Automated System for Pavement Profile Analysis from Profilograph Traces

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An automated method, KSCAN, for reduction of the profilograms produced by the mechanical profilograph into a profile index (PRI) and for identification of bump locations for grinding has been developed. The algorithm followed was the Kansas Test Method KT-46I: Determination of Pavement Profile with the 7.62 m (25-ft) Profilograph. The profilograph trace is scanned to digitize its tracing. An image enhancement program is used to prepare the image for analysis, and then a line is identified, tracked, and digitized. A linear regression analysis is performed to establish the location of the "floating" centerline (corresponding to a "null" or "zero" blanking band) along this line. The PIs are calculated based on deviation of the line from the floating centerline, and bumps are located based on any specified deviation from a 25.4 mm (1-in.) reference moving baseline. Options are available to incorporate blanking band widths of any value into the PRI calculations. Comparison of the results of profile reduction using the manual methods, automated profilographs, and KSCAN showed that KSCAN results should easily satisfy the KT-46I requirement that the results of comparison between manual trace reduction by the Kansas Department of Transportation and automated trace reduction should not differ by more than 32 mm/km (2 in./mi) on a segment by segment basis (0.16 km or 0.1 mi). Extensive tests indicated that the PRI computed by the KSCAN for a given segment generally varied less than ±3 percent from scan to scan, and five or more successive segments showed totals that rarely differed by more than ±1 percent. The process has been implemented on a personal computer, and an assembled system consisting of the software, the special scanning hardware, an IBM-compatible 486 computer, and a printer costs under $7,500.

Pavement smoothness/roughness can be described by the magnitude of profile irregularities and their distribution over the measurement interval. The road surface smoothness on newly constructed pavement is a major concern for the highway industry. This "smoothness" or "riding comfort" is a measure of the quality of the newly constructed pavements because it affects the road users directly. According to Hudson (*1*), the purposes for smoothness measurement are:

1. To maintain construction quality control,
2. To locate abnormal changes in the highway, such as drainage, subsurface problems, or extreme construction deficiencies,
3. To establish a statewide basis for allocation of road maintenance resources, and
4. To evaluate pavement serviceability performance life histories for evaluation of alternate designs.

Since its introduction in 1940, the profilograph has successfully been used to date for the measurements of pavement profile for the construction control of concrete pavements. It was later extended for as-constructed smoothness control of bituminous pavements. The profilograph is a multi-wheeled, rolling straightedge and is propelled by hand. It measures the vertical deviations from a moving, fixed-length reference plane. The result of this test is usually a graphical record, a profilogram or profilograph trace, which indicates the smoothness of a newly paved surface. The scale of the profilogram is usually 1:300 horizontally (longitudinally) and 1:1 vertically. The profilogram is interpreted by an operator/interpreter using a blanking band and a bump template. The blanking band, a plastic scale 43.18 mm (1.70 in.) wide and 536.4 mm (21.12 in.) long, represents a pavement length of 161 m (528 feet) or 0.161 km (1/10 mi). An opaque band of 5.08 mm (0.2 in.) width extends throughout the entire length of the plastic scale near the center. On either side of this band are scribed lines 2.54 mm (0.1 in.) apart, parallel to the opaque band. These lines serve as a convenient scale to measure deviations of the profile trace or "scallops" above and below the blanking band. The bump template is a plastic template having a marked length 25.4 mm (1 in.) long on one face and a slot (or edge) parallel to the marked length. A distance equal to the maximum bump specified, normally 10.16 mm (0.40 in.), separates the two reference lines. The 25.4-mm (1.0-in.) line corresponds to a distance of 7.62 m (25 ft) on the longitudinal scale of the profilogram. The bump template and the blanking band are used for identifying locations of bumps and total deviation from "true" surface in inches/mile, the profile index (PRI), respectively.

Three uniquely different designs for the profilograph are available; California-style, Ames, and Rainhart. Currently, profilographs are manufactured by three companies: (*a*) Ames Profilograph of Ames, Iowa, (*b*) International Pipe Machinery Corporation (McCracken Division) of Sioux City, Iowa, and (*c*) Cox and Sons of Colfax, California. The latter two also manufacture automated or "computerized" profilographs. The outlining procedure used by the manual operator during the profile trace reduction process is accomplished within the computer program by the use of "filters." The blanking band is simulated using offsets from the best-fit centerline, and "deviations" are computed. These devices have become very popular despite higher initial prices (2).

PROBLEM STATEMENT

The road surface smoothness on newly constructed pavement is a major concern for the highway industry. This smoothness or riding comfort indicates the quality of newly constructed pavements because it affects the road users directly. There is a growing interest in attaining smoother pavement surfaces. Results from a 1992 NCHRP study show that of the 22 states reporting, 91 percent used smoothness criteria on new pavement construction (*2*).

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The Kansas Department of Transportation (KDOT) uses a 7.62-m (25-ft) California-type profilograph for determining the smoothness of both concrete and bituminous pavements. Within KDOT, the applicable procedure for identifying locations of bumps and total deviation from true surface in millimeters/kilometer (inches/mile), the PRI, is Kansas Test Method KT-46I: Determination of Pavement Profile with the 7.62-m (25-ft) Profilograph (*3*). Currently this procedure requires the use of a 0 (0.254 mm/0.01 in. for the computerized profilograph) banking band width (or "null" blanking band). With the null blanking band, a reference line placed approximately at the center of the trace is used as a datum for finding deviations from it. This process is very labor intensive and time consuming. The results also vary among operator/interpreters. The relatively high incentives now possible with many of the smoothness specifications place an ever-increasing burden not only on the measurement process but also on the data-reduction process. Variability in test results and interpretation of test results can significantly affect contractor payments (*2*).

According to the 1992 NCHRP study (*2*), the top 10 problems regarding smoothness measurement and interpretation of test results faced by the states are:

1. Comparing profilograph results with other roughness measuring devices,
2. Trace reduction repeatability,
3. Effect of surface type (e.g., short wavelengths on PRI),
4. Interpretation of profilograph traces,
5. Production rate of testing,
6. Equipment repeatability,
7. Operator training,
8. Comparing profilograph results with present serviceability index,
9. Identifying grinding locations, and
10. Ease of operation.

Significant differences between PRI obtained from manual interpretation of profilograph traces and those obtained by profilographs that use on-board computers for interpretation have been observed recently. A 1990 study by the Arizona Department of Transportation has shown that 67 percent of the total operator profilogram interpretation variability was due to the difference between the operators and the repeated trace reductions. There was more variability between the average values among operators than there was variability between the two readings of a single operator (*4*). A Pennsylvania Transportation Institute study in 1989 reported that the variations among operators in profilogram reductions were the same size as the total variations of multiple runs with one person interpreting the data (*5*). It is well established that the major cause of variability in mechanical profilograph test results is the manual interpretation of results.

Since 1987 the Central Federal Lands Highway Division in Denver, Colorado has extensively studied the acceptance of newly constructed bituminous pavements using California-type profilograph measurements (*6*). The study concludes that, when used in conjunction with statistical evaluation procedures, the test method is suitable for acceptance purposes and that computerized trace reduction is superior to manual reduction.

From this discussion, it is clear that there is need for an automated system for interpretation of profilograms. Bonus clauses are associated with pavement smoothness, so it is important that a more rational methodology of interpretation of profilograms be developed.

OBJECTIVE

The major objective of this study was to automate the profilograph trace reduction process. The algorithm was that described in Kansas Test Method KT-46I: Determination of Pavement Profile with the 7.62-m (25-ft) Profilograph. This objective was accomplished by selecting the hardware and developing the software necessary for computation of the PRI and by identification of locations of bumps for grinding.

CURRENT KDOT SMOOTHNESS SPECIFICATIONS

Based on the results of the study of profilographs on both concrete (PCC) and bituminous (AC) pavements from 1985 to 1991, a new set of special provisions was incorporated for construction projects in 1992. The PCC pavements will have the Special Provision 90P-111-R1. This requires use of the null blanking band (or 0.254 mm or 0.01 in. for computerized profilographs) for profilograph trace reduction and establishes the limits on calculated PRI as shown in Table 1. Special Provision 90P-39-R4, incorporated for AC pavement projects, also requires the use of "null" or "zero" blanking band for mechanical profilographs or 0.254-mm (0.01-in.) blanking band for computerized profilographs. The schedule for adjusted payments at various levels of roughness is shown in Table 2. This requirement is applicable to all projects with multiple paver passes, including cold milling with overlay or cold recycle with an overlay. The working depth in those cases may be less than 101.6 mm (4 in.). However, pay adjustment does not apply if the plan thickness is less than 101.6 mm (4 in.) on the existing surfaces (*7*). The implementation of these special provisions resulted in the critical need for fast reduction of profilograph traces for KDOT. This is more important for AC pavements, for which the contractor needs to know within 24 hours whether or not corrective action needs to be taken. The agency also needs to verify the results quickly. It will be difficult for the contractor crew for trace reduction to keep up with the pace of paving, especially for AC, without interrupting the construction. This leads to the need for an automated trace reduction procedure so that the results can be obtained very quickly. The results also are expected to be more reproducible.

DEVELOPMENT OF THE AUTOMATED METHOD FOR PROFILE REDUCTION

Approach

An automated method, KSCAN, for reduction of profilogram into PRI and for identifying locations of bumps for grinding following the algorithm in Kansas Test Method KT-46I: Determination of Pavement Profile with the 7.62-m (25-ft) Profilograph was developed in this study. The approach for automating these tasks began with an image-processing step to convert the strip-chart traces into one-dimensional signals. The profilograph trace was scanned to digitize its tracing. An image enhancement program was used to prepare the image for analysis. After enhancement, a line was tracked using a noncausal moving-average filter to reduce the problem to a single dimension. This simulates the process in which a human operator usually draws a line to outline the trace. A linear regression analysis was used to establish the location of the floating centerline (corresponding to the null blanking band). The PRIs were

TABLE 1 Schedule for Adjusted Payment for PCC Pavements (Special Provision 90P-111-R1)

Profile Index millimeter per kilometer per 0.16 kilometer section (> 72 km/h speed limit)	Profile Index millimeter per kilometer per 0.16 kilometer section (72 km/h or less speed limit & ramps)	Price Adjustment Percent of Contract unit bid price
175 or less	238 or less	108
176 to 238	239 to 397	104
239 to 476	398 to 715	100
477 to 794	716 to 1032	100 (Grind back)
795 or more	1033 or more	95 (Grind back or remove and replace)

Note : 1 in = 25.4 mm, 1 mile = 1.6 km

calculated based on deviations from the floating centerline, and bumps were located based on the specified deviation from a 25.4-mm (1-in.) reference moving baseline. Options are also available to incorporate blanking bands of any value (0 to 10.6 mm or 0 to 0.4 in. or higher) into the calculations.

Hardware

The digitizer for this project was a hand-operated 101.6-mm (4-in.) wide 400-dpi gray scale scanner. Two different hand scanners, ScanMan Model 32 and Matador Plus, were evaluated. Both scanners worked satisfactorily with the supplied software on an IBM-compatible 486 PC for short distances, but the supplied software was not flexible enough for the length of scans required. A software development kit for the ScanMan scanner provided the support needed to write the customized scanning programs (in "C") that can scan unlimited lengths of a trace. Therefore, the ScanMan model 32 hand scanner was selected for the digitizing device. The scanner interfaces to a 486 IBM-compatible PC compatible computer through a board that fits in an Instrument Society of America expansion slot. The scanner is operated in a 200-dpi mode for KSCAN.

Filter Selection

Several filters were tested for preprocessing of the profilograph traces once they had been digitized by the hand-held scanner and extracted using the software developed for that purpose. The filtering was necessary because of the noisy nature of the traces due to vibrations in the profilograph during the recording process (e.g., due to debris).

It is to be noted that a degree of filtering occurs in the mechanical system that provides the trace on paper from movement of the

TABLE 2 Schedule for Adjusted Payment for AC Pavements (Special Provision 90P-39-R4)

Profile Index (mm per km)	Contract Price Adjustment* (Dollars)
110 or less	+ 152.00
111 to 158	+ 76.00
159 to 473	0.00
474 to 631	0.00 (correct back to 473 mm/km or less)
632 to more	-203.00 (correct back to 473 mm/km or less)

* applies to each 0.16 lane-km segment
Note : 1 in = 25.4 mm, 1 mile = 1.6 km

pickup wheel. Also high-speed chatter in the system results in a thicker line rather than distinguishable back and forth movement of the pen. Thus, it does not follow that filtering of a scanned trace should be identical to filtering used in computerized profilographs that obtain unfiltered data from the pickup wheel.

In fact the stated purpose of filtering the data on those systems is to try to duplicate the effect of a person drawing a single line through mechanically produced profilograph trace. Therefore, in this project, we attempted to duplicate that same effect, rather than just filtering this scanned data the same way the computerized units filter raw data. A variety of filtering algorithms were tried, and KDOT personnel picked the one that worked the best. The judging was performed by looking at plots of the various filtered signals overlaid on the original traces using a light table. To our knowledge similar tests of comparing raw data with the filtered output have never been attempted for the automated units.

A variety of Butterworth and Chebyshev low-pass filters with various number of poles and cut-off frequencies were included in the tests, but all were judged inferior to a simple two-sided moving average filter. Also, moving-average filters of various widths were tested. A noncausal, moving-average filter, with a window of 1.91 mm (0.075 in.) (0.57 m or 22.5 in. of pavement) was judged to be the best and was incorporated as the default into the automated trace reduction process. A least-square error analysis was done to fit a straight line to the data points on the 1/10-mi segment. Plot drivers were created for both Epson and Toshiba printers to reproduce the scanned traces along with the best-fit straight line through the data.

Trace Reduction Procedure

The trace information was captured using a hand scanner. Early in the project, the scanner was pulled along the segment with the aid of a straightedge. Later a computer-controlled paper transport unit was developed to automate that process. KDOT now uses these units, which can process unlimited length traces without operator interventions.

During the scanning process the image being scanned will scroll by on the computer monitor. The scanning process is the most important part of the user's interaction with the program. A section to be scanned is marked by drawing a 25.4-mm (1-in.) (or longer) line across the two ends of the section. The length of the section that is marked can be a normal segment or a short segment or can encompass many segments. The scanner itself measures the distance covered so that correct PRI values are calculated for any length. If multiple segments exist between the two marks, the system automatically measures each segment (0.16 km or 0.1 mi) and calculates a PRI value for each segment as well as the entire section. The standard length of a segment is easily changed in a configuration file.

The marking of a section is much the same as marking the individual segment during manual reduction, except that the vertical position of the rule and each segment need not be marked. It is important that the lines marking the end of the segment be perpendicular to the length of the profilogram. This is necessary because the scanner "sees" only a 0.127-mm (1/200-in.) wide strip of the paper at a time, and this strip is perpendicular to the edges of the paper. The program "recognizes" an end mark when a 25.4-mm (1-in.) high (or longer) dark region of that strip is centered (or nearly centered) about the position of the line it has been tracking. If the mark is misaligned by several degrees from the scanner head, the scanner may never see the entire mark during a single strip of the image.

The scanning process takes about 22 sec/0.16-km (0.1-mi) segment. Once the trace of a set of segments has been scanned, the user is given the option of repeatedly analyzing it under a variety of options. Any given analysis may be plotted on a printer so that an annotated record of the analysis is produced. All scanned information is written to a disk file so that it can be read in later for further analysis. Figure 1 illustrates the original and scanned traces of a certain pavement section.

Specifying Reduction Parameters

Several of the reduction parameters are specified interactively during the time that the program is running and the scanning is done. These parameters are the ones that the user may wish to change from one value to another during the processing of a single section of the trace. One such parameter is the blanking band size. For example, the user may wish to reduce a segment under both a 0- and 5.1-mm (0.2-in.) blanking band. Other reduction parameters are constant within one execution of the program and are contained in a special configuration file. These are read by the program when it is first started and are used for all segments processed until the program is terminated. Examples of this type of parameter are the length of a normal length segment and the resolution of scallop height measurements.

RESULTS AND DISCUSSIONS

Comparison with Existing Methods

Nine different traces with average PRI values between 24 mm/km (1.5 in/mi) and 142 mm/km (9.0 in/mi) as determined by the Cox and Sons automated profilograph from a set of 19 0.16-km (0.1-mi) segments of AC were selected for this study. These traces, supplied by Jerry L. Budwig, Division Administrator of the Central Federal Lands Highways Division (CFLHD) in Denver, Colorado, represent the 19 sublots used in profilograph trace reduction study conducted by CFLHD (*6*). In that study, the 19 sublots (Project A) were subdivided to create two additional projects; that is, the nine smoothest sublots formed one of the additional projects (Project B), and the 10 roughest formed the other (Project C). In this study, the smoothest sublots (Project B) were chosen because the range of PRI values of these traces was found to be representative of the smoothness values achieved by the contractors on AC in Kansas. Also, the PRIs of these traces represent the values that are usually harder to reproduce consistently by manual method.

The selected traces were reduced by KSCAN and compared with the results obtained by CFLHD. The CFLHD results were from 14 experienced operators as well as from the programs used in the computerized profilographs (McCracken and Cox and Sons). Table 3 tabulates the results of the comparison for these segments.

In Table 3, the PRI values in the second column were found by averaging the results produced by the Cox and Sons and McCracken automated profilographs. Columns 3 and 5 are the KSCAN results at two standard resolutions. These are 1.27 mm (0.05 in.) and 0.25 mm (0.01 in.), respectively. Columns 4 and 6 show the difference between the KSCAN values and the values for automated profilographs in Column 2. The corresponding values in Row 9 are for the

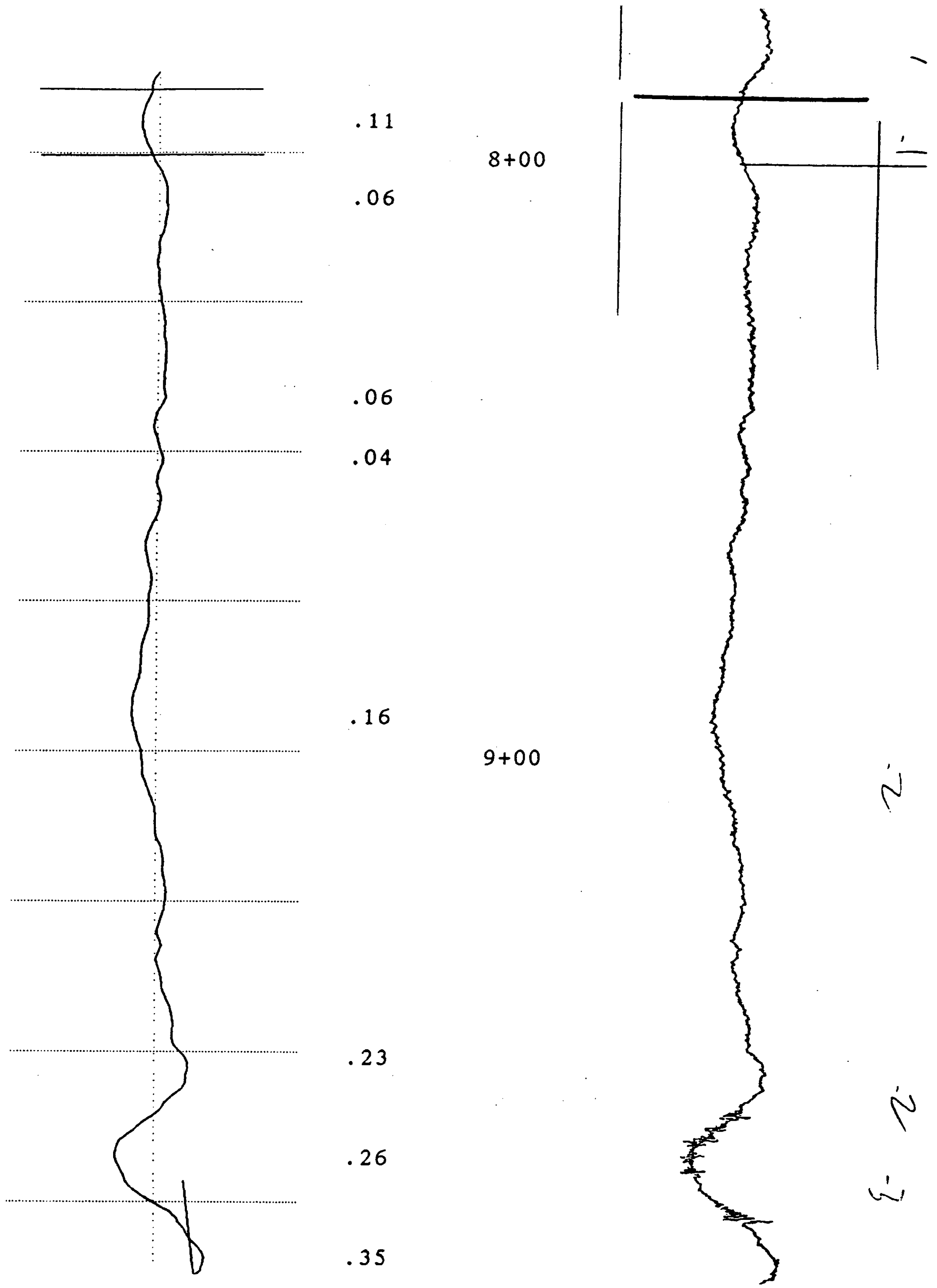

FIGURE 1 Original and scanned traces of a pavement section.

entire nine segments considered together. Row 11 gives PRI differences found by averaging the magnitudes of the segment-by-segment differences. This tends to better reflect the average variation than Row 10, which gives the overall difference. The last row shows the magnitude of the worst-case difference in the nine segments. All of these differences are quite small. However, these results indicate that the KSCAN results show better agreement with the automated profilograph results when the calculations are rounded to 0.254 mm (0.01 in.) instead of 1.27 mm (0.05 in.). A smaller resolution (rounding to the larger value) simply introduces random noise in the trace reduction or PRI computation process, which has no effect on very large sections but has increasing impact as the length decreases. KSCAN PRI values with higher resolution (rounding to a smaller value) are used in the later analysis.

TABLE 3 Comparison of Different Methods of Trace Reduction (KSCAN Resolution = 1.27 mm or 0.05 in.)

Segment No. / CFLHD Segment No.	PRI (mm/km)				
	Automated Profilographs*	KSCAN (Resolution = 1.27 mm)	Difference	KSCAN (Resolution = 0.254 mm)	Difference
1/1	24	16	-8	22	-2
2/3	83	63	-20	82	-1
3/4	122	110	-12	115	-7
4/10	110	103	-7	101	-9
5/12	71	71	0	66	-5
6/13	87	87	0	98	+11
7/17	142	142	0	140	-2
8/18	114	110	-4	106	-8
9/19	79	79	0	76	-3
Set	93	87	-6	90	-3
Avg. of Abs. Diff.			6		4
Max. of Abs. Diff.			20		11

* Average of Cox & Sons and McCracken results
Note : 1 in/mile = 15.78 mm/km

Table 4 compares manual trace reduction with automated reduction of traces, and Figure 2 illustrates the average PRI for the entire section computed by different methods and KSCAN with different resolutions. Column 2 of Table 4 gives the average value of the PRI found by the 14 experienced operators cited in the CFLHD study. The next two columns give information about the considerable variations between the reducers. Columns 5 and 7 show corresponding computer generated values, and 6 and 8 show the respective differences between the values in those columns and the average of the manual reductions. Again, as in Table 3, the last three rows show information about the complete set of nine segments. This table shows very good agreements between the computer reductions and the average manual reductions. The PRI values for the automated profilographs and the KSCAN, in no case, vary more than 17 mm/km (1.08 in/mi) and 12 mm/km (0.76 in/mi), respectively. The values in the last two rows are important relative to the KT-46I test method cited earlier. KT-46I requires that for a given test track, the automated PRI values and manual PRI values vary by no more than 32 mm/km (2 in/mi). Both sets of automated results in Table 4 satisfy this requirement. The worst-case values were 53 percent (Segment 4 for automated) and 38 percent (Segment 7 for KSCAN) of the allowable deviations. The entire-set difference of 3 mm/km (0.02 in/mi) for KSCAN shown for the entire 1.45-km (0.9-mi) section is virtually 0. The sum of all the scallops found in this section differed by less than 4.5 mm (0.2 in.) when comparing the experienced operator average with

TABLE 4 Comparison of Different Methods of Trace Reduction (KSCAN Resolution = .254 mm or 0.01 in.)

Segment No.	PRI (mm/km)						
	Expert Operators			Automated Profilographs*		KSCAN (Resolution = 0.254 mm)	
	Avg.	Std. Dev.	Range	Avg.	Diff.	Value	Diff.
1	33	15	16-71	24	-9	22	-11
2	85	18	55-118	83	-2	82	-3
3	110	13	95-150	122	12	115	5
4	93	13	71-118	110	17	101	8
5	70	9	55-87	71	1	66	-4
6	88	30	55-142	87	-1	98	10
7	128	19	95-166	142	14	140	12
8	107	21	63-142	114	7	106	-1
9	68	15	47-95	79	11	76	8
Set	87			93	6	90	3
Avg. of Abs. Diff.					8		7
Max. of Abs. Diff.					17		12

* Cox & Sons and McCracken automated profilographs
Note: 1 in/mile = 15.78 mm/km

KSCAN. This is less than the amount a manual operator rounds each scallop!

Repeatability of Scanning Process (5.08-mm or 0.2-in blanking band)

Table 5 shows the results from the two different runs of trace reduction using a 5.08-mm (0.2-in.) blanking band on the nine 0.16-km (0.1-mi) segments used earlier. The results show little or no difference in the PRI values from the two runs. More extensive tests indicated that the PRI computed by the KSCAN for a given segment generally varied less than ±3 percent from scan to scan, and five or more successive segments showed totals that rarely differed by more than ±1 percent.

Effect of Filtering on the Computation of PRI

Table 6 shows the effect of filtering on the PRI computation of the nine segments. The difference varies from 0.0 mm/km (in./mi) or 0 percent to 15.78 mm/km (1.0 in./mi) or 10.6 percent for these segments. A shorter than normal filter (KSCAN Filter 5, which averages only five consecutive points instead of the normal 15) was used to reduce the trace. This resulted in less smoothing of the scanned data and thus higher PRI

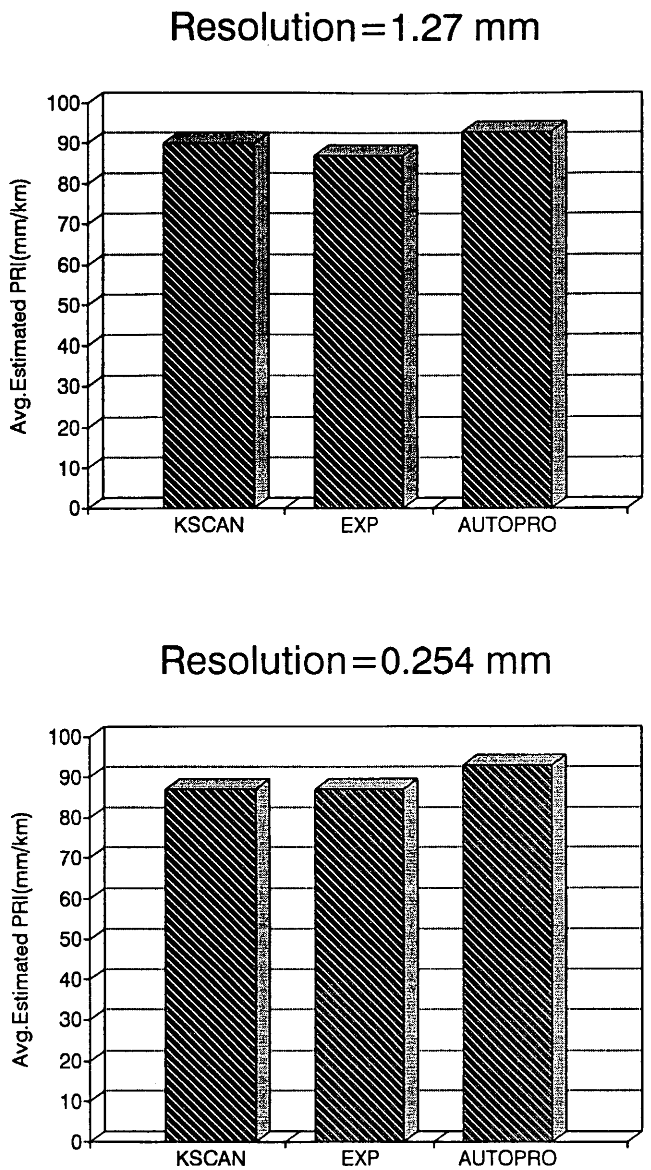

FIGURE 2 Computed PRI values by different methods and KSCAN (with different resolutions).

values. However, KSCAN is normally configured to use a longer (15) filter.

Determination of Location of Bumps

The methodology followed in locating bumps is similar to that of the Cox and Son's automated profilograph (*8*). According to KT-46I, a 10.2-mm (0.4-in.) bump template needs to be used for locating bumps. KSCAN uses a mathematical scheme to locate the bumps with a moving 7.6-m (25-ft) (25.4 mm or 1-in. on the digitized trace) baseline. Normally the template is set at 7.6 m (25 ft) (25.4 mm or 1 in.) in length and 10.2 mm (0.40 in.) in height. The equation for a line between each data point and the data for a point 7.6 m (25 ft) away is calculated. The data point that is the furthest above the line in that 7.6-m (25-ft) length is found. This is repeated for each data point in the segment being processed. Each maximum of this set of values that is greater than the specified grind height (10.16 mm or 0.4 in. in Kansas) represents a must grind location.

It should be noted that this procedure of bump location by KSCAN varies from the manual reduction process as suggested by KT-46I. The manual reduction process uses a fixed length plastic template, so it will measure the correct distance when the 25.4-mm (1-in.) line is horizontal. However, when steep lines are used to match the bump, the angle of the template combined with the highly exaggerated vertical scale causes the plastic template to measure less than the desired running length and less than the desired height. The KSCAN procedure uses the 25.4-mm (1-in.) horizontal distance and 10.16-mm (0.4-in.) vertical height regardless of the slope of the trace. This may sometimes result in the detection of bumps that could go undetected in the manual method.

CONCLUSIONS

An automated method (KSCAN) for reduction of the profilogram produced by the mechanical profilograph into a PRI and for identification of bump locations for grinding has been developed. The algorithm followed was the Kansas Test Method KT-46I: Determination of Pavement Profile with the 7.62-m (25-ft) Profilograph. The profilograph trace was scanned to digitize its tracing. An image enhancement program was used to prepare the image for analysis, and then a line was identified and digitized. A linear regression analysis was performed to establish the location of the floating centerline (corresponding to a null or 0 blanking band) along this line. The PRI were calculated based on deviation of the trace line from the floating centerline, and bumps were located based on the specified deviation from a 25.4-mm (1-in.) reference moving baseline. Parameters such as blanking band width and bump template height can be varied by the operator to conform to the existing specifications.

Comparison of the results of profile reduction for nine, smooth, 0.16-km (0.1-mi) segments using the manual methods, automated profilographs, and KSCAN showed that KSCAN results easily satisfy the KT-46I requirement and that the results of comparison between manual trace reduction by the KDOT and automatic trace reduction should not differ by more than 32 mm/km (2 in./mi). It appeared that KSCAN results showed better agreement with the automated profilograph results when the calculations were rounded to 0.25 mm (0.01 in.) instead of 1.27 mm (0.05 in.). Extensive tests indicated that the PRI computed by the KSCAN for a given segment generally varied less than ±3 percent from scan to scan, and five or more successive segments showed totals that rarely differed by more than ±1 percent. The process has been implemented on a personal computer, and an assembled system consisting of the software, the special scanning hardware, an IBM-compatible 486 computer, and a printer costs under $7,500.

ACKNOWLEDGMENTS

This project was funded under the Kansas Transportation Research and New Development (K-TRAN) program by KDOT. The authors are grateful to KDOT for this support. Thanks are due to Lon Ingram, P.E., Chief of Bureau of Materials and Research, and Richard McReynolds, P.E., Engineer of Research, for their continued interest and support for smoothness research in Kansas. The following graduate students of the EECE Department at KSU contributed to the development of computer code for KSCAN: M.

TABLE 5 Repeatability of Scanning Process (5.08 mm or 0.2 in Blanking Band)

Segment No.	Avg. Estimated PRI (mm/km)			
	Run 1	Run 2	Diff.	Diff. (%)
1	22.09	22.09	0.0	0.00
2	82.03	82.03	0.00	0.00
3	115.16	113.59	-1.57	-1.39
4	100.96	100.96	0.00	0.00
5	66.26	66.26	0.00	0.00
6	97.81	97.81	0.00	0.00
7	140.41	140.41	0.00	0.00
8	105.70	104.12	-1.58	-1.52
9	75.73	75.73	0.00	0.00

Note: 1 in/mile = 15.78 mm/km

TABLE 6 Effect of Filtering on the Computation of PRI

Segment No.	Avg. Estimated PRI (mm/km)			
	Filter 1	Filter 2*	Diff.	Diff. (%)
1	22.09	22.09	0.0	0.00
2	82.04	91.50	9.46	10.34
3	115.16	123.05	7.89	6.41
4	100.97	108.85	7.88	7.25
5	66.26	74.17	7.91	10.64
6	97.81	107.27	9.46	8.82
7	140.41	156.18	15.77	10.10
8	105.69	112.01	6.32	5.63
9	75.73	75.73	0.00	0.00

*shorter filter

Note: 1 in/mile = 15.78 mm/km

Ediger, B. Ensminger, J. Herrmann, T. Peglow, and R. Zhou. Their enthusiastic support for KSCAN is acknowledged.

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Publication of this report sponsored by Committee on Pavement Monitoring, Evaluation, and Data Storage.