACP	5.00 (7.90)	0.25	4.76	-0.50	-11.11
	2	20		4.00 (6.32)	2.00	33.33	0.75	15.79
	3	21		4.50 (7.11)	0.75	14.29	2.25	33.33
	AVE			4.50 (7.11)	1.00	18.18	0.83	15.62
	STD DEV			0.41				
SWP04	1	22	ACP	12.00 (18.96)	-1.25	-11.63	-0.25	-2.13
	2	23		11.50 (18.17)	1.50	11.54	2.50	17.86
	3	24		11.50 (18.17)	2.50	17.86	1.25	9.80
	AVE			11.67 (18.43)	0.92	7.28	1.17	9.09
	STD DEV			0.24				
SWP05	1	25	ACP	2.50 (3.95)	-0.25	-11.11	-1.00	-66.67
	2	26		2.00 (3.16)	-0.50	-33.33	-0.75	-60.00
	3	27		2.00 (3.16)	0.50	20.00	0.00	0.00
	AVE			2.17 (3.42)	-0.08	-4.00	-0.58	-36.84
	STD DEV			0.24				
SWP06	1	28	ACP	9.50 (15.01)	0.50	5.00	-0.50	-5.56
	2	29		11.50 (18.17)	-1.00	-9.52	-1.25	-12.20
	3	30		9.50 (15.01)	1.75	15.56	1.00	9.52
	AVE			10.17 (16.06)	0.42	3.94	-0.25	-2.52
	STD DEV			0.94				
HBR01	1	31	JCP	91.80 (145.02)	7.20	7.27	-0.30	-0.33
	2	32		90.80 (143.44)	3.70	3.92	5.20	5.42
	3	33		92.30 (145.81)	8.20	8.16	2.20	2.33
	AVE			91.63 (144.76)	6.37	6.50	2.37	2.52
	STD DEV			0.62				

Note: Values in parentheses are centimetres/kilometer and conversion factor is 1 inch/mile * 1.58 = cm/km

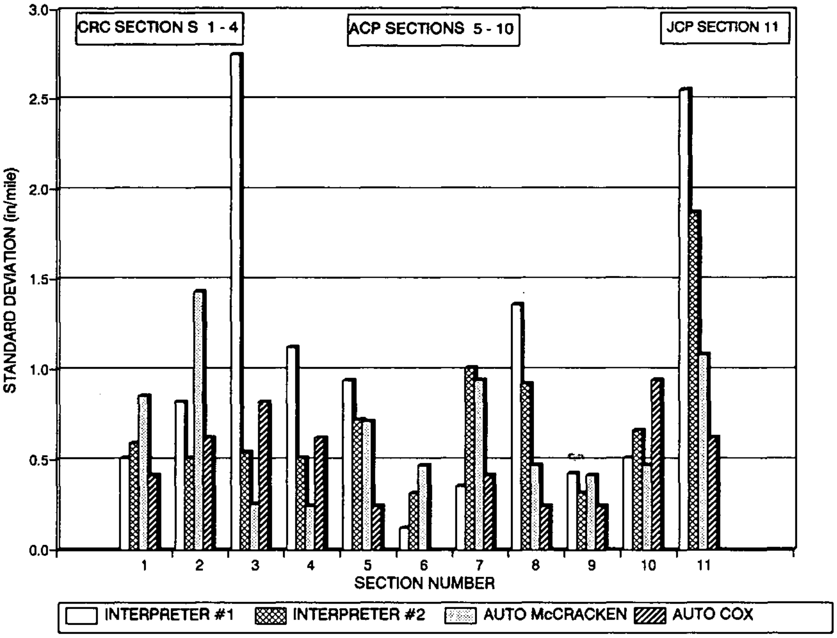

FIGURE 1 Standard deviations from all instruments on all test sites.

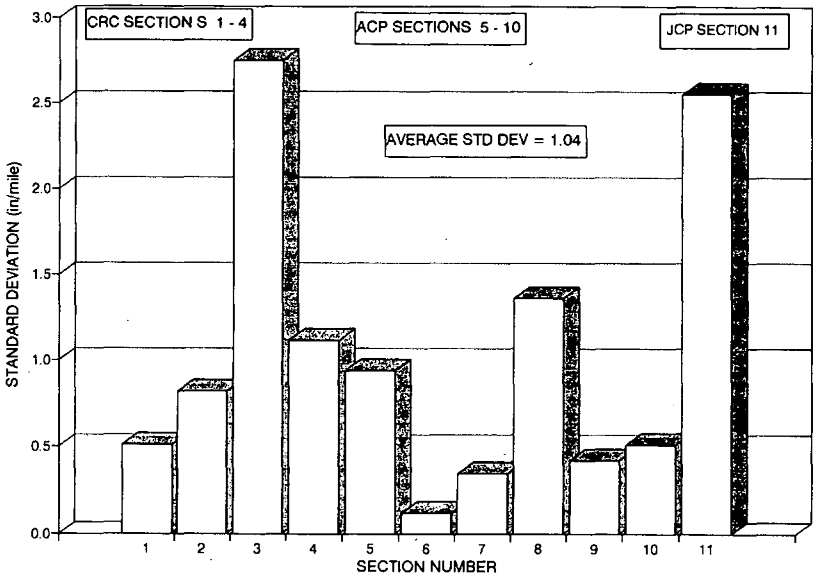

FIGURE 2 Standard deviations for Interpreter 1 on all test sites.

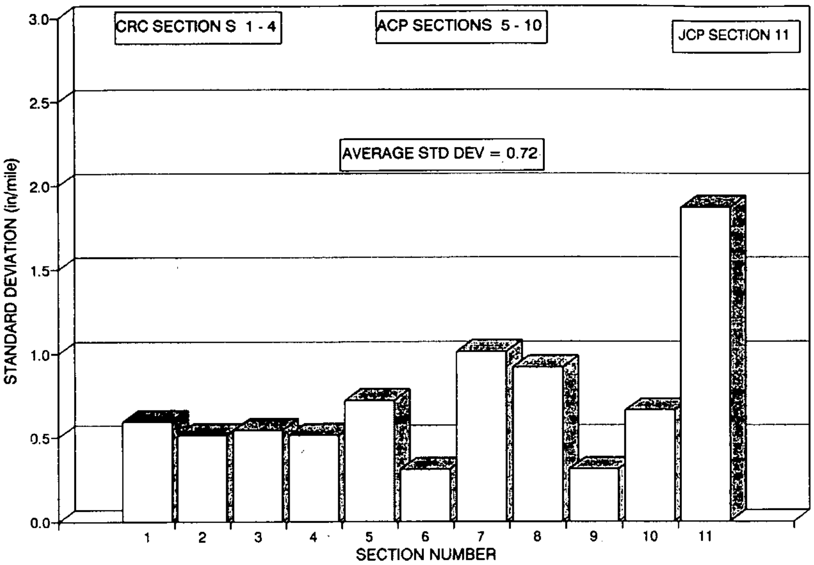

FIGURE 3 Standard deviations for Interpreter 2 on all test sites.

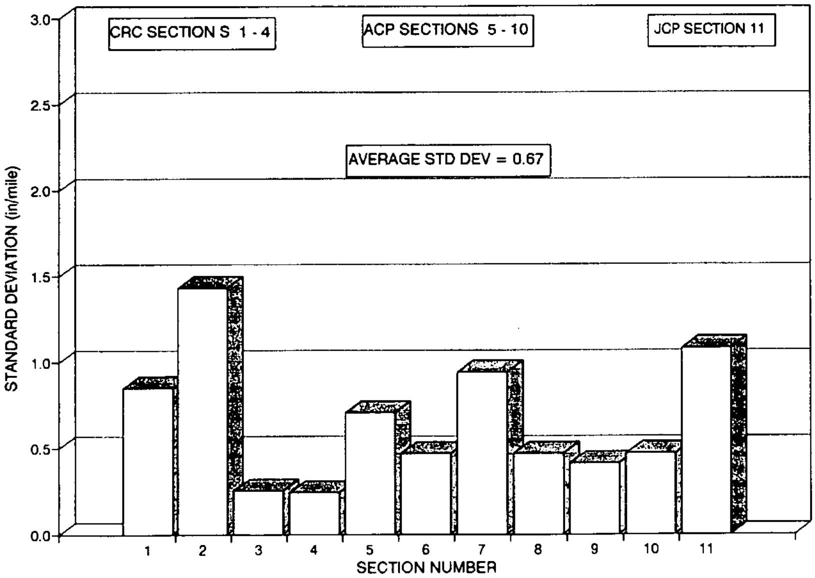

FIGURE 4 Standard deviations for automated McCracken on all test sites.

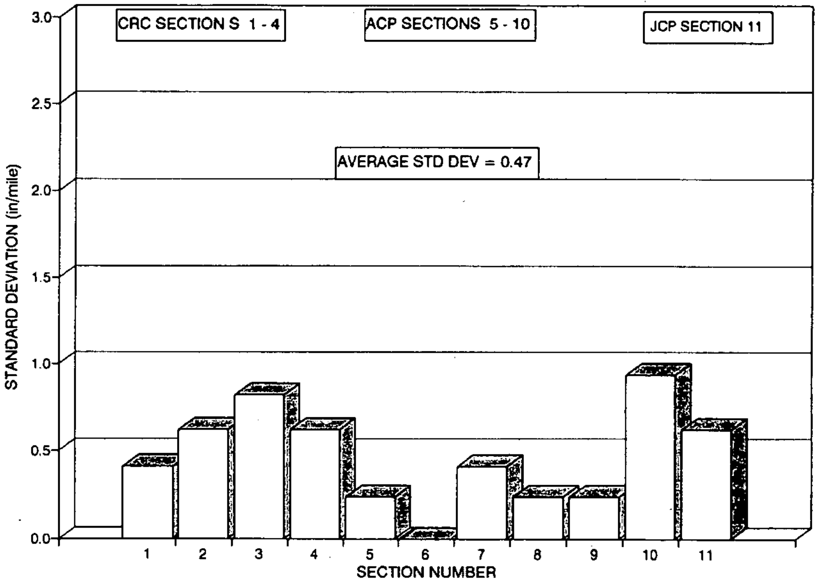

FIGURE 5 Standard deviations for automated Cox on all test sites.

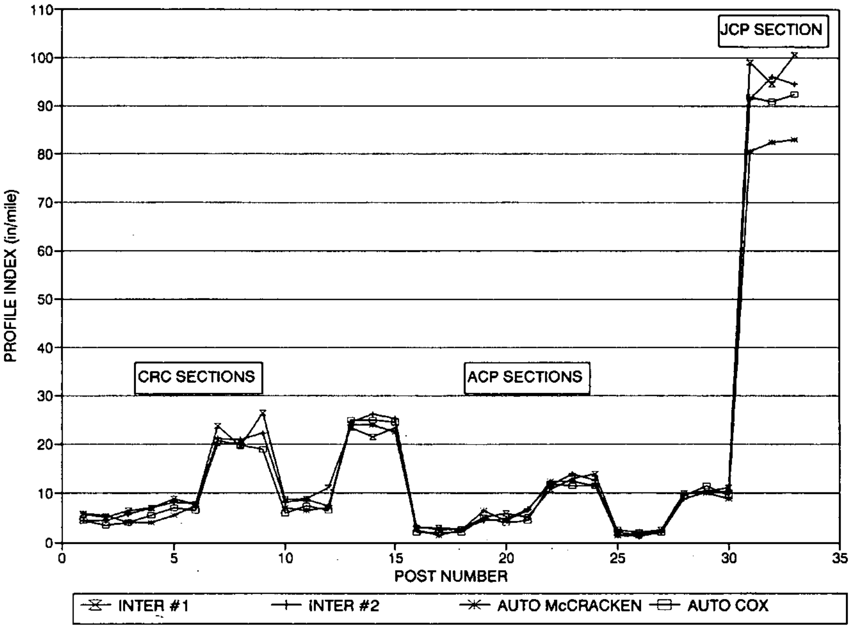

FIGURE 6 Plot of all instruments on all test sites.

−0.25 PI on both runs in the case of Interpreter 1 and −1.5 and −1.0 PI in the case of Interpreter 2. Thereafter, the general trend of positive differences holds. The automated Cox profilograph also showed a 0.0 difference between Interpreter 2 on the first run of section LAG01.

Regression and Residual Errors

Table 2 provides a series of linear regression equations when the actual data points are plotted, the resulting R^2 values, and the sum of the residuals calculated from the resulting residual

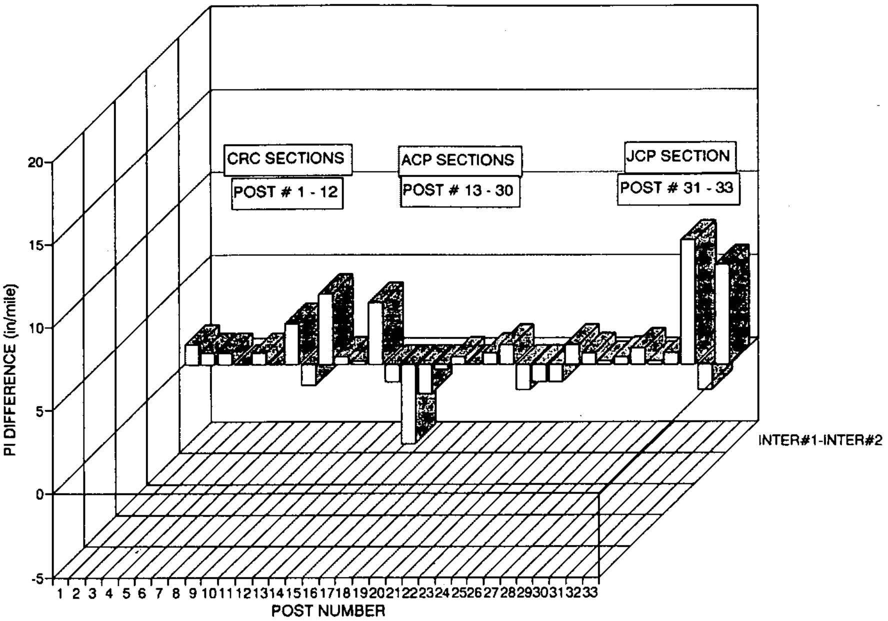

FIGURE 7 Interpreter 1–Interpreter 2 differences in PI index for all sites.

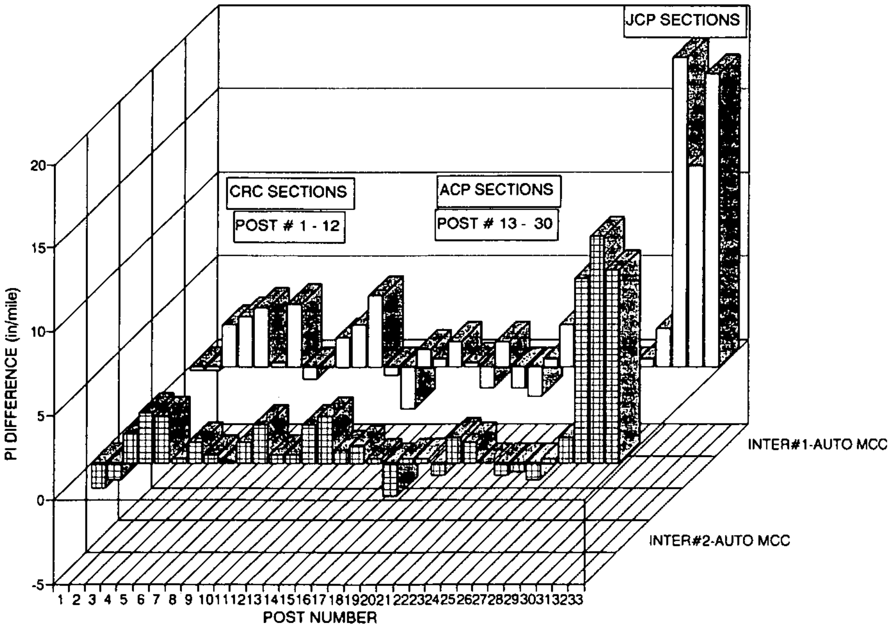

FIGURE 8 Differences in PI between both interpreters and automated McCracken.

errors associated with each regression. These regressions were computed without the data points associated with the JCP test section. The first regression equation, Interpreter 1 versus Interpreter 2, indicates that the fit between the two interpreters has very good correlation with the *y*-intercept, which is slightly negative (−0.47 in./mi), a slope of 1.015, $R^2 = 0.95$, and that the sum of the residuals is close to 0 (−0.05). Interpreter 2 was generally lower than interpreter 1, which is verified by the *y*-intercept. The R^2 value of 0.95 is less than that of the remainder of the regressions, whereas the slope is closer to a perfect 1.0. The greatest differences between the two interpreters occur as the PI count of the test section increases. The run numbers with the greatest residual errors generally occur on test sections with the greatest PI count. These observations can be expected because, as the PI count of a section goes up, the differences in the manual interpre-

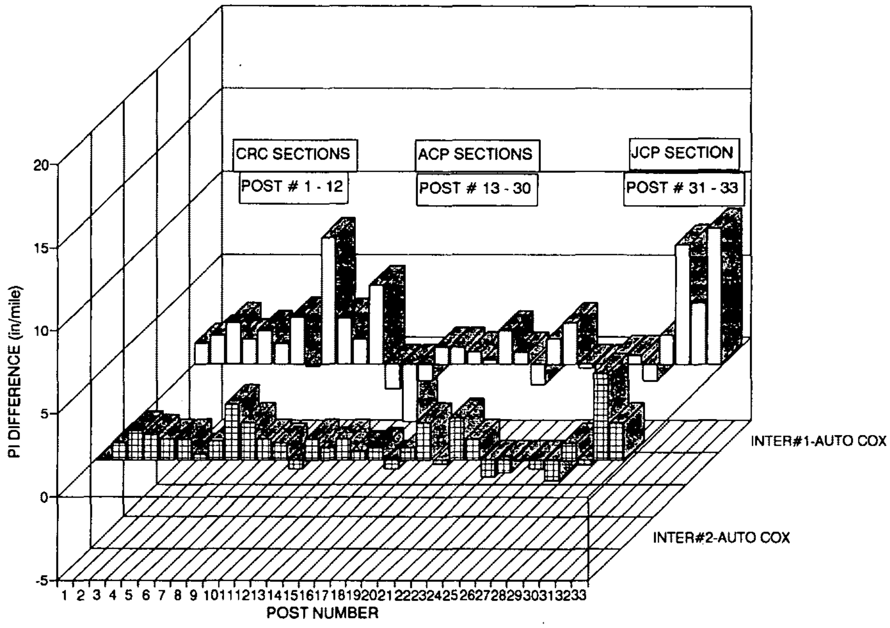

FIGURE 9 Differences in PI between both interpreters and automated Cox.

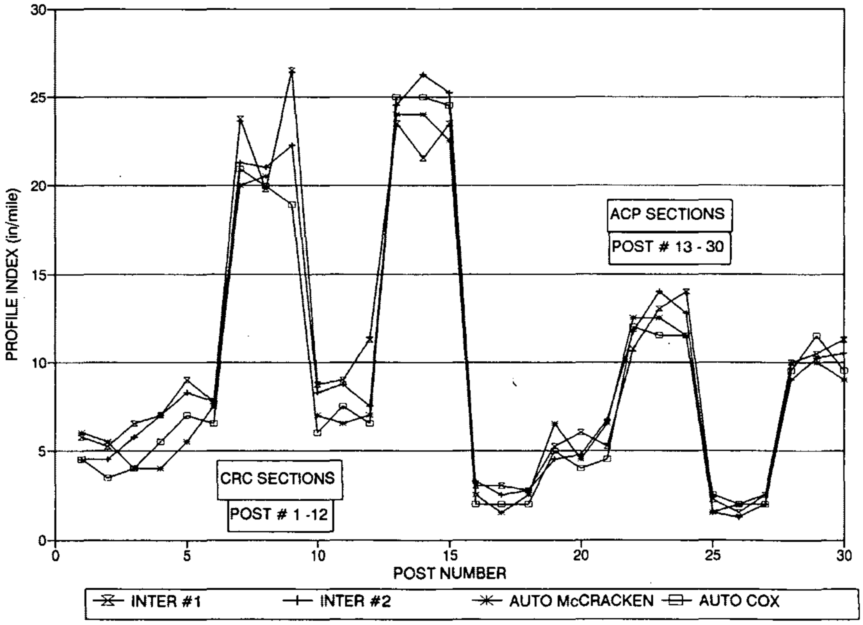

FIGURE 10 Plot of all instruments on all test sites except JCP site.

tation generally will increase because of the subjectivity in the manual interpretations.

The Table 2 regressions for the automated profilographs were performed using only the results from Interpreter 2. Interpreter 2 results generally were closer to the automated results and, therefore, represent the best correlations from the data set. Because the correlation between the two interpreters was so good, it appeared redundant to regress the results against both interpreters. Both sets of regression data and the resulting residual errors indicate that the automated profilographs are reading slightly lower than the manual interpretation, even though the *y*-intercept from the automated McCracken is positive. The correlation (R^2 value) is higher between the automated profilographs and Interpreter 2 than that for the manual interpreters because the automated units have better standard deviations and therefore are more repeatable.

Breakdown by Pavement Type

Tables 3 and 4 contain the regression equations, R^2 values, and the sum of the residual errors for the individual pavement types. Table 3 illustrates the results from only the CRC data points, whereas Table 4 shows the results from only the ACP data points. The results of these two tables can be summed up by the following statements:

1. The regression analysis results from the CRC pavement sections are worse than those from the ACP sections. This is the case even when comparing the two manual interpreters against each other.
2. The R^2 values from each of the CRC regressions generally are less than those from either Table 2 or 4, and the slopes of the lines generally are further from 1.0.
3. The *y*-intercepts in Table 3 are all negative, indicating that the automated profilographs are reading lower PI values than both manual interpreters.

CONCLUSIONS

The following general conclusions can be drawn about the correlation between the automated profilographs and the manual interpretation of the profilograms. These conclusions are based on a very limited amount of data and cannot be considered conclusive evidence in quantitative terms with reference to the extent of correlation between automated and manual profilographs. The correlation results indicate that PI values derived by both automated profilographs are close to those derived manually.

1. There is good correlation between both automated models of the profilograph and the manual interpreters. This conclu-

TABLE 2 Regression Results from All Test Sections Except JCP Site

Y VALUE	X VALUE	REGRESSION EQUATION	R^2 VALUE	SUM OF RESIDUALS
INTERP. #2	INTERP. #1	Y=-0.47+1.015(X)	0.95	-0.05
AUTO McCRACKEN	INTERP. #2	Y=0.079+0.93(X)	0.97	-1.33
AUTO COX	INTERP. #2	Y=-0.46+0.97(X)	0.98	-0.743
AUTO McCRACKEN	AUTO COX	Y=0.65+0.93(X)	0.98	0.896

TABLE 3 Regression Results from CRC Pavement Sites

Y VALUE	X VALUE	REGRESSION EQUATION	R^2 VALUE	SUM OF RESIDUALS
INTERP. #2	INTERP. #1	Y=0.077+0.897(X)	0.96	1.0
AUTO McCRACKEN	INTERP. #1	Y=-1.3+0.95(X)	0.91	-0.26
AUTO McCRACKEN	INTERP. #2	Y=-0.71+0.97(X)	0.94	-0.05
AUTO COX	INTERP. #1	Y=-0.84+0.86(X)	0.93	0.16
AUTO COX	INTERP. #2	Y=-0.97+0.96(X)	0.98	0.66
AUTO McCRACKEN	AUTO COX	Y=0.55+0.95(X)	0.96	0.24

TABLE 4 Regression Results from ACP Sites

Y VALUE	X VALUE	REGRESSION EQUATION	R^2 VALUE	SUM OF RESIDUALS
INTERP. #2	INTERP. #1	Y=-0.87+1.116(X)	0.98	0.0
AUTO McCRACKEN	INTERP. #1	Y=-0.38+1.019(X)	0.97	0.12
AUTO McCRACKEN	INTERP. #2	Y=0.44+0.91(X)	0.98	0.19
AUTO COX	INTERP. #1	Y=-1.08+1.09(X)	0.97	0.68
AUTO COX	INTERP. #2	Y=-0.17+0.97(X)	0.98	0.77
AUTO McCRACKEN	AUTO COX	Y=0.66+0.93(X)	0.99	-0.26

sion must be qualified by the following statement. The individual manufacturers' specified filter settings (5 for the Cox and 2.5 ft for the McCracken) must be used.

2. The correlations between both the interpreters against each other, each interpreter against each automated unit, and both automated units against each other are worse on smooth CRC pavement than on ACP pavements and rough CRC pavements. The tining on CRC pavements may be the cause of the differences observed on the smooth CRC sections. The manual interpreter must subjectively draw a line through the small jagged deviations on the profilogram, thereby smoothing the trace and providing a reference line for obtaining the PI counts. The placement of this line and positioning of the blanking band can be critical in the PI value calculation on smooth pavement sections. The automated profilograph software essentially performs the task of smoothing the trace by applying a filter.

3. No valid conclusions can be drawn from this experiment regarding JCP. Another set of correlation data will need to be collected on some jointed pavement sections on the basis of the results of the smooth CRC correlation.

4. The PI results from the automated type of profilographs appear more repeatable than those from the manual interpretation of the profilogram.

5. The automated profilographs allow the PI values of a pavement section to be instantly available, whereas the manual profilographs require that the values be brought from the field and subjectively reduced.

RECOMMENDATIONS

The data reduction filters used by the automated profilographs are software based and could be modified. The highway authority must devise a methodology for determining whether the specified filter is actually in use during pavement testing. This could be accomplished by spot checks with a state-owned profilograph, whether it is manual or automated.

Because the smooth CRC pavement sections appear to be read smoother by the automated profilographs, it could be that different filters or a lower cutoff frequency of the same filter should be used on these sections. As an alternative to different filter settings, the highway authority could specify a universal filter setting and reduce the bonus scale for CRC pavements when automated profilographs are being used.

A set of procedures needs to be developed for the acceptance of new automated profilograph types that may exist in the future. These procedures need to specify a standard against which to measure and, on the basis of these results, include a spectrum of pavement types with a range of roughness.

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