Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA/TX-95/1378-1 | | |
| 4. Title and Subtitle<br>PROSCAN SYSTEM EVALUATION | | 5. Report Date<br>December 1994<br>6. Performing Organization Code |
| 7. Author(s)<br>Emmanuel G. Fernando and Gerardo M. Carmona | | 8. Performing Organization Report No.<br>Research Report 1378-1 |
| 9. Performing Organization Name and Address<br>Texas Transportation Institute<br>The Texas A&M University System<br>College Station, Texas 77843-3135 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>Study No. 0-1378 |
| 12. Sponsoring Agency Name and Address<br>Texas Department of Transportation<br>Research and Technology Transfer Office<br>P. O. Box 5080<br>Austin, Texas 78763-5080 | | 13. Type of Report and Period Covered<br>Interim:<br>June 1994 - October 1994<br>14. Sponsoring Agency Code |

15. Supplementary Notes

Research Performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: Development of Ride Quality Specification Criteria for ACP Overlays

16. Abstract

The Texas Department of Transportation (TxDOT) is implementing a Profilograph-based QC/QA smoothness specification wherein surface smoothness is measured using the Profile Index (PI) determined from Profilograph data. In view of the relative importance of the daily average PI, it is imperative that the reduction of profilograms be completed expeditiously. Failure to do so can result in construction delays.

This report presents a method for automated reduction of profile data from manual Profilographs. From experience, the manual method of reducing profilograms is both time consuming and subjective, and a faster and more consistent alternative is definitely warranted. To address this need, researchers evaluated a computerized data reduction system called ProScan to establish its accuracy and consistency in determining the Profile Index and defect stations from profilograms. In this method, a profilogram is scanned, and the determination of PI's and defect stations is accomplished automatically via software. Output shows the calculated Profile Indices for the scanned segments and the locations of defects (bumps and dips).

In view of the potential improvement in productivity that ProScan may bring, TxDOT requested the product evaluation presented in this report. This evaluation consisted of comparing the results obtained automatically by ProScan with the results obtained manually using the method specified by TxDOT under Test Method Tex-1000-S, "Operation of Pavement Profilograph and Evaluation of Profiles." The main finding from the study is that ProScan gives accurate and consistent results, at significantly less time and effort, compared to the manual method. The operational experience in using ProScan is described, along with recommendations for additional improvements.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Smoothness Specification, Manual Profilograph, Roughness Measurement, Profile Index, ProScan | No Restrictions. This document is available to the public through NTIS:<br>National Technical Information Service<br>5285 Port Royal Road<br>Springfield, Virginia 22161 |

| 19. Security Classif.(of this report) | 20. Security Classif.(of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 68 | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PROSCAN SYSTEM EVALUATION

by

Emmanuel G. Fernando
Assistant Research Engineer
Texas Transportation Institute

and

Gerardo M. Carmona
Graduate Research Assistant
Texas Transportation Institute

Research Report 1378-1
Research Study Number 0-1378
Research Study Title: Development of Ride Quality Specification Criteria for ACP Overlays

Sponsored by the
Texas Department of Transportation
In Cooperation with
U. S. Department of Transportation
Federal Highway Administration

December 1994

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

## IMPLEMENTATION STATEMENT

The ProScan System evaluated in this report deserves to be accepted as an alternative method of reducing data from manual Profilographs. The findings show that compared to the manual method of profilogram reduction, ProScan provides accurate and more consistent results with significantly less time and effort. A 1/24th reduction in processing time was realized in this study from use of ProScan. Thus, the researchers expect its implementation for quality control and assurance of surface smoothness will improve the productivity that can be achieved on projects where the contractor owns and operates a manual Profilograph.

This study recommends a pilot implementation on selected projects to identify and address implementation issues related to data reporting and training of contractor and agency personnel. Standard TxDOT report forms should be established and incorporated into the library of report forms in the ProScan software. The output from the program can then automatically be printed on the standard report form after data processing to further streamline the Quality Control/Quality Assurance (QC/QA) process. Additionally, consideration should be given to interfacing the output from ProScan with a computer program to calculate the pay factors automatically.

This evaluation also identified the following recommended improvements to ProScan:

1. Addition of a profilogram take-up spool; and
2. Modification of the output format to maximize the print area allotted to the scanned trace.

The Texas Transportation Institute (TTI) can provide technical assistance to TxDOT should it decide to proceed with implementing ProScan as an alternative method of profilogram reduction on QC/QA projects.

## DISCLAIMER

# ACKNOWLEDGMENTS

The work reported herein was conducted as part of a research study sponsored by TxDOT to develop and implement smoothness specifications for asphalt concrete overlays. The assistance provided by Mr. Carl Bertrand of the Pavements Section, and Mr. Arthur Blondeau of the Bryan District in providing the profilograms used in this evaluation is gratefully acknowledged. In addition, Messrs. Fritz Jooste and Mark Simmons assisted in the collection and reduction of manual Profilograph data. A special note of thanks is also extended to Dr. John Devore of Kansas State University, the ProScan system developer, for lending the ProScan unit evaluated herein at no cost to the study.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## SUMMARY

The Texas Department of Transportation (TxDOT) requested the evaluation of the ProScan System as an alternative method of reducing manual Profilograph traces automatically to determine profile indices (PI's) and defect stations on paving projects. In view of the implementation of TxDOT's QC/QA end-result smoothness specification, it is imperative that profilogram reduction be completed expeditiously. Based on the results from this investigation, the researchers determined that the ProScan system will satisfy this need. Specifically, comparisons between the system and the manual method of data reduction have shown that:

1. A strong, positive, linear relationship exists between the manual and ProScan PI's;
2. Differences between the manual and ProScan PI's are not statistically significant;
3. The variability in the manual PI's from various raters is approximately 10 times higher than the variability in the ratings from repeat runs of ProScan;
4. Defect stations reported by ProScan are consistent with those identified using the manual method and show less variability; and
5. Data reduction time is reduced significantly.

Based on the study findings, this study recommends that TxDOT accept the ProScan system as an alternative to the manual method of data reduction. A pilot implementation on a number of projects is warranted to identify and address implementation issues related to data reporting and training of contractor and agency personnel.

# CHAPTER 1. INTRODUCTION

The Texas Department of Transportation (TxDOT) requested the evaluation of the ProScan System to determine its accuracy and consistency in obtaining the profile index (PI) and defect stations from profilograms. The ProScan System is a computerized, automatic profile-reduction system consisting of a paper transport unit, a Scanman 32 hand scanner, and the ProScan software and User's Guide. Figure 1 shows a picture of the paper transport unit and the Scanman 32 scanner. Details of system operation are found in the User's Guide. The unit is available from Devore Systems, Incorporated of Manhattan, Kansas and costs $6000 without the computer. The company can be reached at (913) 537 - 1799.

ProScan automates the reduction of profilograms taken with a manual Profilograph, which is both time consuming and subjective. In view of the relative importance of the daily average PI, as required by TxDOT's QC/QA end-result smoothness specification, it is imperative that the profilogram reduction be completed expeditiously. Failure to do so can result in construction delays.

In the ProScan method, a profilogram is initially scanned and the reduced data are saved to the computer's hard disk. During the scanning process, the profilogram is divided into 0.16-km (0.1-mile) segments or to some other segment length prescribed by the user. Reports showing the calculated profile indices (PI's) for the scanned segments and the locations of defects (bumps and dips) can be printed out after completion of the data reduction.

In view of the potential improvement in productivity that may be gained from use of the ProScan system, the researchers conducted the product evaluation presented in this report. This evaluation consisted of comparing the results obtained automatically by the ProScan System with the results obtained manually using the

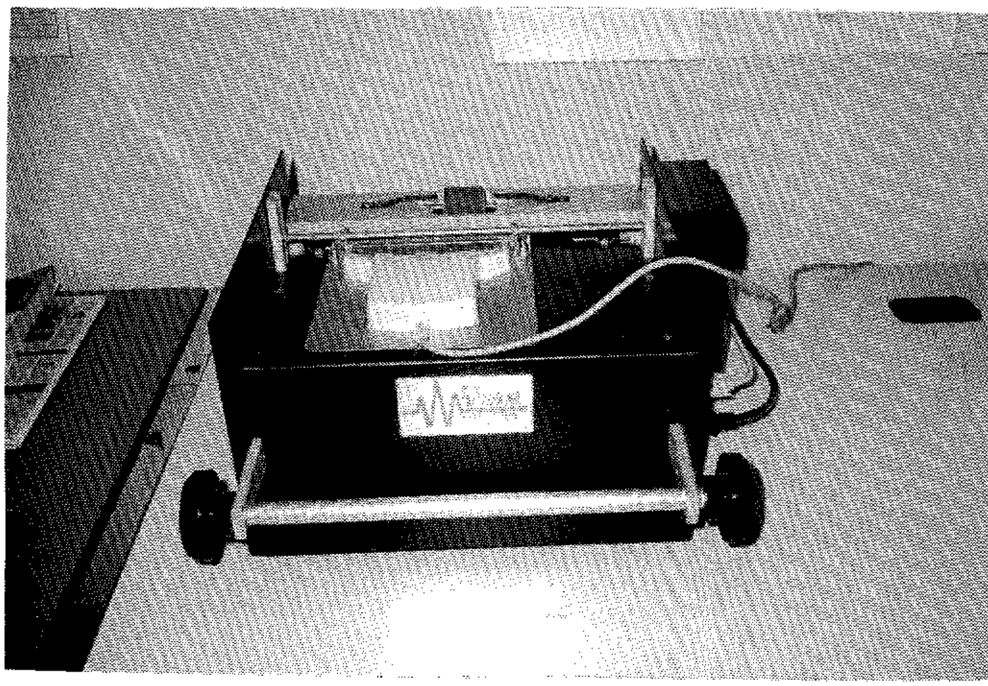


Figure 1. Picture of the ProScan System showing the paper transport unit and scanner.

method specified by TxDOT under Test Method Tex-1000-S, "Operation of Pavement Profilograph and Evaluation of Profiles" (1). The report also makes suggestions for further refinements of the ProScan System hardware.

Data for the evaluation consisted of the following two profilograms:

1. Profilogram #1 was provided by the Pavements Section of TxDOT's Design Division and consisted of nine 0.16-km (0.1-mile) segments;
2. Profilogram #2 was obtained by personnel from TxDOT's Bryan District and the Texas Transportation Institute (TTI) on a 3.54-km (2.2-mile) section of SH 6, north of Bryan, from the FM 2818 interchange to approximately the Robertson county line.

Profilograph data reduction was accomplished manually and through the use of the ProScan system. Results from both methods were then compared and statistical tests conducted to establish the significance of the differences in the computed profile indices between the two methods. The defect stations reported by ProScan and by each rater were also compared. Results of the evaluation are presented subsequently.

# CHAPTER 2. COMPARISON OF MANUAL AND PROSCAN METHODS OF PROFILOGRAM REDUCTION

## COMPARISON OF MANUAL VERSUS PROSCAN PROFILE INDICES

This section describes the evaluation of the ProScan System with respect to the profile index. First, it presents a comparison of the manual and ProScan PI's using Profilogram #1. This is followed by a comparison of the ratings determined from processing Profilogram #2.

### Initial Evaluation With Profilogram #1

The initial ProScan evaluation was performed using Profilogram #1. First, one evaluator manually reduced the profilogram to obtain the manual PI's. Then, the ProScan system was used to reduce the profilogram. The manual and ProScan PI values obtained are shown in Table 1 and are plotted in Figures 2 and 3. There are nine 0.16-km (0.1-mile) segments for this profilogram.

The scatter plot of the data, Figure 2, shows a strong positive linear relationship between ProScan and manual PI's as indicated by the coefficient of determination, $R^2$, of 0.997. The regression equation between the ProScan and manual PI's was also determined. A slope of 1 and an intercept of 0 for the regression equation would indicate that the values obtained using both methods are equal. The actual slope calculated by regression is 0.97, and the intercept is 1.73, indicating that ProScan and manual PI's are approximately the same. Considering that the profile indices are in mm/km, the intercept value of 1.73 is negligible. Further, a statistical test of significance for the intercept coefficient showed that it is not significantly different from zero.

The bar chart of ProScan versus manual PI's, Figure 3, also indicates the favorable agreement between ProScan and manual ratings. A statistical test, known as a paired t-test, was conducted which showed that the differences between the ProScan and manual PI's are not significant. Table 1 summarizes the statistical test conducted.

Table 1. ProScan and Manual PI's for Profilogram #1.

| Segment | ProScan PI | | Manual PI | | Difference in PI's | |
|---|---|---|---|---|---|---|
| | mm/km | in/mile | mm/km | in/mile | mm/km | in/mile |
| 1 | 600 | (38.0) | 608 | (38.5) | -8 | (-0.5) |
| 2 | 140 | (8.9) | 166 | (10.5) | -26 | (-1.6) |
| 3 | 90 | (5.7) | 87 | (5.5) | 3 | (0.2) |
| 4 | 545 | (34.5) | 545 | (34.5) | 0 | (0.0) |
| 5 | 93 | (5.9) | 87 | (5.5) | 6 | (0.4) |
| 6 | 95 | (6.0) | 90 | (5.7) | 5 | (0.3) |
| 7 | 541 | (34.3) | 576 | (36.5) | -35 | (-2.2) |
| 8 | 92 | (5.8) | 87 | (5.5) | 5 | (0.3) |
| 9 | 85 | (5.4) | 90 | (5.7) | -5 | (-0.3) |
| | | | | | | |
| Mean | 254 | (16.1) | 259 | (16.4) | -6 | (-0.4) |
| Standard Deviation | 232 | (14.7) | 240 | (15.2) | 14 | (0.9) |

The steps in the paired t-test are (2):

1. $H_0$: $\Delta = 0$ (where $\Delta$ represents the difference in ratings)
2. $H_a$: $\Delta \neq 0$
3. A confidence level of 95 percent requires a t-value of ±2.306 with 8 df.
4. Criterion: Reject $H_0$ if $t < -2.306$ or if $t > +2.306$ where the t-statistic is:

$$t = \frac{\bar{D}}{\frac{\sigma_D}{\sqrt{n}}}$$

where, $\bar{D}$ , is the mean of the differences, $\sigma_D$, the standard deviation of the differences, and n, is the sample size.

5. Using the data given in Table 1, a t-statistic of -1.3 is computed. Since this value is within the interval, $-2.306 \leq t \leq +2.306$, $H_0$ cannot be rejected. The ProScan and manual PI's are not significantly different.

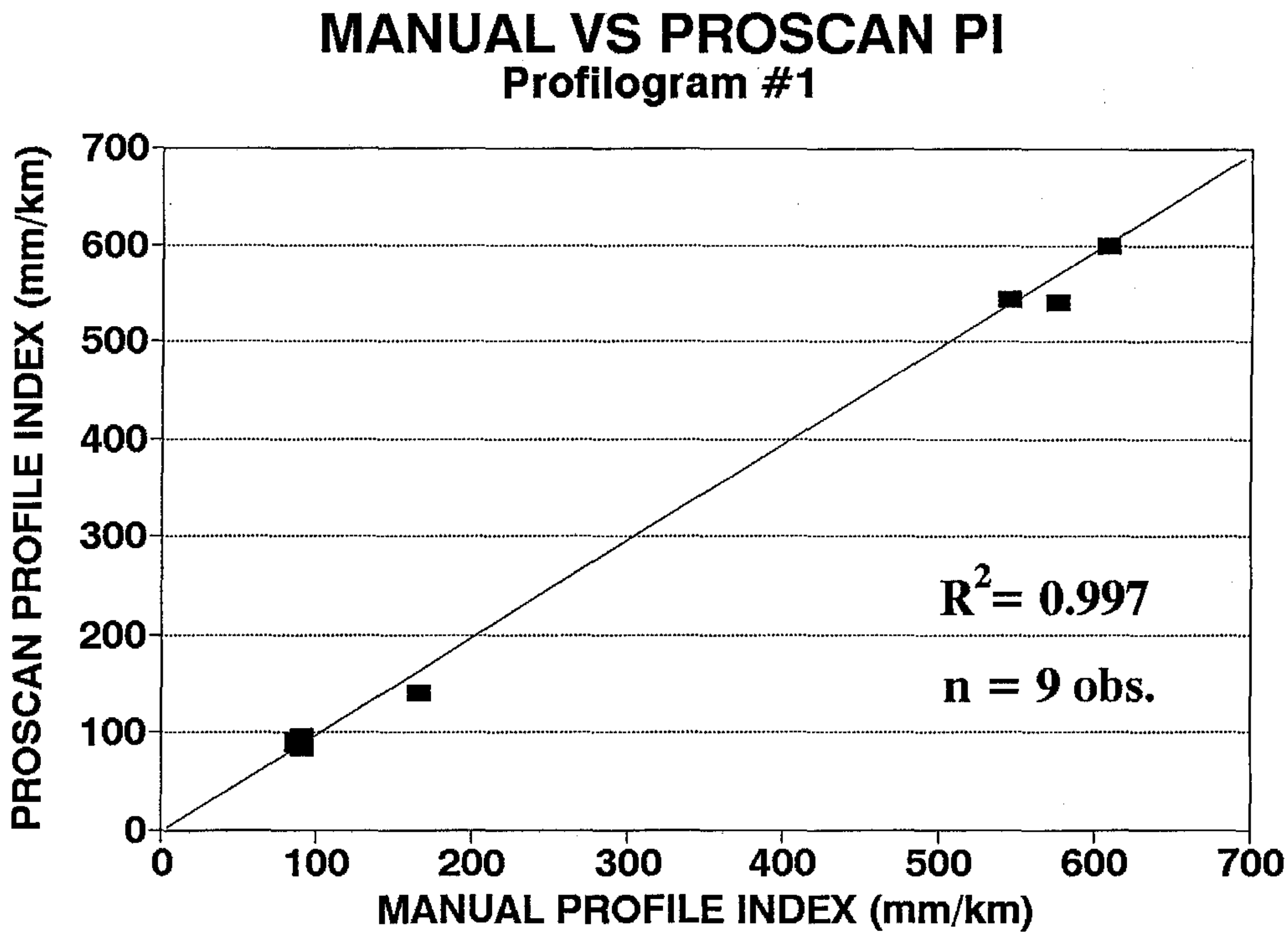



Figure 2. Scatter plot of ProScan and manual PI's determined for Profilogram #1.

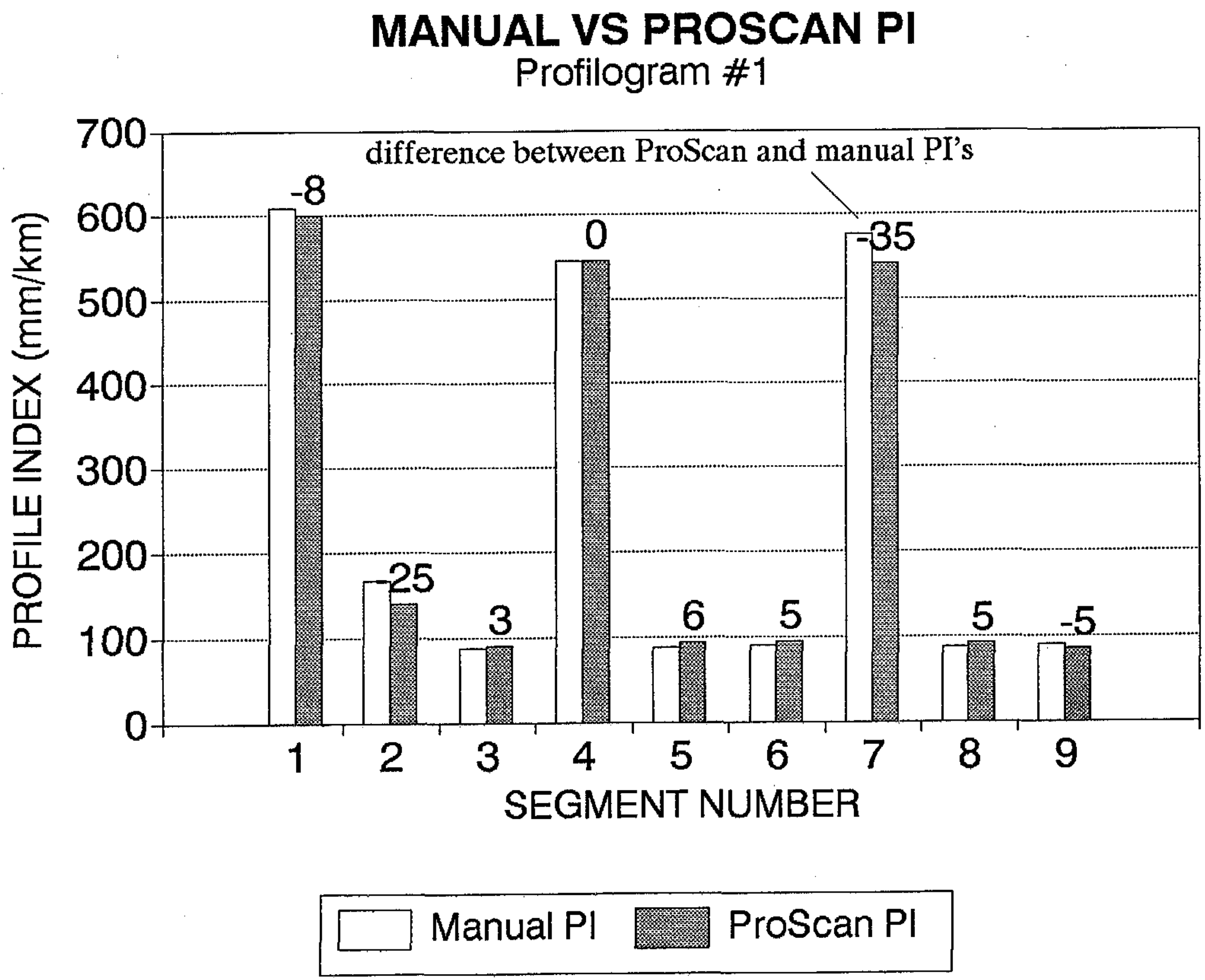



Figure 3. Bar chart of ProScan and manual PI's determined for Profilogram #1.

**Evaluation With Profilogram #2**

Figure 2 revealed that the data from Profilogram #1 were limited to low and high values of roughness and that additional data were needed for the mid-range PI values. Researchers attempted to find additional test segments to survey and, based on profile data collected with TxDOT's Surface Dynamics Profilometer, identified a portion of SH 6, north of Bryan, which included segments that covered a much broader range of surface roughness. Consequently, a survey was conducted using the Bryan District's manual Profilograph. Actual testing was performed by personnel from the District office and TTI, and covered the northbound, outside lane of SH 6, from the FM 2818 overpass to the Robertson county line, a distance of 3.54 km (2.2 miles).

The profilogram obtained from the survey was subsequently evaluated. Initially, each member of a 5-person panel of raters manually reduced the profilogram. Prior to the data reduction, a meeting was held to familiarize the panel members with the procedure for profilogram evaluation given in Test Method Tex-1000-S (1). This meeting was attended by a certified Level IB roadway specialist from the Bryan District who was also a member of the rating panel.

An attempt was made to provide a copy of the profilogram to each member of the panel. However, it was difficult getting a duplicate that was free of distortions caused by lateral movement of the profilogram as the roll of chart paper was being copied. Consequently, the decision was made to have each evaluator work from the original profilogram with the instruction that all marks made during the data reduction would be cleanly erased so as to avoid influencing the next rater. This approach worked well due to the care exercised by each evaluator in handling the profilogram.

The ratings from the evaluators are given in Table 2. The mean PI and the standard deviation of the ratings are also tabulated. The variability in the manual PI's for each segment, as measured by the standard deviation, varied from 11 to 76 mm/km (0.7 to 4.8 in/mile), with an average standard deviation of 46 mm/km (2.9

Table 2. Profile Indices from Different Evaluators [1].

| Segment | Evaluator | | | | | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| 1 | 55 (3.5) | 63 (4.0) | 150 (9.5) | 87 (5.5) | 55 (3.5) | 82 (5.2) | 39 (2.5) | 0.49 |
| 2 | 387 (24.5) | 410 (26.0) | 497 (31.5) | 426 (27.0) | 355 (22.5) | 415 (26.3) | 54 (3.4) | 0.13 |
| 3 | 197 (12.5) | 166 (10.5) | 253 (16.0) | 237 (15.0) | 150 (9.5) | 200 (12.7) | 44 (2.8) | 0.22 |
| 4 | 47 (3.0) | 39 (2.5) | 95 (6.0) | 39 (2.5) | 24 (1.5) | 49 (3.1) | 27 (1.7) | 0.55 |
| 5 | 134 (8.5) | 174 (11.0) | 158 (10.0) | 189 (12.0) | 126 (8.0) | 156 (9.9) | 27 (1.7) | 0.17 |
| 6 | 260 (16.5) | 174 (11.0) | 237 (15.0) | 253 (16.0) | 150 (9.5) | 215 (13.6) | 51 (3.2) | 0.23 |
| 7 | 663 (42.0) | 671 (42.5) | 734 (46.5) | 718 (45.5) | 679 (43.0) | 693 (43.9) | 32 (2.0) | 0.05 |
| 8 | 371 (23.5) | 387 (24.5) | 473 (30.0) | 371 (23.5) | 331 (21.0) | 387 (24.5) | 52 (3.3) | 0.14 |
| 9 | 174 (11.0) | 79 (5.0) | 142 (9.0) | 110 (7.0) | 47 (3.0) | 110 (7.0) | 51 (3.2) | 0.45 |
| 10 | 126 (8.0) | 126 (8.0) | 166 (10.5) | 118 (7.5) | 63 (4.0) | 120 (7.6) | 36 (2.3) | 0.31 |
| 11 | 24 (1.5) | 16 (1.0) | 32 (2.0) | 8 (0.5) | 8 (0.5) | 17 (1.1) | 11 (0.7) | 0.59 |
| 12 | 339 (21.5) | 316 (20.0) | 450 (28.5) | 395 (25.0) | 276 (17.5) | 355 (22.5) | 68 (4.3) | 0.19 |
| 13 | 647 (41.0) | 631 (40.0) | 710 (45.0) | 718 (45.5) | 592 (37.5) | 660 (41.8) | 54 (3.4) | 0.08 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

Table 2. Profile Indices from Different Evaluators (continued) [1].

| Segment | Evaluator | | | | | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| 14 | 852 (54.0) | 821 (52.0) | 933 (59.1) | 884 (56.0) | 908 (57.5) | 879 (55.7) | 44 (2.8) | 0.05 |
| 15 | 189 (12.0) | 158 (10.0) | 300 (19.0) | 237 (15.0) | 174 (11.0) | 211 (13.4) | 57 (3.6) | 0.27 |
| 16 | 237 (15.0) | 174 (11.0) | 253 (16.0) | 237 (15.0) | 103 (6.5) | 200 (12.7) | 63 (4.0) | 0.31 |
| 17 | 331 (21.0) | 237 (15.0) | 324 (20.5) | 300 (19.0) | 197 (12.5) | 278 (17.6) | 58 (3.7) | 0.21 |
| 18 | 450 (28.5) | 473 (30.0) | 592 (37.5) | 513 (32.5) | 473 (30.0) | 500 (31.7) | 55 (3.5) | 0.11 |
| 19 | 955 (60.5) | 868 (55.0) | 1,026 (65.0) | 931 (59.0) | 892 (56.5) | 934 (59.2) | 62 (3.9) | 0.07 |
| 20 | 284 (18.0) | 221 (14.0) | 316 (20.0) | 300 (19.0) | 213 (13.5) | 267 (16.9) | 47 (3.0) | 0.18 |
| 21 | 253 (16.0) | 205 (13.0) | 292 (18.5) | 221 (14.0) | 182 (11.5) | 230 (14.6) | 43 (2.7) | 0.19 |
| 22 | 39 (2.5) | 47 (3.0) | 71 (4.5) | 71 (4.5) | 32 (2.0) | 52 (3.3) | 19 (1.2) | 0.35 |
| 23 | 122 (7.7) | 126 (8.0) | 55 (3.5) | 243 (15.4) | 58 (3.7) | 122 (7.7) | 76 (4.8) | 0.63 |
| | | | | | | Mean | 46 (2.9) | 0.26 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

in/mile). In terms of the coefficient of variation, defined as the ratio of the standard deviation to the mean, the variability ranged from 5 to 63 percent with an average value of 26 percent. These statistics seem to be consistent with the findings from a study done by Kulakowski and Wambold (3) who reported a standard deviation of 73 mm/km (4.6 in/mile) in the ratings from different individuals reducing the same profilogram. These numbers provide a measure of the variability that may be expected due to the subjectivity inherent in the interpretation of manual Profilograph traces.

Next, researchers reduced the profilogram with the ProScan system. Five runs were performed so that a mean and standard deviation could be obtained for comparison with the manual method and to evaluate the repeatability of the system. The results from this evaluation are presented in Table 3 where one may observe that the standard deviation of the repeat measurements ranged from 0 to 13 mm/km (0 to 0.8 in/mile) with an average standard deviation of 5 mm/km (0.3 in/mile). In terms of the coefficient of variation, the variability ranged from 0 to 5 percent with a mean of 2 percent. Comparison of these statistics with those determined for the manual PI's suggest that the ProScan system would provide more consistent results by eliminating the variability in the manual ratings that stems from the subjectivity of the person doing the profilogram reduction.

The reduced variability, notwithstanding, a comparison of the ProScan and manual PI's was conducted to verify whether ProScan is simulating acceptably the manual method of data reduction. If it is, the mean ratings from the two methods should be highly correlated, indicating that both provide similar answers. A scatter plot of the ratings for Profilogram #2 is presented in Figure 4. This plot shows a strong, positive, linear relationship between the ProScan and manual PI's as indicated by the high, $R^2$, of 0.98. The intercept and slope of the regression line were determined to be -4.55 and 1.02, respectively, indicating that the ratings from both methods are approximately equal. Further, a statistical test of significance for the intercept coefficient showed that it is not significantly different from zero.

Table 3. Profile Indices from Repeat Runs of ProScan [1].

| Segment | ProScan Run Number | | | | | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| 1 | 80 (5.1) | 76 (4.8) | 76 (4.8) | 77 (4.9) | 80 (5.1) | 77 (4.9) | 3 (0.2) | 0.03 |
| 2 | 412 (26.1) | 414 (26.2) | 410 (26.0) | 410 (26.0) | 412 (26.1) | 412 (26.1) | 2 (0.1) | 0.00 |
| 3 | 183 (11.6) | 182 (11.5) | 182 (11.5) | 182 (11.5) | 182 (11.5) | 182 (11.5) | 0 (0.0) | 0.00 |
| 4 | 46 (2.9) | 44 (2.8) | 44 (2.8) | 43 (2.7) | 44 (2.8) | 44 (2.8) | 2 (0.1) | 0.03 |
| 5 | 159 (10.1) | 172 (10.9) | 159 (10.1) | 172 (10.9) | 159 (10.1) | 164 (10.4) | 6 (0.4) | 0.04 |
| 6 | 208 (13.2) | 205 (13.0) | 204 (12.9) | 204 (12.9) | 208 (13.2) | 205 (13.0) | 3 (0.2) | 0.01 |
| 7 | 724 (45.9) | 705 (44.7) | 724 (45.9) | 721 (45.7) | 710 (45.0) | 717 (45.4) | 9 (0.6) | 0.01 |
| 8 | 382 (24.2) | 385 (24.4) | 384 (24.3) | 388 (24.6) | 390 (24.7) | 385 (24.4) | 3 (0.2) | 0.01 |
| 9 | 88 (5.6) | 87 (5.5) | 88 (5.6) | 88 (5.6) | 90 (5.7) | 88 (5.6) | 2 (0.1) | 0.01 |
| 10 | 96 (6.1) | 103 (6.5) | 95 (6.0) | 103 (6.5) | 95 (6.0) | 98 (6.2) | 5 (0.3) | 0.04 |
| 11 | 16 (1.0) | 17 (1.1) | 17 (1.1) | 16 (1.0) | 16 (1.0) | 16 (1.0) | 2 (0.1) | 0.05 |
| 12 | 355 (22.5) | 360 (22.8) | 357 (22.6) | 358 (22.7) | 358 (22.7) | 358 (22.7) | 2 (0.1) | 0.01 |
| 13 | 649 (41.1) | 653 (41.4) | 650 (41.2) | 655 (41.5) | 653 (41.4) | 652 (41.3) | 3 (0.2) | 0.00 |
| 14 | 915 (58.0) | 922 (58.4) | 922 (58.4) | 928 (58.8) | 942 (59.7) | 926 (58.7) | 9 (0.6) | 0.01 |
| 15 | 211 (13.4) | 205 (13.0) | 207 (13.1) | 204 (12.9) | 207 (13.1) | 207 (13.1) | 3 (0.2) | 0.01 |
| 16 | 197 (12.5) | 199 (12.6) | 196 (12.4) | 194 (12.3) | 194 (12.3) | 196 (12.4) | 2 (0.1) | 0.01 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

Table 3. Profile Indices from Repeat Runs of ProScan (continued) [1].

| Segment | ProScan Run Number | | | | | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| 17 | 257 (16.3) | 265 (16.8) | 260 (16.5) | 265 (16.8) | 267 (16.9) | 264 (16.7) | 5 (0.3) | 0.02 |
| 18 | 634 (40.2) | 657 (41.6) | 630 (39.9) | 634 (40.2) | 636 (40.3) | 638 (40.4) | 11 (0.7) | 0.02 |
| 19 | 866 (54.9) | 862 (54.6) | 865 (54.8) | 865 (54.8) | 865 (54.8) | 865 (54.8) | 2 (0.1) | 0.00 |
| 20 | 290 (18.4) | 264 (16.7) | 264 (16.7) | 264 (16.7) | 264 (16.7) | 268 (17.0) | 13 (0.8) | 0.04 |
| 21 | 208 (13.2) | 223 (14.1) | 208 (13.2) | 210 (13.3) | 208 (13.2) | 211 (13.4) | 6 (0.4) | 0.03 |
| 22 | 60 (3.8) | 60 (3.8) | 60 (3.8) | 60 (3.8) | 60 (3.8) | 60 (3.8) | 0 (0.0) | 0.00 |
| 23 | 123 (7.8) | 137 (8.7) | 123 (7.8) | 123 (7.8) | 123 (7.8) | 126 (8.0) | 6 (0.4) | 0.05 |
| | | | | | | Mean | 5 (0.3) | 0.02 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

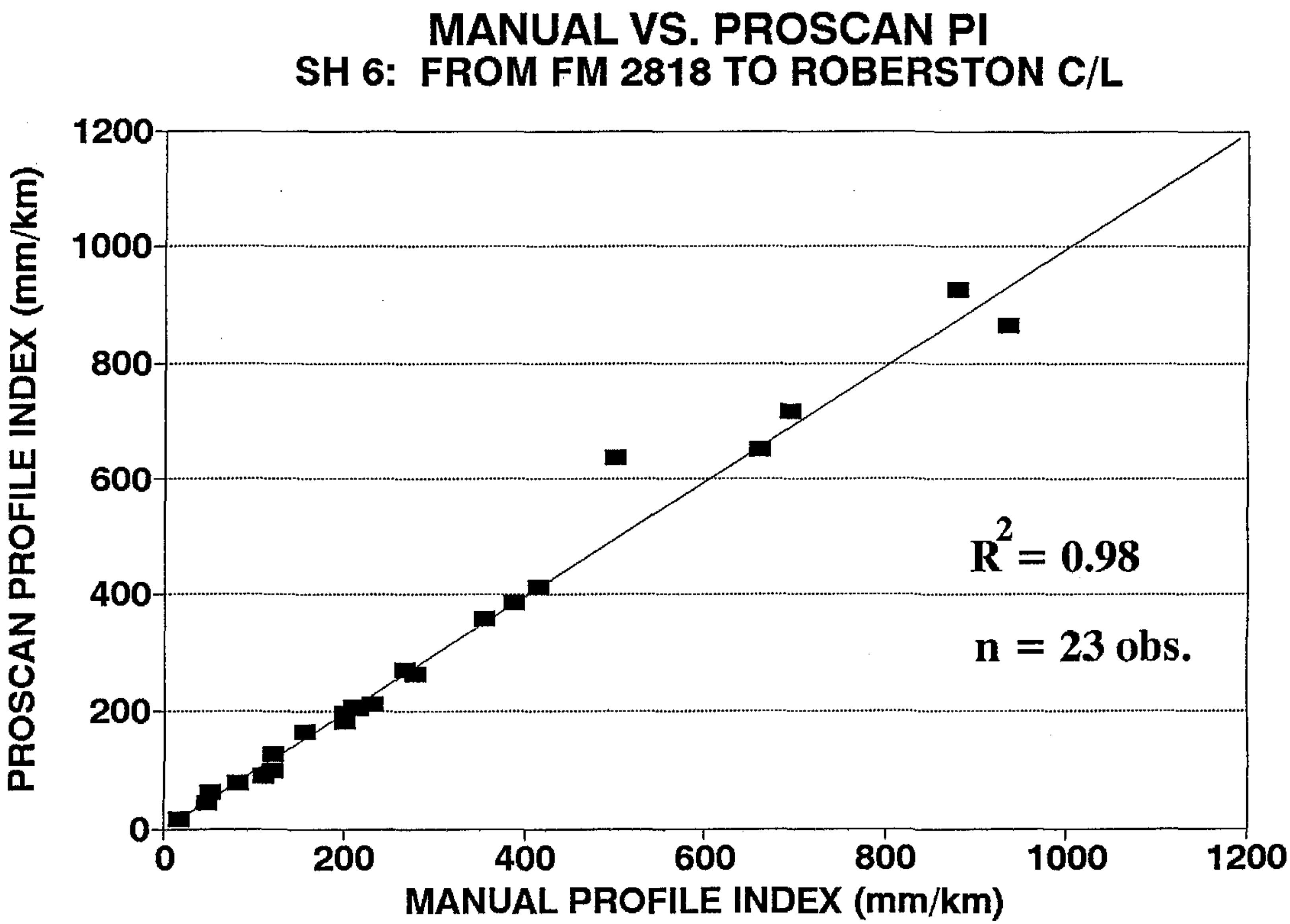



Figure 4. Scatter plot of ProScan and manual PI's determined for Profilogram #2.

Researchers conducted statistical tests on the differences between the ProScan and manual mean ratings to determine if the means were significantly different. The results from this evaluation are summarized in Table 4, where the following notations are used:

$\bar{x}_1$ is the mean of the ProScan PI's for a given segment

$\bar{x}_2$ is the mean of the manual PI's for a given segment

$s_1$ is the standard deviation of the ProScan PI's for a given segment

$s_2$ is the standard deviation of the manual PI's for a given segment

$$S_{1-2} = \sqrt{\frac{s_1^2 + s_2^2}{n - 1}}$$ where, n, the sample size, is 5 for this evaluation

$$\text{t-statistic} = \frac{\bar{x}_1 - \bar{x}_2}{S_{1-2}}$$

The comparison of the means follows the t-test procedure given by Clark and Schkade (2). At a 95 percent confidence level, and for 8 degrees of freedom (df), the ProScan and manual PI's are significantly different if the absolute value of the t-statistic is greater than 2.306. Of the 23 segments evaluated, only one segment (#18), was found where the mean ratings were significantly different. For this segment, the ProScan mean is higher than the manual mean by 138 mm/km (8.7 in/mile). An investigation was conducted to explain this difference. The Profilograph trace for segment 18 was examined as well as the printout of the scanned trace from ProScan. It was found that, at the end of segment 18, a sizeable bump exists, as observed from Figure 5 which shows a printout of the scanned trace for this segment. The ProScan system "saw" this bump as being a feature of segment 18. The evaluators, on the

Table 4. Results of Statistical Tests on Differences Between ProScan and Manual PI's [1].

| Segment | ProScan | | Manual | | $\bar{x}_1 - \bar{x}_2$ | $s_{1-2}$ | t-statistic |
|---|---|---|---|---|---|---|---|
| | $\bar{x}_1$ | $s_1$ | $\bar{x}_2$ | $s_2$ | | | |
| 1 | 77 (4.9) | 3 (0.2) | 82 (5.2) | 39 (2.5) | -5 (-0.3) | 20 (1.27) | -0.20 |
| 2 | 412 (26.1) | 2 (0.1) | 415 (26.3) | 54 (3.4) | -3 (-0.2) | 27 (1.68) | -0.13 |
| 3 | 182 (11.5) | 0 (0.0) | 200 (12.7) | 44 (2.8) | -18 (-1.2) | 22 (1.40) | -0.84 |
| 4 | 44 (2.8) | 2 (0.1) | 49 (3.1) | 27 (1.7) | -5 (-0.3) | 14 (0.86) | -0.35 |
| 5 | 164 (10.4) | 6 (0.4) | 156 (9.9) | 27 (1.7) | 8 (0.5) | 14 (0.86) | 0.60 |
| 6 | 205 (13.0) | 3 (0.2) | 215 (13.6) | 51 (3.2) | -10 (-0.6) | 25 (1.58) | -0.36 |
| 7 | 717 (45.4) | 9 (0.6) | 693 (43.9) | 32 (2.0) | 24 (1.5) | 16 (1.03) | 1.50 |
| 8 | 385 (24.4) | 3 (0.2) | 387 (24.5) | 52 (3.3) | -2 (-0.1) | 26 (1.67) | -0.04 |
| 9 | 88 (5.6) | 2 (0.1) | 110 (7.0) | 51 (3.2) | -22 (-1.4) | 25 (1.58) | -0.89 |
| 10 | 98 (6.2) | 5 (0.3) | 120 (7.6) | 36 (2.3) | -22 (-1.4) | 18 (1.17) | -1.18 |
| 11 | 16 (1.0) | 2 (0.1) | 17 (1.1) | 11 (0.7) | -1 (-0.1) | 5 (0.33) | -0.18 |
| 12 | 358 (22.7) | 2 (0.1) | 355 (22.5) | 68 (4.3) | 3 (0.2) | 34 (2.16) | 0.07 |
| 13 | 652 (41.3) | 3 (0.2) | 660 (41.8) | 54 (3.4) | -8 (-0.5) | 27 (1.70) | -0.28 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

Table 4. Results of Statistical Tests on Differences Between ProScan and Manual PI's (continued) [1].

| Segment | ProScan | | Manual | | $\bar{x}_1 - \bar{x}_2$ | $s_{1-2}$ | t-statistic |
|---|---|---|---|---|---|---|---|
| | $\bar{x}_1$ | $s_1$ | $\bar{x}_2$ | $s_2$ | | | |
| 14 | 926 (58.7) | 9 (0.6) | 879 (55.7) | 44 (2.8) | 47 (2.9) | 23 (1.44) | 2.04 |
| 15 | 207 (13.1) | 3 (0.2) | 211 (13.4) | 57 (3.6) | -4 (-0.3) | 29 (1.83) | -0.16 |
| 16 | 196 (12.4) | 2 (0.1) | 200 (12.7) | 63 (4.0) | -4 (-0.3) | 31 (1.98) | -0.14 |
| 17 | 264 (16.7) | 5 (0.3) | 278 (17.6) | 58 (3.7) | -14 (-0.9) | 29 (1.85) | -0.51 |
| 18 | 638 (40.4) | 11 (0.7) | 500 (31.7) | 55 (3.5) | 138 (8.7) | 28 (1.80) | 4.84 |
| 19 | 865 (54.8) | 2 (0.1) | 934 (59.2) | 62 (3.9) | -69 (-4.4) | 31 (1.94) | -2.28 |
| 20 | 268 (17.0) | 13 (0.8) | 267 (16.9) | 47 (3.0) | 1 (0.1) | 24 (1.53) | 0.09 |
| 21 | 211 (13.4) | 6 (0.4) | 230 (14.6) | 43 (2.7) | -19 (-1.2) | 22 (1.38) | -0.87 |
| 22 | 60 (3.8) | 0 (0.0) | 52 (3.3) | 19 (1.2) | 8 (0.5) | 9 (0.58) | 0.87 |
| 23 | 126 (8.0) | 6 (0.4) | 122 (7.7) | 76 (4.8) | 4 (0.3) | 38 (2.42) | 0.13 |

[1] PI's given in mm/km and in (in/mile) by numbers in parentheses.

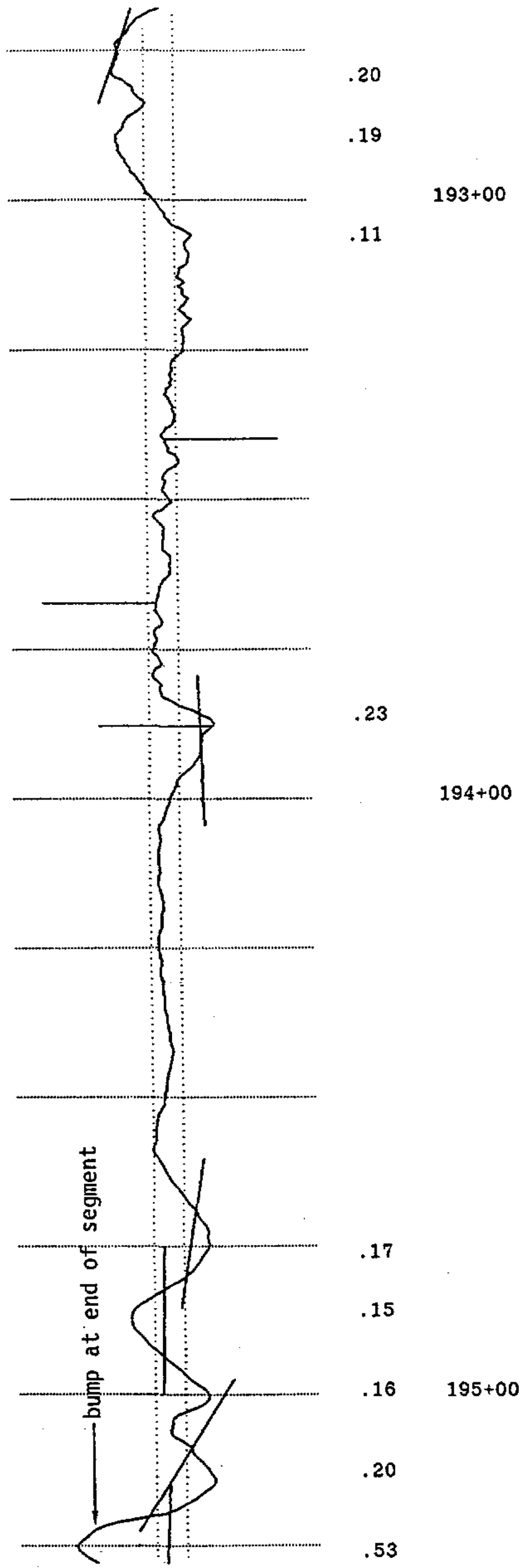



Figure 5. Partial printout of scanned trace for segment 18 showing the bump at the end of the segment (Station 195 + 25).

other hand, saw the bump as a feature at the beginning of segment 19. Thus, a higher mean PI was calculated from the ProScan ratings for segment 18, while the opposite is true for segment 19. The absolute value of the t-statistic for segment 19 is only a little bit less than the critical t-value of 2.306 indicating that the ProScan and manual PI's for this segment are close to being significantly different.

The location of a bump is generally determined by the location of its peak. In a situation where the bump is located very close to the boundary of two adjacent segments, it is conceivable that the peak location can be influenced significantly by a number of factors:

1. the variability in wheelpath tracking during the Profilograph measurement, the effect of which becomes more pronounced over longer distances;
2. the variability in the positioning of the blanking band from one segment to the next - over a long profilogram, the variations may accumulate significantly enough to influence where the bump is located; and
3. distance errors in the instrument - in practice, these errors are minimized by horizontal calibration of the Profilograph and the scanner of the ProScan system. Calibration checks were done in this study.

In view of the above factors, it becomes inappropriate to ask which particular method, i.e., manual, ProScan, or even computerized Profilograph, is correct. The result, however, may significantly affect the outcome of the acceptance testing so that a protocol needs to be established to deal with the case discussed above. For example, given two adjacent segments, one rough and one smooth, how much a contractor gets paid or penalized may depend on whether the bump gets assigned to the rough or the smooth segment during the data reduction.

## COMPARISON OF MANUAL VERSUS PROSCAN DEFECT STATIONS

The research team created line graphs to evaluate ProScan's ability to locate defects (i.e., bumps and dips) within the segment surveyed. They compared the means of the defect stations calculated from the 5 ProScan runs with those identified by the raters. Initially, the defect stations from the various runs were compared to establish the repeatability of the system. This evaluation showed that the system is very consistent in identifying defects as reflected in Figures 6 and 7 which show the locations of bumps and dips, respectively, from each run of ProScan. In general, every run identified the same defects. In view of this consistency, researchers decided to compare the means of the ProScan defect stations with the defects identified by the raters. The reported defect stations from the ProScan system and the evaluators are tabulated in Appendix A.

Figure 8 compares the mean bump stations from ProScan with the bump stations identified by the individual evaluators. Similarly, Figure 9 compares the dip stations. In these charts, the ProScan system is referred to as evaluator number zero. Examination of Figures 8 and 9 shows that ProScan generally detected the same defects that were found by the evaluators. As expected, there was relatively more variability in the defect stations identified by the different raters (Figures 8 and 9) than in the defects detected between repeat runs of ProScan (Figures 6 and 7). Again, this is attributed to the subjectivity inherent in the manual evaluation.

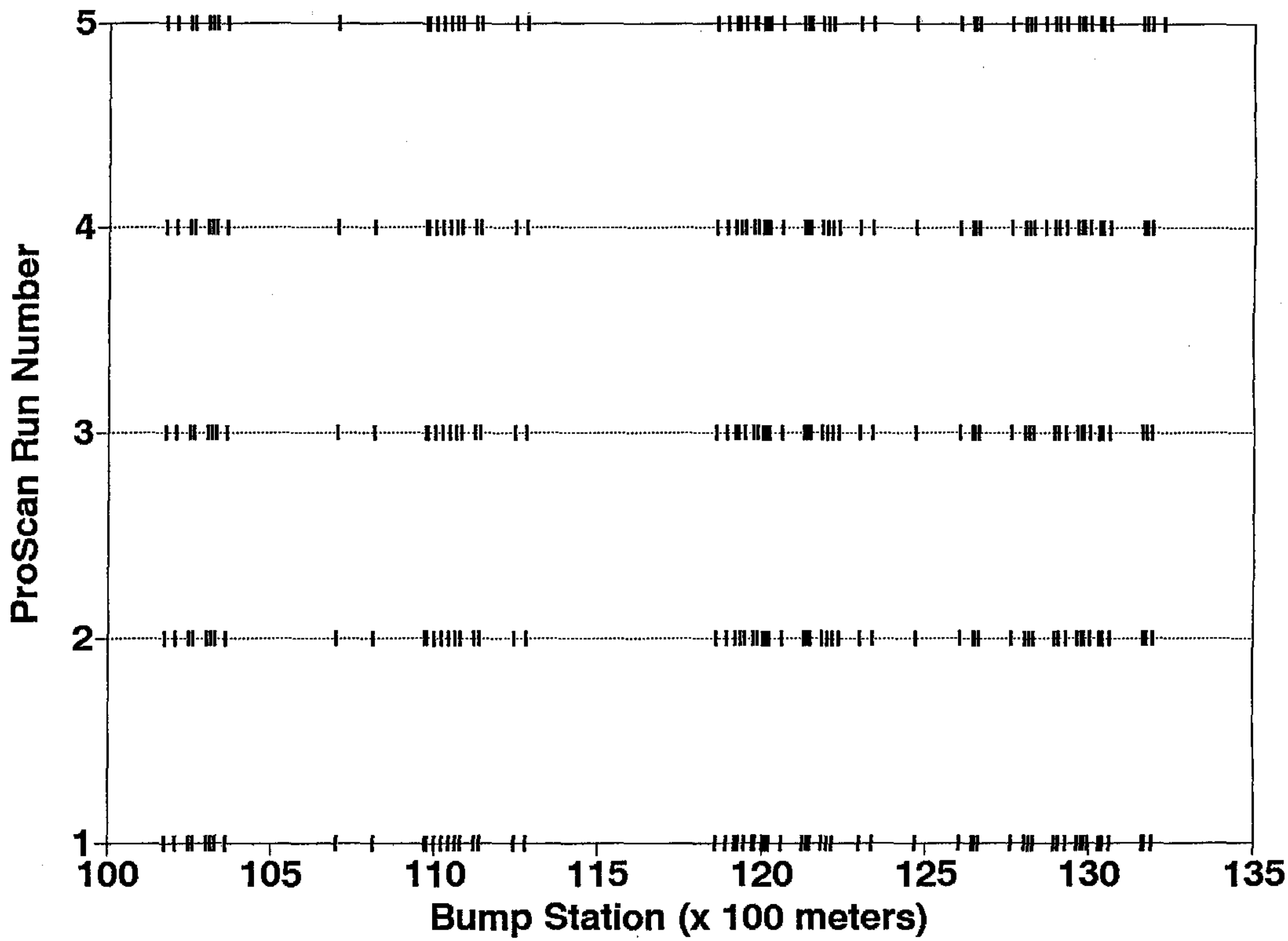



Figure 6. Comparison of bump stations from repeat runs of ProScan.

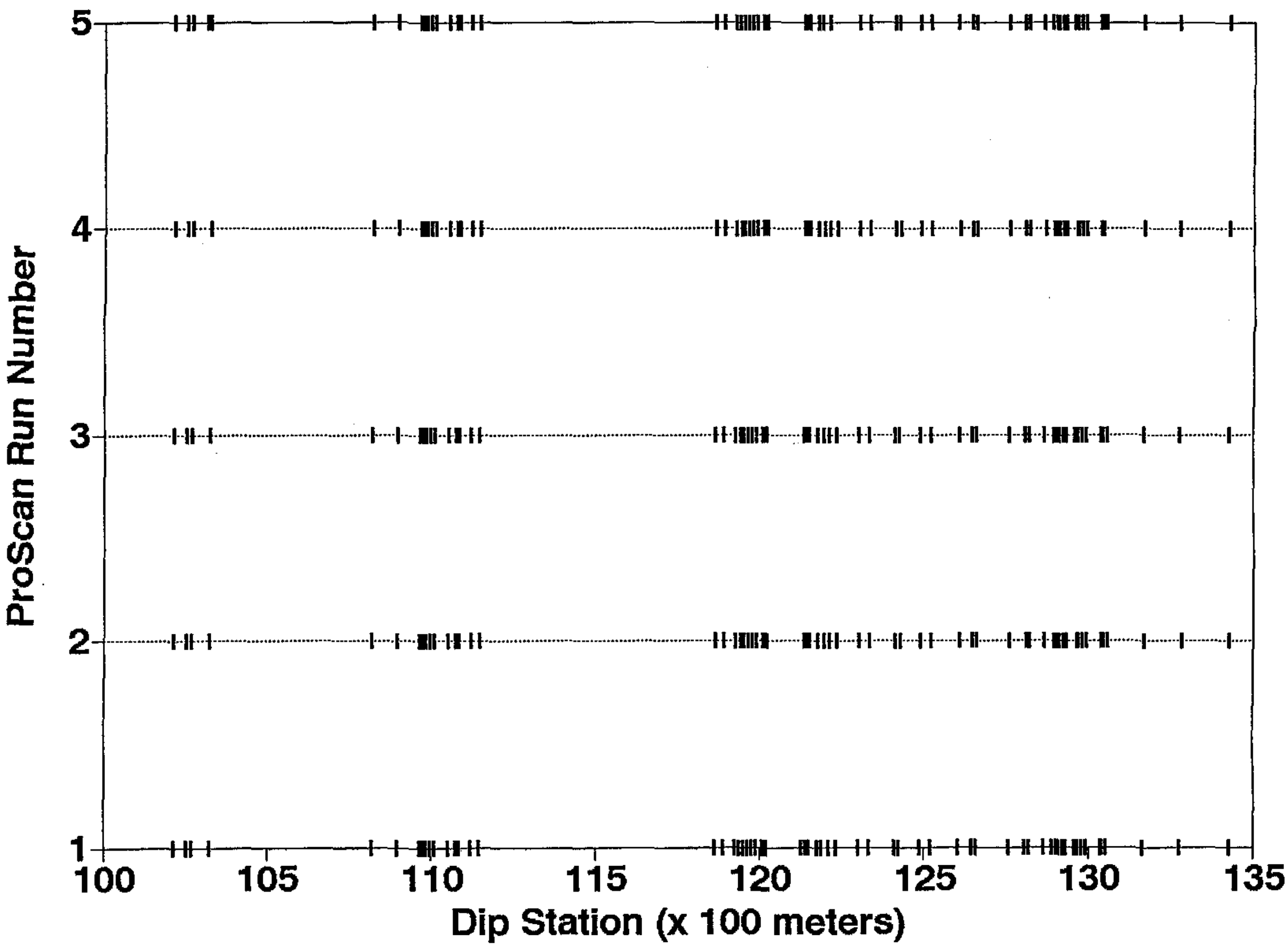



Figure 7. Comparison of dip stations from repeat runs of ProScan.

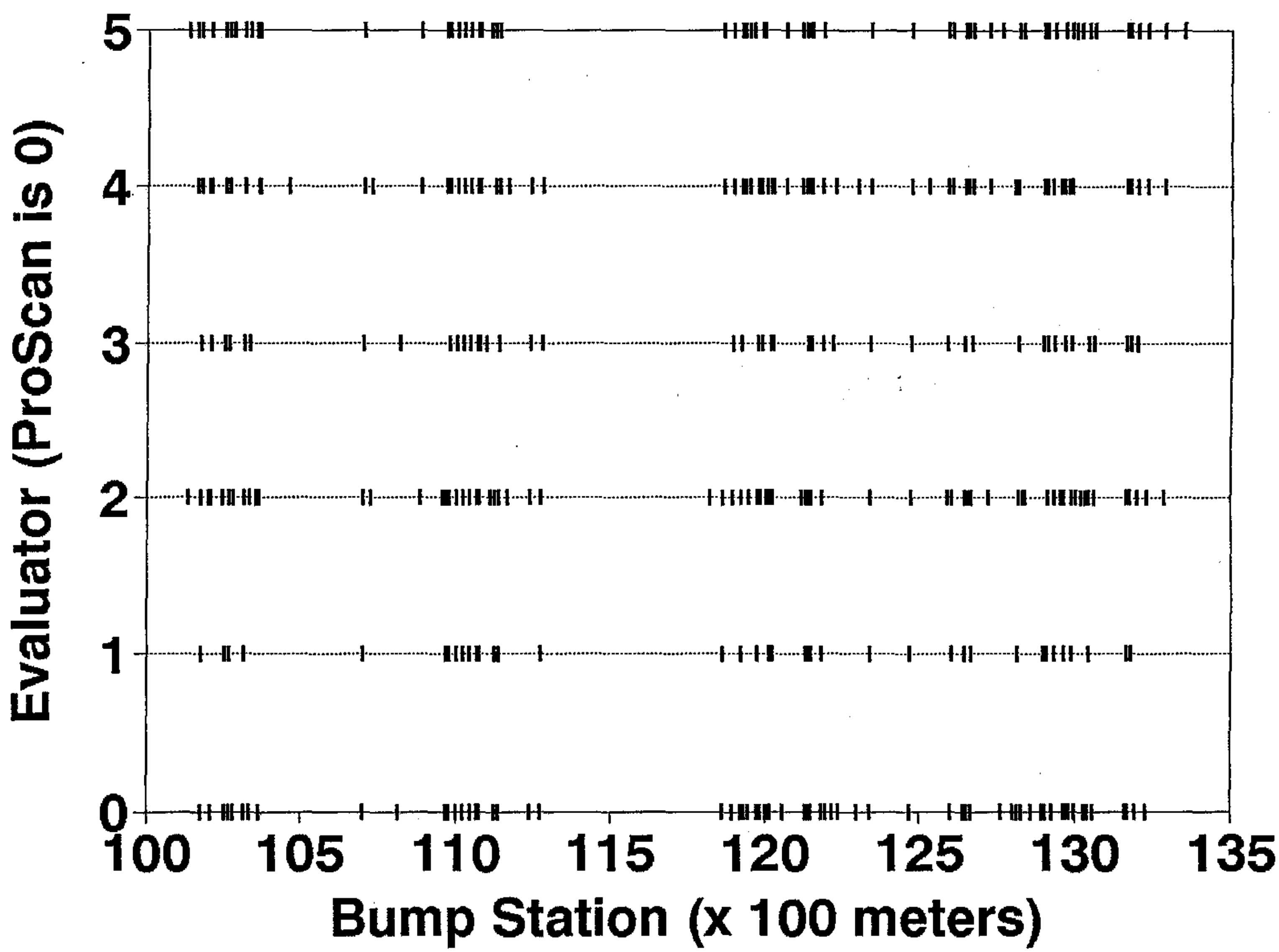



Figure 8. Comparison of bump stations from ProScan and panel of evaluators.

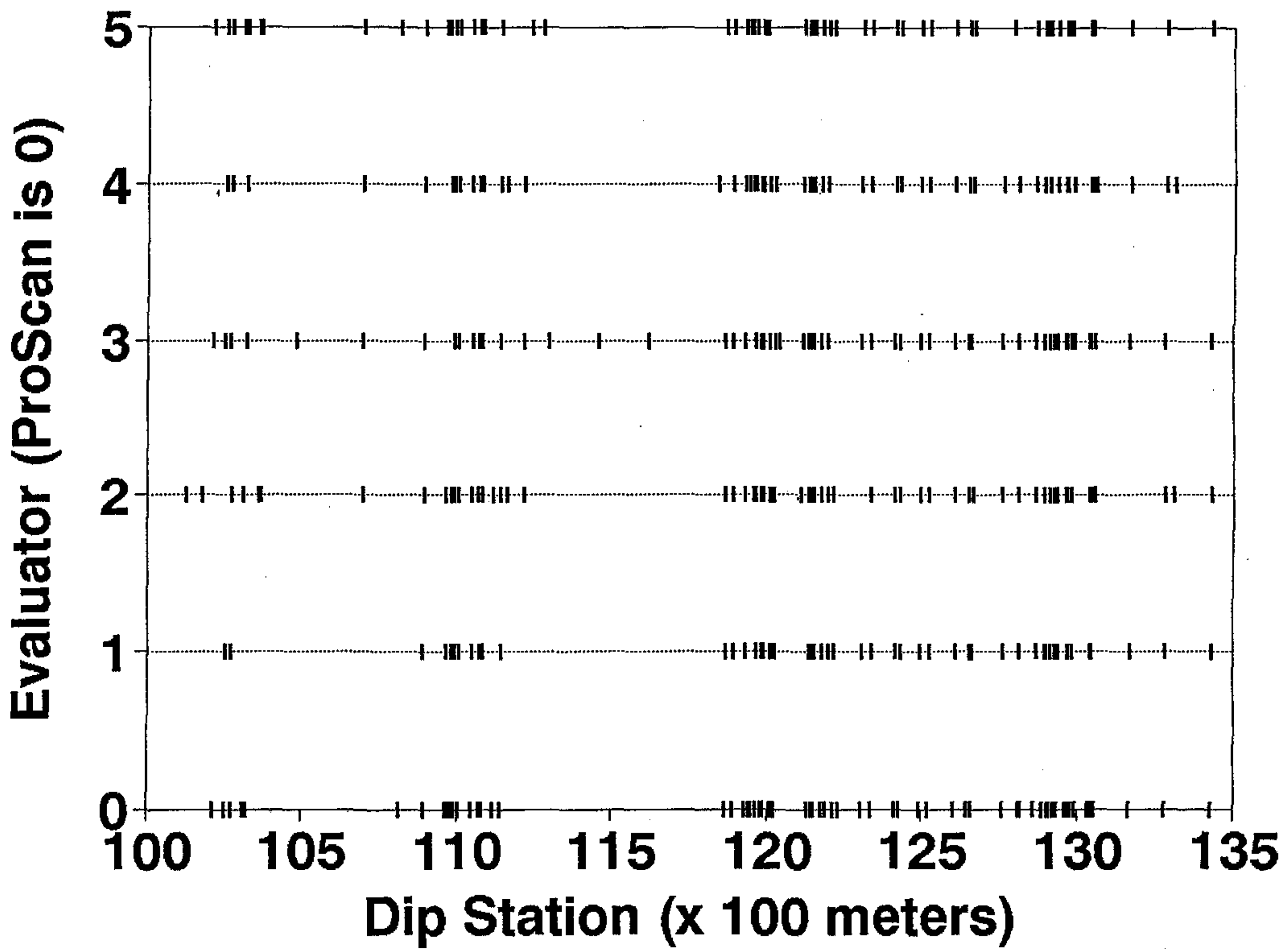



Figure 9. Comparison of dip stations from ProScan and panel of evaluators.

# CHAPTER 3. SUMMARY OF FINDINGS

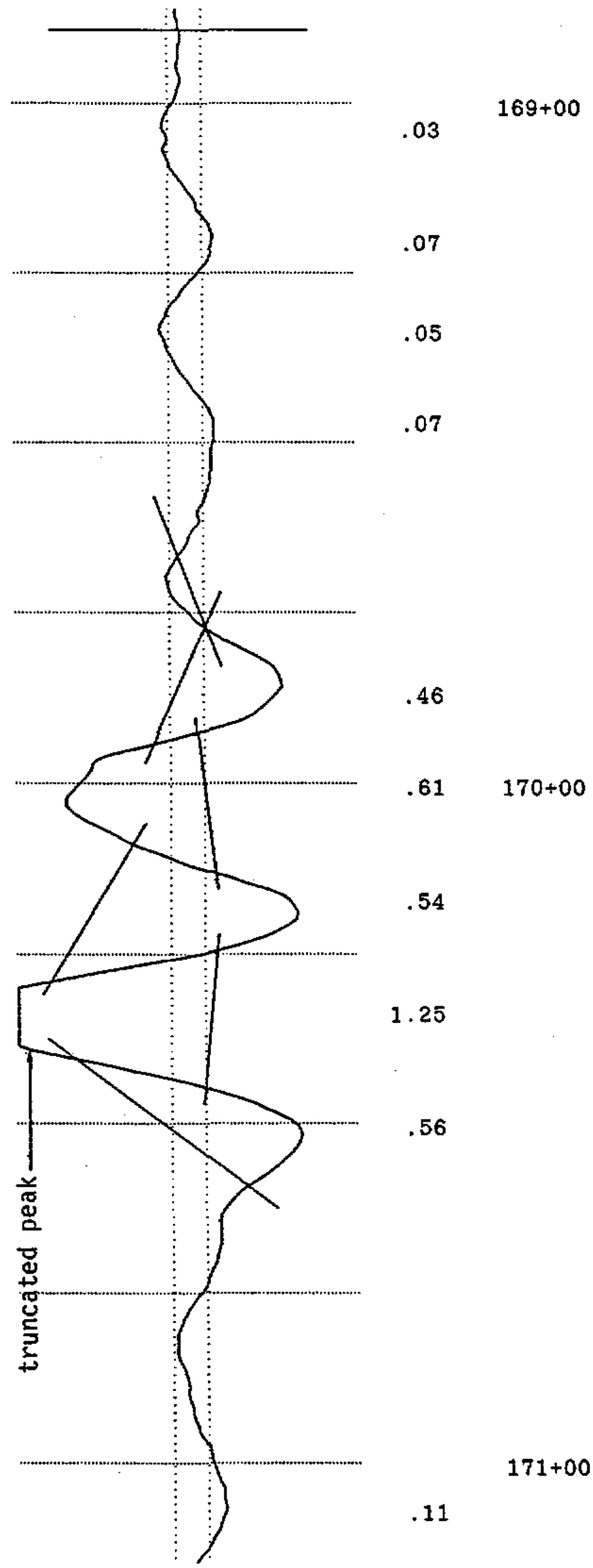
This study made evident the potential for realizing substantial time savings using ProScan. To cite a specific experience, the average time required to manually reduce the State Highway 6 data (Profilogram #2), was approximately 4 hours. Using ProScan, data reduction per run took only 10 minutes, 1/24th of the average time required for manual reduction. Considering that in actual practice the profilograph trace per wheelpath must be reduced to determine the average PI for each 0.16-km (0.1-mile) segment, an automated system for processing Profilograph data is needed so that the contractor can keep up with the daily production rate. In view of the favorable results obtained from this investigation, it is concluded that the ProScan system can satisfy this need. Specifically, comparisons between the system and the manual method of data reduction have shown that:

1. A strong, positive, linear relationship exists between the manual and ProScan PI's for both profilograms considered in this evaluation. This is reflected in the high coefficients of determination, $R^2$, and in the intercepts and slopes of the regression equations determined between the manual and ProScan ratings for both profilograms reduced in this investigation;
2. Differences between the manual and ProScan PI's are not statistically significant;
3. Based on the average standard deviation, the variability in the PI's determined manually is approximately 10 times higher than the variability in the ratings from repeat runs of the ProScan system. This finding reflects the subjectivity in the manual interpretation of Profilograph traces which can be eliminated if an automated procedure, such as ProScan is used;
4. In general, the defect stations reported by ProScan are consistent with those identified by the evaluators. There was relatively more variability in the defect stations identified by the different raters than in the defects detected between repeat runs of ProScan. Again, this is attributed to the subjectivity inherent in the manual method of data reduction.

# CHAPTER 4. OPERATIONAL EXPERIENCE WITH PROSCAN

In general, ProScan is easy to use. However, a discussion of the experience gained in evaluating this device is useful to point out certain operational guidelines and identify areas where the system can be improved. One important guideline for an operator to follow is to observe the monitor during the scanning process to check that the trace is being scanned properly. The importance of this guideline was demonstrated during this evaluation. In one instance, the scanner picked up a mark used to denote a bump in the profilogram being evaluated. This mark was left inadvertently from the manual data reduction that was conducted prior to the automated processing with the ProScan system. The result was a PI significantly different from the corresponding manual rating. The trace was subsequently re-scanned with the extraneous mark removed and a more comparable PI was determined.

A printout of the scanned trace for any segment can be obtained which allows the operator to check if the trace was scanned properly even after completion of the data processing. However, during the course of this evaluation, researchers discovered that the printout of the scanned trace is limited to within a certain print area, and that features of the trace will not be printed if such features lie outside this area. This is best explained by referring to Figure 10, which shows the printout of the scanned trace for Segment 14 of Profilogram #2, along with other output data. As may be observed, one of the scallops in the middle of the figure has its peak truncated, suggesting that the scallop may not have been scanned completely. However, after closer scrutiny, it was found that the height of the scallop above the blanking band, as measured from the Profilograph trace, is consistent with the height measured by ProScan - 31.75 mm (1.25 in), in Figure 10. This means that the scallop in question was scanned completely and that there was some other reason why the peak was truncated. This was later determined to be due to the limitation in the




```
PROSCAN - PROFILOGRAM SCANNING SYSTEM
VERSION V3.00 - DEVORE SYSTEMS, INC.

File RUN1
Track 1 Segment 14

Station  168+89.0 to  174+17.0
Segment length 21.12in (528ft, .100mi)

Up is to the left

Scallop (Filter 15)
  minimum height              .025  in
  minimum width (300:1)       .08   in
  resolution                  .01   in
Blanking band                 .20   in
Defect template height        .30   in
Defect template depth        -.30   in

Profile Roughness Index  58.0 in/mi
Defect at    169+72.0 Bump
             169+86.0 Dip
             170+03.0 Bump
             170+20.0 Dip
             170+34.0 Bump
             170+49.5 Dip
             171+32.0 Dip
             171+44.5 Bump
             171+84.5 Dip
             172+02.5 Bump
             172+49.0 Dip
             172+65.5 Bump
             173+15.5 Dip
```

Figure 10. Partial printout of scanned trace for segment 14 showing truncated peak at station 170 + 34.

print area allotted to the scanned trace. Based on this experience, a modification in the format of the output, to show the scanned trace completely, is highly desirable. One alternative is to print the scanned trace in the middle of the paper, and to move the information on output file name, segment number, wheelpath tracked, segment endpoints, computed PI, ProScan parameter settings, and defect locations ahead or after the printout of the scanned trace. In this way, the print area for the trace is maximized.

Another lesson learned during this evaluation is that care should be taken in handling the profilogram. If the roll gets crumpled, the creases that form can be detected as dark bands which will cause the software to terminate prematurely. This is because ProScan uses a line drawn across the profilogram to identify the endpoints of a segment to be processed. These markers appear as dark bands in the computer display of the scanned data. The creases may be detected as dark areas causing the scanning to terminate. If this occurs, one remedy suggested by the system developer is to cover the creases with translucent plastic tape, such as magic tape.

The system hardware could also be improved by the addition of a profilogram take-up spool. From the experience gained in this evaluation, it was difficult for one person to roll up the profilogram as it moves past the scanner and into the back of the paper transport unit, and at the same time to observe the computer display, as suggested in the user's guide. The guide recognizes that this task requires fairly undivided attention due to the speed with which the scanned data rolls up the screen. However, if one lets the profilogram pile up at the back of the paper transport unit, the roll may jam, as occurred in one instance during this evaluation. This resulted in the profilogram getting crumpled which led to problems in scanning described previously.

However, based on communications with the system developer, researchers found that the addition of a take-up spool will significantly add to the cost of the unit. Since this recommendation was based on the need to prevent jamming of the profilogram during the scanning operation, a number of other options were identified to prevent this from happening. One way is to simply provide sufficient space at the back of the paper transport unit (PTU). In a videotaped demonstration, the system developer showed that the McCracken paper will stack up at the back of the PTU without jamming and user intervention. In this demonstration, about 4.8 km (3 miles) of profilograph data were scanned. The profilogram was simply allowed to stack up behind the PTU and in front of a book end, which was placed about 0.7 meters from the PTU. Alternatively, with the PTU on top of a desk or table, the operator may simply allow the profilogram to roll onto the floor. After scanning, the profilogram may be rolled back by first removing the scanner and then turning the knob of the McCracken paper dispenser located in front of the PTU.

The operator may also have to adjust the scanner contrast setting so that the trace appears dark and the background completely white on the computer display. This helps to ensure that software tracks the trace properly. During this study, researchers found the mid-setting of the contrast to be the most appropriate. They found that if the contrast was set towards one of the extreme settings, the software failed to track the trace because it appeared faint to the scanner (i.e., setting was too light), or extraneous data get scanned that appear as dark bands causing the software to terminate prematurely (i.e., setting was too dark). It is recognized that the mid-setting may not be the best for all cases. For example, if the Profilograph trace itself is light, then the contrast may have to be adjusted towards the dark setting. The operator can initially experiment with different settings to establish the range within which the ProScan unit should be operated. This is easy to do and will not take much time.

In addition to the scanner contrast setting, the operator should check the ProScan configuration file to verify that data reduction parameters are set at values consistent with the specifications in a given state. The parameter settings for any given run are printed as part of the ProScan report. Thus, for this evaluation, researchers set the segment length to 0.16-km (0.1 mile), the width of the blanking band to 5 mm (0.2 in), the template height (for detecting bumps and dips) to 7.6 mm (0.30 in), and the minimum scallop width to 2 mm (0.08 in). These settings are consistent with the specifications established by TxDOT for reduction of profilograms as embodied in Test Method Tex-1000-S (February 1994 version).

The minimum scallop height is another parameter in the ProScan configuration file. Under the February 1992 version of Test Method Tex-1000-S, the appropriate setting for this variable was 0.8 mm (0.03 in). Specifically, the procedure stated that:

*"Short scallops less than 0.03 inch high shall not be counted unless they are greater than two feet long on the roadway (0.08 inch on the profilogram)."*

However, no reference to a minimum scallop height is found in the February 1994 version of the test method. Consequently, in the evaluation performed herein, the effect of this parameter on the computed PI's was initially evaluated. The minimum scallop height was varied from 0.6 to 0.9 mm (0.025 to 0.035 in), with the other parameters held at their appropriate settings. It was found that the parameter has negligible effect on the computed PI's for the range that it was varied. In view of this finding, the minimum scallop height was set to 0.6 mm (0.025 in), corresponding to the lower limit of the range used in evaluating its effect. This finding was also brought up with the system developer who suggested that the effect of the parameter is perhaps influenced by the blanking band used. In Kansas, where a blanking band width of zero is used, the minimum scallop height may show a greater effect than was observed in this evaluation.

Still another parameter, which is perhaps one of the most important in terms of influencing the results, is the filter length. Based on communications with the system developer, researchers used the recommended filter length of 15 in this evaluation. This quantity represents the number of samples used in calculating a moving average, with all samples weighted equally. It defines the window of the moving average filter built into the software. According to the system developer, a variety of filters were evaluated during the development of ProScan, including Butterworth and Chebyshev low-pass filters. Based on comparisons of the filtered data with corresponding profilograms, a simple two-sided moving average filter was found as best duplicating the process of tracing through a profilogram during the preliminary stage of data reduction. A recommended filter length of 15 samples was established after testing a variety of window sizes. The filter study conducted is summarized in a report by Devore and Hossain (4) which also documents the ProScan development effort.

# CHAPTER 5. RECOMMENDATIONS

Based on the findings noted previously, it is evident that the ProScan system provides an accurate and consistent simulation of the manual method of data reduction. It will significantly reduce the time it takes to process data from manual Profilographs as well as eliminate the subjectivity inherent in the manual method, resulting in less variability in the computed PI's and defect stations. Considering the upcoming implementation of TxDOT's QC/QA specifications on all projects beginning with the 1995 construction season, there will be a greater need by contractors and TxDOT engineers alike for an automated system of processing traces from manual Profilographs. Therefore, this study recommends that TxDOT accept the ProScan system as an alternative to the manual method of data reduction. A pilot implementation on a number of selected construction projects is warranted to identify and address implementation issues related to data reporting procedures and training of contractor and agency personnel.

A standard TxDOT report form should be included in the library of state highway agency forms that come with the system so that a completed report can immediately be printed after data processing. Consideration should also be given to interfacing the output from ProScan with a computer program to calculate the pay factors automatically. Issues related to data security, such as preventing data tampering and minimizing fraud, should also be identified and addressed. TTI will assist in this pilot implementation if requested by TxDOT.

Additional areas for improving the system were identified as a result of this evaluation. These were explained previously and are simply noted below:

1. Addition of a profilogram take-up spool; and
2. Modification of the output format to maximize the print area allotted to the scanned trace.

Finally, a protocol for dealing with defects located very close to the boundary between two adjacent segments must be established and included in Test Method Tex-1000-S. This recommendation has nothing to do with the performance of ProScan, but the need for this protocol was demonstrated in this evaluation.

# REFERENCES


1. Test Method Tex-1000-S, "Operation of Pavement Profilograph and Evaluation of Profiles," Manual of Testing Procedures, Vol. 3, Texas Department of Transportation, Austin, Texas, 1994.
2. Clark, C. T., and L. L. Schkade, "Statistical Analysis for Administrative Decisions," South-Western Publishing Company, Cincinnati, Ohio, 1979.
3. Kulakowski, B. T., and J. C. Wambold, "Development of Procedures for the Calibration of Profilographs," Report No. FHWA-RD-89-110, The Pennsylvania Transportation Institute, The Pennsylvania State University, University Park, Pennsylvania, 1989.
4. Devore, J. J., and M. Hossain, "An Automated System for Determination of Pavement Profile Index and Location of Bumps for Grinding from the Profilograph Traces," Report No. K-TRAN: KSU-93-2, Kansas State University, Manhattan, Kansas, May 1994.

## APPENDIX: TABLES OF REPORTED DEFECT STATIONS

Table A.1 Bump Locations Identified Using ProScan[1].

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 2 | 101.76 | 101.76 | 101.76 | 101.76 | 101.76 |
| 2 | 102.09 | 102.09 | 102.09 | 102.09 | 102.09 |
| 2 | 102.49 | 102.49 | 102.49 | 102.49 | 102.49 |
| 2 | 102.64 | 102.64 | 102.64 | 102.64 | 102.64 |
| 2 | 103.05 | 103.05 | 103.05 | 103.05 | 103.05 |
| 2 | 103.18 | 103.18 | 103.18 | 103.18 | 103.18 |
| 3 | 103.30 | 103.30 | 103.30 | 103.30 | 103.30 |
| 3 | 103.64 | 103.64 | 103.64 | 103.64 | 103.64 |
| 5 | 107.00 | 107.00 | 107.00 | 107.00 | 107.00 |
| 6 | 108.13 | 108.13 | 108.13 | 108.13 | |
| 6 | 109.69 | 109.69 | 109.69 | 109.69 | 109.69 |
| 7 | 109.77 | 109.77 | 109.77 | 109.77 | 109.77 |
| 7 | 110.01 | 110.02 | 110.02 | 110.02 | 110.01 |
| 7 | 110.23 | 110.23 | 110.23 | 110.23 | 110.23 |
| 7 | 110.45 | 110.45 | 110.45 | 110.45 | 110.45 |
| 7 | 110.66 | 110.66 | 110.66 | 110.66 | 110.66 |
| 7 | 110.77 | 110.77 | 110.77 | 110.77 | 110.77 |
| 7 | 111.23 | 111.23 | 111.23 | 111.23 | 111.23 |
| 8 | 111.39 | 111.39 | 111.39 | 111.39 | 111.39 |
| 8 | 112.41 | 112.42 | 112.42 | 112.42 | 112.41 |
| 8 | 112.76 | 112.76 | 112.76 | 112.76 | 112.76 |
| 12 | 118.60 | 118.61 | 118.60 | 118.60 | 118.60 |
| 12 | 118.93 | 118.93 | 118.93 | 118.93 | 118.93 |
| 12 | 119.20 | 119.21 | 119.20 | 119.21 | 119.20 |
| 12 | 119.30 | 119.30 | 119.30 | 119.30 | 119.30 |

[1] Locations given are in hundred meters.

Table A.1 Bump Locations Identified Using ProScan (continued).

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 13 | 119.43 | 119.44 | 119.43 | 119.45 | 119.43 |
| 13 | 119.71 | 119.72 | 119.72 | 119.72 | 119.72 |
| 13 | 119.82 | 119.82 | 119.82 | 119.82 | 119.82 |
| 13 | 120.02 | 120.03 | 120.02 | 120.02 | 120.02 |
| 13 | 120.10 | 120.10 | 120.10 | 120.10 | 120.10 |
| 13 | 120.17 | 120.17 | 120.17 | 120.17 | 120.17 |
| 13 | 120.58 | 120.59 | 120.58 | 120.58 | 120.58 |
| 14 | 121.25 | 121.26 | 121.25 | 121.25 | 121.25 |
| 14 | 121.35 | 121.35 | 121.35 | 121.35 | 121.35 |
| 14 | 121.44 | 121.45 | 121.44 | 121.45 | 121.44 |
| 14 | 121.78 | 121.78 | 121.78 | 121.78 | 121.78 |
| 14 | 121.95 | 121.96 | 121.95 | 121.95 | 121.95 |
| 14 | 122.15 | 122.15 | 122.15 | 122.15 | 122.15 |
| 14 | | 122.34 | 122.33 | 122.33 | |
| 15 | 122.97 | 122.97 | 122.97 | 122.97 | 122.97 |
| 15 | 123.37 | 123.38 | 123.37 | 123.37 | 123.37 |
| 16 | 124.64 | 124.65 | 124.65 | 124.65 | 124.64 |
| 17 | 125.98 | 125.99 | 125.98 | 125.98 | 125.98 |
| 17 | 126.41 | 126.42 | 126.41 | 126.41 | 126.41 |
| 17 | 126.49 | 126.50 | 126.49 | 126.49 | 126.49 |
| 17 | 126.61 | 126.62 | 126.61 | 126.61 | 126.61 |

Table A.1 Bump Locations Identified Using ProScan (continued).

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 18 | 127.59 | 127.59 | 127.58 | 127.59 | 127.58 |
| 18 | 128.01 | 128.01 | 128.00 | 128.01 | 128.00 |
| 18 | 128.11 | 128.11 | 128.11 | 128.11 | 128.11 |
| 18 | 128.27 | 128.28 | 128.27 | 128.27 | 128.27 |
| 18 | | | | 128.60 | 128.59 |
| 18 | 128.92 | 128.93 | 128.92 | 128.92 | 128.92 |
| 18 | 129.03 | 129.04 | 129.04 | 129.04 | 129.04 |
| 19 | 129.25 | 129.25 | 129.25 | 129.25 | 129.25 |
| 19 | 129.61 | 129.62 | 129.61 | 129.61 | 129.61 |
| 19 | 129.73 | 129.74 | 129.73 | 129.73 | 129.73 |
| 19 | 129.81 | 129.82 | 129.81 | 129.82 | 129.81 |
| 19 | 129.97 | 129.98 | 129.97 | 129.97 | 129.97 |
| 19 | 130.30 | 130.31 | 130.31 | 130.31 | 130.30 |
| 19 | 130.37 | 130.38 | 130.37 | 130.38 | 130.37 |
| 19 | 130.58 | 130.59 | 130.58 | 130.58 | 130.58 |
| 20 | 131.61 | 131.62 | 131.62 | 131.62 | 131.61 |
| 20 | 131.70 | 131.71 | 131.71 | 131.71 | 131.71 |
| 20 | 131.91 | 131.92 | 131.92 | 131.92 | 131.91 |
| 20 | | | | | 132.27 |

Table A.2 Dip Locations Identified Using ProScan[1].

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 2 | 102.13 | 102.13 | 102.13 | 102.13 | 102.13 |
| 2 | 102.53 | 102.54 | 102.53 | 102.53 | 102.53 |
| 2 | 102.72 | 102.72 | 102.72 | 102.72 | 102.72 |
| 2 | | | | | 103.14 |
| 3 | 103.22 | 103.22 | 103.22 | 103.22 | 103.22 |
| 6 | 108.16 | 108.16 | 108.16 | 108.16 | 108.16 |
| 6 | 108.95 | 108.95 | 108.95 | 108.95 | 108.95 |
| 6 | 109.65 | 109.65 | 109.65 | 109.65 | 109.65 |
| 6 | 109.73 | 109.73 | 109.73 | 109.73 | 109.73 |
| 7 | 109.83 | 109.83 | 109.83 | 109.83 | 109.83 |
| 7 | 109.94 | 109.94 | 109.94 | 109.94 | 109.94 |
| 7 | 110.06 | 110.06 | 110.06 | 110.06 | 110.06 |
| 7 | 110.50 | 110.50 | 110.50 | 110.50 | 110.50 |
| 7 | 110.71 | 110.71 | 110.71 | 110.71 | 110.71 |
| 7 | 110.82 | 110.82 | 110.82 | 110.82 | 110.82 |
| 7 | 111.19 | 111.19 | 111.18 | 111.18 | 111.19 |
| 8 | 111.43 | 111.43 | 111.43 | 111.43 | 111.43 |
| 12 | 118.63 | 118.64 | 118.64 | 118.64 | 118.64 |
| 12 | 118.88 | 118.89 | 118.88 | 118.88 | 118.88 |
| 12 | 119.24 | 119.24 | 119.24 | 119.24 | 119.24 |
| 12 | 119.39 | 119.39 | 119.39 | 119.39 | 119.39 |
| 13 | 119.51 | 119.52 | 119.51 | 119.52 | 119.51 |
| 13 | 119.64 | 119.64 | 119.64 | 119.64 | 119.64 |
| 13 | 119.76 | 119.76 | 119.76 | 119.76 | 119.76 |
| 13 | 119.87 | 119.88 | 119.87 | 119.87 | 119.87 |
| 13 | 120.06 | 120.07 | 120.06 | 120.07 | 120.06 |
| 13 | 120.13 | 120.14 | 120.14 | 120.14 | 120.14 |
| 13 | 120.20 | 120.21 | 120.20 | 120.20 | 120.20 |

[1] Locations given are in hundred meters.

Table A.2 Dip Locations Identified Using ProScan (continued).

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 14 | 121.29 | 121.30 | 121.30 | 121.30 | 121.30 |
| 14 | 121.40 | 121.40 | 121.40 | 121.40 | 121.40 |
| 14 | 121.49 | 121.49 | 121.49 | 121.49 | 121.49 |
| 14 | 121.74 | 121.74 | 121.74 | 121.74 | 121.74 |
| 14 | 121.90 | 121.91 | 121.90 | 121.90 | 121.90 |
| 14 | 122.10 | 122.10 | 122.10 | 122.10 | 122.10 |
| 14 | 122.30 | 122.32 | 122.32 | 122.32 | |
| 15 | 123.00 | 123.02 | 123.02 | 123.02 | 123.00 |
| 15 | 123.33 | 123.33 | 123.33 | 123.33 | 123.33 |
| 15 | 124.08 | 124.09 | 124.08 | 124.08 | 124.08 |
| 16 | 124.24 | 124.25 | 124.24 | 124.25 | 124.24 |
| 16 | 124.88 | 124.89 | 124.88 | 124.89 | 124.88 |
| 16 | 125.17 | 125.18 | 125.18 | 125.18 | 125.18 |
| 17 | 126.02 | 126.03 | 126.02 | 126.02 | 126.02 |
| 17 | 126.44 | 126.45 | 126.45 | 126.45 | 126.44 |
| 17 | 126.57 | 126.58 | 126.57 | 126.57 | 126.57 |
| 18 | 127.55 | 127.56 | 127.55 | 127.55 | 127.55 |
| 18 | 128.05 | 128.06 | 128.06 | 128.06 | 128.06 |
| 18 | 128.18 | 128.18 | 128.18 | 128.18 | 128.18 |
| 18 | 128.61 | 128.62 | 128.62 | 128.63 | 128.61 |
| 18 | 128.88 | 128.89 | 128.89 | 128.89 | 128.88 |
| 18 | 129.00 | 129.01 | 129.00 | 129.01 | 129.00 |

Table A.2 Dip Locations Identified Using ProScan (continued).

| Segment | Run Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 19 | 129.07 | 129.09 | 129.07 | 129.08 | 129.07 |
| 19 | 129.19 | 129.20 | 129.20 | 129.20 | 129.20 |
| 19 | 129.30 | 129.31 | 129.31 | 129.31 | 129.31 |
| 19 | 129.57 | 129.58 | 129.57 | 129.58 | 129.58 |
| 19 | 129.65 | 129.66 | 129.65 | 129.66 | 129.65 |
| 19 | 129.77 | 129.78 | 129.77 | 129.78 | 129.77 |
| 19 | 129.89 | 129.90 | 129.89 | 129.89 | 129.89 |
| 19 | 130.34 | 130.35 | 130.34 | 130.34 | 130.34 |
| 19 | 130.40 | 130.41 | 130.40 | 130.41 | 130.40 |
| 19 | 130.53 | 130.54 | 130.53 | | 130.53 |
| 20 | 131.66 | 131.67 | 131.66 | 131.67 | 131.66 |
| 21 | 132.78 | 132.79 | 132.78 | 132.79 | 132.78 |
| 22 | 134.27 | 134.28 | 134.27 | 134.28 | 134.27 |

Table A.3 Bump Locations Identified by Different Evaluators[1].

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | | 101.36 | | | 101.35 |
| 2 | | | | 101.61 | 101.61 |
| 2 | 101.76 | 101.76 | 101.76 | 101.76 | 101.76 |
| 2 | | 101.98 | | 102.01 | |
| 2 | | 102.09 | 102.09 | 102.09 | 102.09 |
| 2 | 102.49 | 102.48 | 102.49 | 102.50 | 102.49 |
| 2 | 102.63 | 102.63 | 102.64 | 102.64 | 102.64 |
| 2 | | 102.79 | | | 102.78 |
| 2 | 103.17 | 103.18 | 103.18 | 103.19 | 103.18 |
| 3 | | 103.29 | 103.31 | | 103.30 |
| 3 | | 103.56 | | 103.57 | 103.53 |
| 3 | | 103.64 | | 103.65 | 103.64 |
| 3 | | | | 104.56 | |
| 5 | 107.01 | 107.00 | 107.01 | 107.01 | 107.01 |
| 5 | | 107.24 | | 102.21 | |
| 6 | | | 108.17 | | |
| 6 | | 108.83 | | 108.83 | 108.83 |
| 6 | | 109.59 | | | |
| 6 | 109.69 | 109.68 | . | 109.69 | 109.68 |
| 7 | 109.77 | 109.77 | 109.78 | 109.77 | 109.77 |
| 7 | 110.01 | 110.01 | 110.02 | 110.02 | 110.01 |
| 7 | 110.23 | 110.24 | 110.24 | 110.23 | 110.23 |
| 7 | 110.45 | 110.45 | 110.45 | 110.45 | 110.45 |
| 7 | 110.66 | 110.65 | 110.67 | 110.66 | 110.66 |
| 7 | 110.77 | 110.77 | 110.78 | 110.76 | 110.77 |
| 7 | | | 110.97 | | |
| 7 | | 111.08 | | | 111.08 |
| 7 | 111.23 | 111.23 | | 111.23 | 111.23 |

[1] Locations given are in hundred meters.

Table A.3 Bump Locations Identified by Different Evaluators (continued).

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 8 | 111.39 | 111.39 | 111.39 | 111.39 | 111.39 |
| 8 | | 111.65 | | 111.66 | |
| 8 | | 112.41 | 112.43 | 112.42 | |
| 8 | 112.73 | 112.74 | 112.77 | 112.77 | |
| 12 | | 118.18 | | | |
| 12 | 118.61 | 118.61 | | 118.61 | 118.62 |
| 12 | | 118.94 | 118.95 | 118.95 | 118.95 |
| 12 | 119.22 | 119.21 | 119.22 | 119.21 | 119.22 |
| 12 | | | | 119.33 | 119.32 |
| 13 | | 119.46 | | 119.46 | 119.47 |
| 13 | | | | | 119.57 |
| 13 | 119.73 | 119.73 | 119.74 | 119.71 | |
| 13 | | 119.84 | 119.85 | 119.84 | 119.86 |
| 13 | | | | | 119.92 |
| 13 | | 120.03 | | 120.03 | |
| 13 | 120.12 | 120.13 | 120.13 | 120.13 | |
| 13 | 120.18 | 120.19 | 120.20 | 120.18 | |
| 13 | | | | 120.60 | 120.60 |
| 14 | | 121.16 | | 121.15 | 121.16 |
| 14 | 121.28 | 121.29 | | 121.26 | 121.28 |
| 14 | 121.37 | 121.36 | 121.38 | 121.37 | 121.37 |
| 14 | 121.46 | 121.47 | 121.48 | 121.47 | 121.47 |
| 14 | 121.81 | 121.81 | 121.83 | 121.81 | 121.82 |
| 14 | | | 122.19 | 122.20 | |
| 15 | | | | 122.98 | |
| 15 | 123.39 | 123.40 | 123.41 | 123.40 | 123.41 |
| 16 | 124.67 | 124.68 | 124.69 | 124.68 | 124.69 |
| 16 | | | | 125.27 | |

Table A.3 Bump Locations Identified by Different Evaluators (continued).

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 17 | | 125.87 | 125.87 | 125.86 | 125.87 |
| 17 | 126.01 | 126.02 | | 126.01 | 126.02 |
| 17 | 126.44 | 126.44 | 126.46 | 126.44 | 126.45 |
| 17 | | 126.53 | | 126.53 | 126.53 |
| 17 | 126.64 | 126.64 | 126.66 | 126.66 | 126.65 |
| 17 | | 127.20 | | 127.21 | 127.21 |
| 18 | | | | | 127.62 |
| 18 | | | | 128.04 | |
| 18 | 128.15 | 128.16 | 128.16 | 128.15 | 128.15 |
| 18 | | 128.32 | | | 128.32 |
| 18 | | 128.37 | | | |
| 18 | 128.96 | | 128.98 | 128.97 | 128.97 |
| 19 | 129.07 | 129.09 | 129.09 | 129.07 | 129.08 |
| 19 | 129.29 | 129.28 | 129.30 | 129.27 | 129.30 |
| 19 | | 129.53 | | 129.53 | |
| 19 | 129.65 | 129.64 | 129.67 | 129.65 | 129.67 |
| 19 | | | | 129.75 | |
| 19 | 129.86 | 129.86 | 129.88 | 129.87 | 129.87 |
| 19 | | 130.01 | | | 130.02 |
| 19 | | 130.17 | | | 130.19 |
| 19 | | 130.34 | | | |
| 19 | 130.42 | 130.41 | 130.43 | | 130.42 |
| 19 | | 130.61 | 130.64 | | 130.63 |
| 20 | 131.66 | 131.66 | 131.67 | 131.64 | 131.67 |
| 20 | 131.76 | 131.74 | 131.77 | 131.76 | 131.76 |
| 20 | | 131.96 | 131.97 | 131.96 | 131.97 |
| 21 | | 132.32 | | 132.31 | 132.32 |
| 21 | | 132.86 | | 132.87 | 132.88 |
| 21 | | | | | 133.47 |

Table A.4 Dip Locations Identified by Different Evaluators[1].

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | | 101.30 | | | |
| 2 | | 101.81 | | | |
| 2 | | | 102.14 | | 102.13 |
| 2 | 102.53 | | 102.52 | 102.54 | 102.54 |
| 2 | 102.72 | 102.72 | 102.72 | 102.72 | 102.72 |
| 2 | | 103.13 | | | 103.14 |
| 3 | | | 103.22 | 103.24 | 103.23 |
| 3 | | 103.60 | | | 103.60 |
| 3 | | 103.69 | | | 103.69 |
| 4 | | | 104.83 | | |
| 5 | | 106.97 | 106.96 | 106.97 | 106.96 |
| 6 | | | | | 108.15 |
| 6 | 108.91 | 108.95 | 108.95 | 108.94 | 108.95 |
| 6 | 109.65 | 109.63 | | | 109.64 |
| 6 | | | | | 109.73 |
| 7 | 109.83 | 109.85 | | 109.83 | |
| 7 | 109.93 | 109.92 | 109.94 | 109.93 | 109.93 |
| 7 | 110.06 | 110.07 | 110.07 | 110.06 | 110.06 |
| 7 | 110.50 | 110.49 | 110.51 | 110.49 | 110.51 |
| 7 | 110.71 | 110.69 | 110.72 | 110.71 | 110.71 |
| 7 | 110.82 | 110.81 | 110.82 | 110.82 | 110.82 |
| 7 | | 111.18 | | | |

[1] Locations given are in hundred meters.

Table A.4 Dip Locations Identified by Different Evaluators (continued).

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 8 | 111.44 | 111.43 | 111.44 | 111.43 | 111.44 |
| 8 | | 111.61 | | 111.61 | |
| 8 | | 112.19 | 112.19 | 112.18 | |
| 8 | | | | | 112.42 |
| 8 | | | | | 112.77 |
| 9 | | | 112.96 | | |
| 10 | | | 114.57 | | |
| 11 | | | 116.18 | | |
| 12 | | | | 118.40 | |
| 12 | 118.64 | 118.64 | 118.64 | | 118.66 |
| 12 | | | | 118.86 | |
| 12 | 118.89 | 118.90 | 118.89 | | 118.90 |
| 12 | 119.25 | 119.25 | 119.26 | 119.25 | 119.27 |
| 13 | | | | 119.40 | 119.40 |
| 13 | | | | | 119.51 |
| 13 | | 119.54 | | 119.55 | |
| 13 | 119.65 | 119.65 | 119.65 | 119.65 | 119.63 |
| 13 | 119.77 | 119.77 | 119.78 | 119.78 | |
| 13 | | | | | 119.82 |
| 13 | 119.89 | 119.89 | 119.89 | 119.89 | 119.89 |
| 13 | | | | | 119.96 |
| 13 | 120.07 | 120.08 | 120.08 | 120.07 | |
| 13 | 120.15 | 120.16 | | | |
| 13 | 120.22 | 120.21 | 120.23 | 120.23 | |
| 13 | | | 120.39 | | |

Table A.4 Dip Locations Identified by Different Evaluators (continued).

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 14 | | 121.11 | 121.11 | 121.12 | 121.12 |
| 14 | 121.32 | 121.32 | 121.32 | 121.32 | 121.32 |
| 14 | 121.41 | 121.42 | 121.42 | 121.42 | 121.42 |
| 14 | 121.51 | 121.53 | 121.52 | 121.53 | 121.52 |
| 14 | 121.76 | 121.77 | 121.76 | 121.76 | 121.77 |
| 14 | 121.92 | 121.92 | 121.92 | 121.92 | 121.93 |
| 14 | 122.11 | 122.12 | | | 122.13 |
| 15 | 123.03 | | 123.03 | 123.03 | 123.04 |
| 15 | 123.35 | 123.35 | 123.35 | 123.35 | 123.36 |
| 15 | 124.10 | 124.10 | 124.10 | 124.12 | 124.11 |
| 16 | 124.27 | 124.27 | 124.27 | 124.27 | 124.28 |
| 16 | 124.91 | 124.91 | 124.91 | 124.92 | 124.92 |
| 16 | 125.21 | 125.20 | 125.20 | 125.21 | 125.22 |
| 17 | 126.05 | 126.07 | 126.05 | 126.05 | 126.06 |
| 17 | 126.48 | 126.49 | 126.48 | 126.48 | 126.49 |
| 17 | 126.60 | 126.61 | 126.60 | 126.60 | 126.61 |
| 18 | 127.58 | 127.58 | 127.58 | 127.59 | |
| 18 | | | | | 127.94 |
| 18 | 128.08 | 128.10 | 128.09 | 128.09 | |
| 18 | 128.65 | 128.66 | 128.65 | 128.65 | 128.66 |
| 18 | 128.91 | 128.92 | 128.90 | 128.92 | 128.93 |
| 18 | 128.99 | | | | 129.01 |

Table A.4 Dip Locations Identified by Different Evaluators (continued).

| Segment | Evaluator | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 19 | | | | | 129.05 |
| 19 | 129.12 | 129.12 | 129.12 | 129.12 | 129.13 |
| 19 | 129.23 | 129.25 | 129.23 | | |
| 19 | 129.34 | 129.35 | 129.35 | 129.35 | 129.36 |
| 19 | | 129.61 | 129.61 | 129.61 | 129.62 |
| 19 | 129.69 | 129.70 | 129.69 | 129.69 | 129.70 |
| 19 | 129.80 | 129.80 | 129.80 | | 129.82 |
| 19 | | | | 129.87 | |
| 19 | | | 129.93 | | |
| 19 | 130.37 | 130.39 | 130.37 | 130.39 | 130.39 |
| 19 | 130.43 | 130.45 | 130.43 | 130.46 | 130.45 |
| 19 | | 130.59 | 130.57 | 130.58 | |
| 20 | 131.70 | | 131.69 | 131.69 | 131.71 |
| 21 | 132.82 | 132.82 | 132.82 | 132.83 | 132.84 |
| 21 | | 133.09 | | 133.10 | |
| 22 | 134.32 | 134.33 | 134.32 | | 134.33 |