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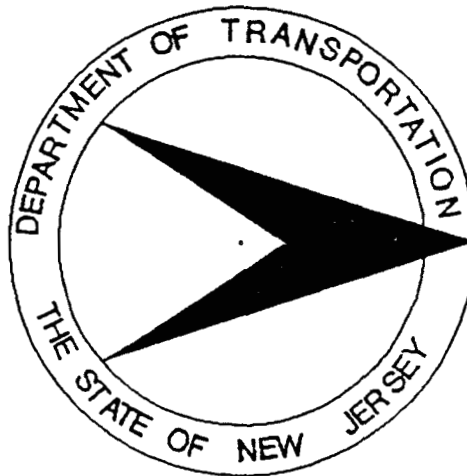
**CORRELATION OF USER PERCEIVED PAVEMENT ROUGHNESS (PSR)
WITH PHYSICAL ROUGHNESS MEASUREMENTS**

BY

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IN COOPERATION WITH

**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION**

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16. Abstract This report describes New Jersey's pavement ride quality Panel Studies. It highlights the experimental design, testing and data analyses of the 1985 and 1986 Panel Studies. These studies were conducted to establish the relationship between user opinion of pavement roughness and the mechanical measurement of roughness as estimated with a Mays Meter, an ARAN and an Inertial Profilometer. An exponential model was found to be the best fit curve for the data. An analyses of the data proved that a single curve defined the relationship between user opinion and mechanical measurement for each device. Multiple curves were not necessary to distinguish between bituminous, composite and concrete pavements types. The studies also established the terminal serviceability indices (TSI) for each pavement type. This is the level at which the average user feels a pavement needs rehabilitation. The analyses suggested that New Jersey motorists are more tolerant of bituminous pavements than the raters at the AASHO Road Test, where the TSI was 2.5. Our tests indicate that the TSI for bituminous pavements section was 2.0 while concrete and composite was approximately 2.5. The report outlines the preliminary work of selecting test sites, vehicles, and panelists, the testing procedure and the data analyses for both the 1985 and 1986 studies. The 1986 study was conducted as part of NCHRP 1-23(2), "Pavement Roughness and Rideability - Field Experiment".					
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IMPLEMENTATION STATEMENT

The PSR/Roughness relationships and terminal serviceability levels determined as part of these studies have already been used to establish the ranking of the Pavement Management Priority List and to modify the action levels of the Highway Performance Monitoring System (HPMS) analyses.

ACKNOWLEDGMENTS

The Bureau of Transportation Structures Research and the Pavement Management Task Force wish to express our appreciation to all those who participated in these studies; especially the user panelist who made this study successful.

We are grateful to the Pavement Management Group from the Bureau of Maintenance for their cooperation and assistance in collecting the Mays Meter and ARAN roughness data and for helping to operate the test vehicles.

A special note of thanks is extended to Mr. Michael Janoff, principal investigator for the NCHRP Study, for his cooperation and guidance.

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1.0 INTRODUCTION AND OBJECTIVES

This study was conducted by the Bureau of Transportation Structures Research in conjunction with the Pavement Management Group in the Bureau of Maintenance.

The overall goal of this study is to correlate physical measurements of road roughness (i.e., measurements produced by the Mays Meter, ARAN and Profilometer) with subjective user evaluation of pavement ride quality.

The specific objectives of the study were to:

1. Evaluate and quantify user perception of pavement ride quality
2. Determine the user-perceived terminal serviceability index of the pavement roughness for each pavement type
3. Correlate the user opinion of road roughness with the physical measurements and develop the translation equation(s) necessary to predict the Present Serviceability Rating (PSR) from the physical measurements of road roughness.

Development of the above relationships permits use of the mechanical measurement as a surrogate for the more time-consuming and costly panel evaluation. It also allows changes of ride quality to be monitored over time, and identification of pavement sections which the motorist would judge to be candidates for rehabilitation. That this evaluation is performed on every mile of State-maintained highways only underscores the importance of this study.

The study was divided into two stages. The initial project was a limited experiment conducted in 1985 containing 28 quarter-mile test sites, two pavement types (bituminous and concrete), and 21 raters. The Mays Meter was used to collect the mechanical roughness measurements.

The second stage was conducted in 1986 as part of NCHRP Project 1-23(2), "Pavement Roughness and Rideability - Field Experiment". This was a more extensive experiment including 69 quarter- to half-mile test sites, three pavement types (bituminous, composite, and concrete), and 48 raters. The physical measurements of each site's roughness were taken with a Mays Meter, an ARAN and an Inertial Profilometer.

2.0 BACKGROUND

When developing the Pavement Management System, the New Jersey Department of Transportation focused on the need for a rational procedure (based on objective measurements of the pavement's condition) to select candidate projects for

pavement rehabilitation and resurfacing. This approach evaluates each pavement section's condition relative to all other sections on the State-maintained network.

Ride quality is conventionally defined as the subjective evaluation of pavement roughness, while pavement roughness is defined as the longitudinal deviations of a pavement surface from a true plane. (1)

The developers of New Jersey's Pavement Management System placed a significant emphasis on ride quality in evaluating the pavement's overall condition. New Jersey presently uses the Mays Meter and the ARAN to collect road roughness data. The objective measurement of pavement roughness is without meaning unless these values are correlated with the user's opinion of the road's ride quality.

To establish this correlation, it was necessary to design and conduct an experiment in which user opinion of road's ride quality is matched with the output of an objective measuring device - the Mays Meter, the ARAN or the Inertial Profilometer. In this way, the roughness data can be transformed into user-perceived ride quality values on each pavement type without the cost of reconvening a panel.

In addition, this panel-roughness experiment was designed to provide information on the terminal serviceability index -- the level at which 50% of the users feel a pavement needs rehabilitation based on its ride quality. Terminal serviceability indices were determined for each pavement type.

3.0 OVERVIEW OF THE 1985 PANEL STUDY

In order to meet the objectives of the initial study, each experiment was divided into three phases.

3.1 Phase I - Preliminary Work

The design of the Department's experiments were modeled on the AASHO Road Test reports by Carey and Irick (2) and documentation on the conduct of panel studies by Janoff and Nick of Keytron, Inc. (3).

The modified Weaver-AASHO direct scale, shown in Figure 1, was used to gauge the individual panelist's opinions. Since many transportation professionals associate a PSR of 2.5 with the terminal serviceability index, the original Weaver-AASHO scale was modified by printing the scale without the numerical values. As Figure 1 illustrates, only the qualitative descriptions were provided.

RIDE RATING PANEL

SECTION NUMBER _____ DATE _____ TIME _____

RATER (NAME) _____ VEHICLE NUMBER _____ POSITION IN VEHICLE _____

}	VERY GOOD	
	GOOD	
	FAIR	IS THIS RIDE ACCEPTABLE?
	POOR	YES <input type="checkbox"/>
	VERY POOR	UNDECIDED <input type="checkbox"/>
		NO <input type="checkbox"/>

Figure 1. - Modified Weaver-AASHTO Rating Scale

A second aspect of the design involved selection of quarter-mile test sections. A total of 28 test sites (14 bituminous and 14 concrete) were selected from over 40 potential sites. The following procedure was used to select the study sites:

1. Identify approximately 40 test sections which cover the full range of expected roughness from computer files of recent surveys. Each section should be at least three-quarter-miles long, with consistent roughness along its length. From this section only the center quarter-mile will be rated.

2. Locate these sections in the field; mark the limits of the section on the shoulder.

3. Verify the current level of roughness of each pavement section with a calibrated Mays Meter. Reference (4)

4. From the list of verified test sections, create two loops: one exclusively concrete and the other bituminous. Each loop had have 14 quarter-mile sections. (The order in which the sections of various roughness were encountered were randomized as much as possible.)

The final list of sections was chosen to allow 6-10 minutes between sites. This strategy allowed testing of half the bituminous and half the concrete sites on a single day, and completion of the testing in two days while allowing time each day for retesting of any site. (The final list of panel test sites is provided as Appendix 1.)

The third aspect of the design centered around the panel selection. A panel size of 21 provides the necessary volume of data based on the 28 test sites. The panel was composed of seven technical professionals (four females and three males), seven non-technical males and seven non-technical females. As defined here, "technical" panelist was a person who had experience rating pavements and who had specific knowledge of NJ's Pavement Management System. The "non-technical" panelists did not actively rate pavements. One panelist from each of the three categories was selected randomly as a passenger in each car. Each panelist selected his/her own seat position in the car. However, once chosen, that position became his/her assigned seat for the remainder of the experiment.

3.2 Phase II - Testing Phase

The panelists were given an orientation prior to the actual testing. They were told the purpose of the experiment, provided with written instructions, and assigned to vehicles. After the orientation, the panelists were driven over two

bituminous "calibration" sites (an extremely rough and an extremely smooth site) as a frame of reference for their ratings. (A copy of the written panelist instructions is provided as Appendix 2.)

The key points stressed during the orientation was that each rater should record his/her own opinions; there is no "wrong" answer, and that he/she should concentrate solely on the ride quality of the section. The two questions which the raters answered for each test section were, "How would you rate this section's pavement ride quality?", and "Is the ride quality at an acceptable level or would you like to see the State spend your tax money to improve it?".

The following is a summary of the conditions and procedures used during the actual testing.

1. Tests were run under a single weather condition (i.e. sunny day).

2. All rater vehicles had tire pressures set at manufacturer's recommended pressure and full gas tanks.

3. Vehicles traveled through the section at the posted speed or with the flow of traffic.

4. After their orientation and "calibration", panelists were driven along bituminous and concrete pavement loops.

5. At the beginning of each test site (the beginning and end delineated by cones), the panelists were provided the site's number and asked to rate the pavement's ride quality. They were instructed that the rating was based on a scale from very poor to very good and was made immediately after he or she passed over the section. Panelists also answer the question, "Is this ride acceptable?", by selecting the "yes", "no" or "undecided" block on the form.

6. The forms were collected at the end of each site and were subsequently collected by Research personnel.

3.3 Phase III - Data Analyses

1. The data was analyzed to estimate the model (i.e., the mathematical form of the relationships) for transforming the Mays Meter measurements to PSR, the average user opinion of the road's roughness. In addition, terminal serviceability values were determined as the level at which 50 percent of the panelists felt that the ride quality was not acceptable.

2. The data was analyzed to determine if the curves developed for bituminous and concrete pavements were significantly different.

3.3.1 Data Reduction

The panel rating data for each test section was reduced to a numerical value by measuring the rater's marks (on the form scale) to the nearest 0.1 inch. A 0-5 scale was overlaid on the rating scale (see Figure 2, 0-5 PSR Scale).

3.3.2 Data Base

The information from the 1985 panel study was placed in a mainframe Ramis data base with fields shown in Figure 3. Each field represents a possible variable affecting the individual ratings. A summary of the data is shown in Figure 4.

3.3.3 Regression Analyses

A scatter diagram of rater opinions and Mays Meter values for each site is presented in Figure 5. The analysis subsequently performed determined the relationships between the mechanical and subjective measurements of road roughness.

As cited in the discussion paper by R. Barros (Appendix 3), the high variability of user opinion was immediately noticeable. The spread of 2.5 PSR units appeared to be excessively large, especially on the 0-5 scale range. However, a reasonableness check with a 1983 Keytron study (Reference 5) and a 1963 Purdue Study revealed a similar degree of variability.

One critical aspects of the analyses was to determine the appropriate form of the model. In assessing the potential alternative models, two boundary constraints were believed necessary to satisfy engineering judgment. First, both subjective and mechanical measurements of pavement roughness have known values for perfectly smooth pavements. For Mays measurements, this value is 0.0 inches per mile and for user opinion, the PSR value is 5.0. Secondly, since pavement roughness can increase indefinitely while the minimum PSR value is 0.0, the mathematical function must be asymptotic to the PSR-axis at infinity.

It was subsequently concluded that the following model satisfied the boundary conditions and provided the best overall fit to the experimental data:

$$Y = 5.0 * e^{a * X^b}$$

The 'best fit' equation was estimated by the nonlinear regression techniques contained in the Statistical Analysis System (SAS). Based on separate analyses, unique curves for each pavement type are not justified.

RIDE RATING PANEL

SECTION NUMBER 18 DATE _____ TIME _____

RATER (NAME) _____ VEHICLE NUMBER _____ POSITION IN VEHICLE _____

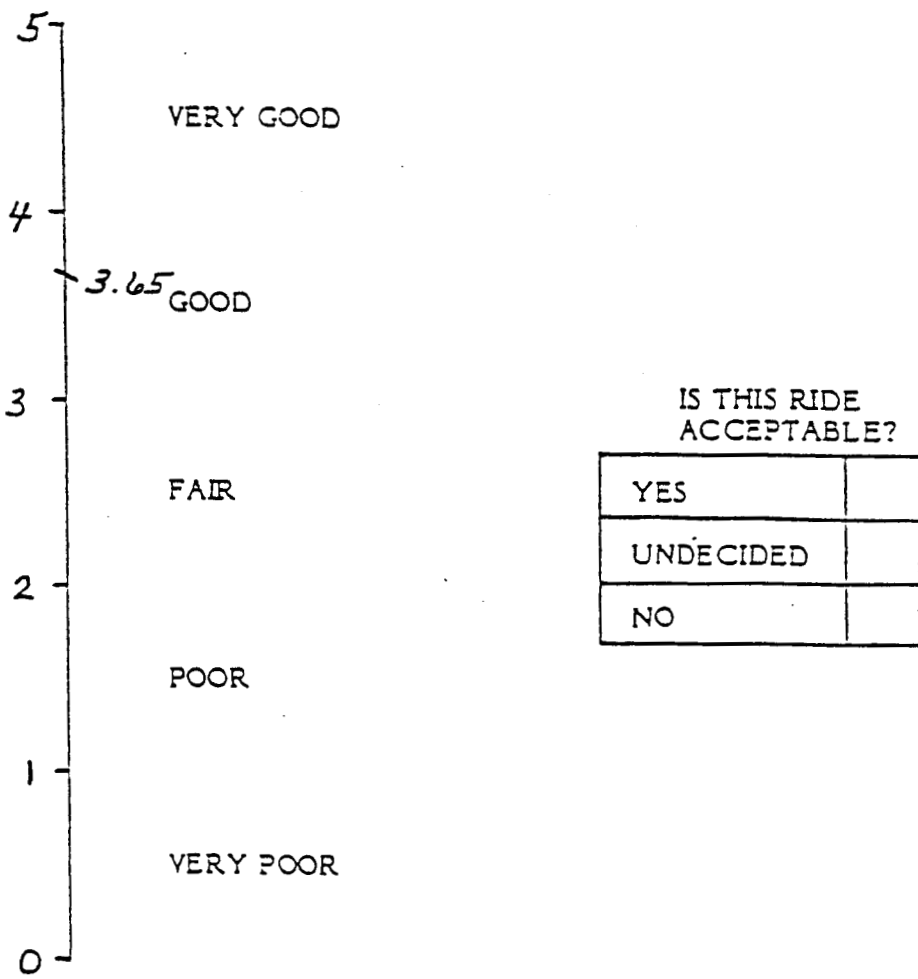


Figure 2 - 0-5 Scale (PSR)

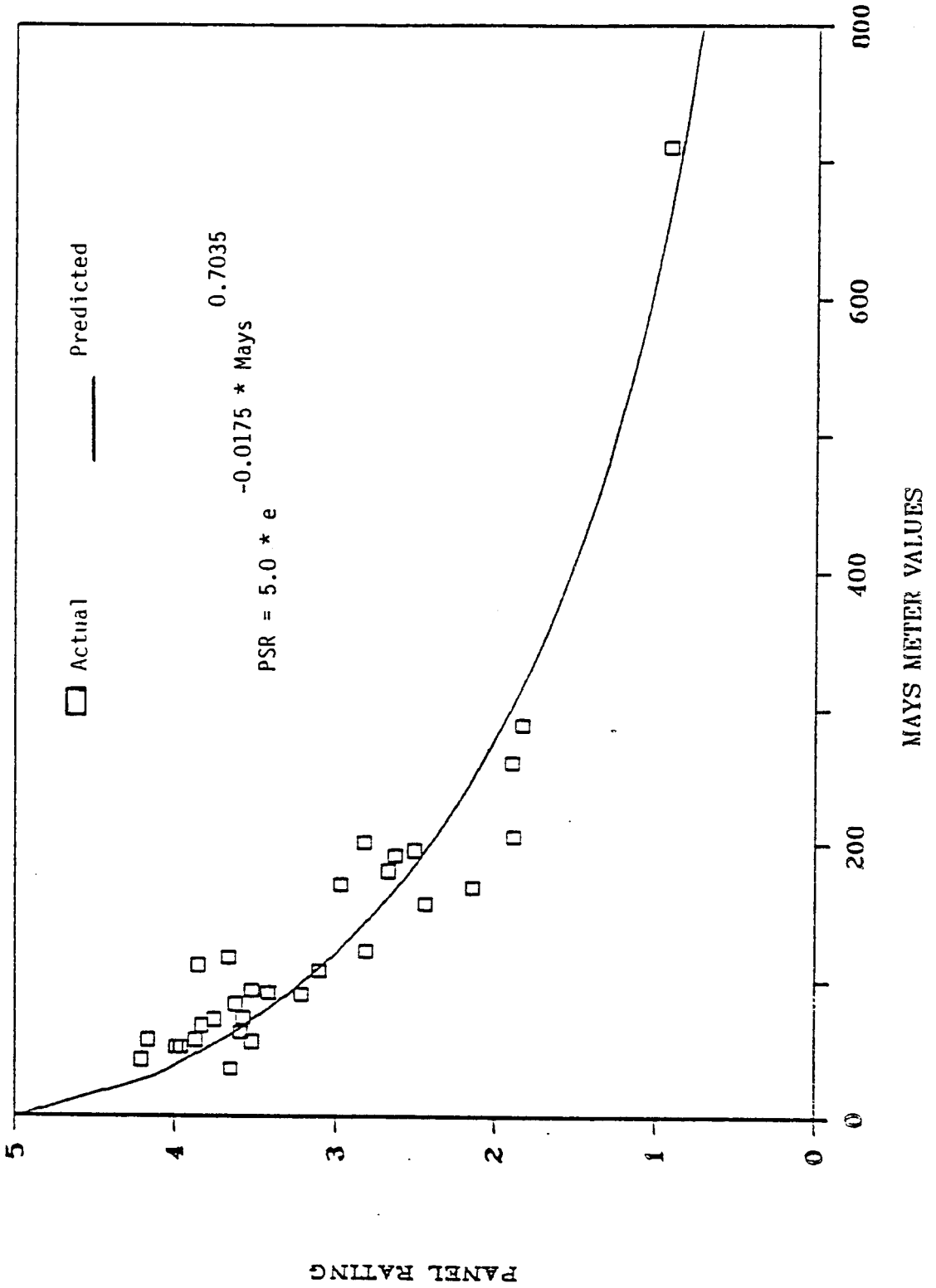
<u>LIST</u>	<u>FIELDNAME</u>	
1	Site No.	1, 2, 10-37
2	Pavement Type	BC, RC, CO
3	Date	082785, 082885
4	Time	AM, PM
5	TD 401	} Mays value of each site Taken with TD 401, TD 402, or TD 588
6	TD 402	
7	TD 588	
8	Person's Name	(21 Raters)
9	Driving Experience	Years with license
10	Sex	M, F
11	Category	Technical, Non-technical
12	Panelist Test Vehicle	(7 TD Numbers)
13	Position in Car	Right front, right rear, left rear
14	Panelist Rating	0 - 5
15	Acceptable	Yes, No, Undecided

FIGURE 3 - RAMIS FIELDS

<u>PAVEMENT</u>	<u>SITE</u>	<u>AVERAGE RATING</u>	<u>STANDARD DEVIATION</u>	<u>AVERAGE MAYS</u>
BC	1	4.17	.39	55
	2	.92	.43	711
	10	3.85	.48	110
	14	3.66	.60	116
	15	3.52	.49	54
	23	3.99	.63	50
	24	3.10	.55	106
	26	2.81	.53	121
	27	2.44	.70	156
	30	3.75	.52	70
	31	3.87	.44	55
	32	3.42	.56	90
	33	4.21	.39	41
	34	3.96	.48	50
	35	3.65	.57	34
	37	3.83	.65	66
	RC	11	2.97	.83
12		1.89	.71	259
13		3.57	.76	72
16		2.51	.85	195
17		3.62	.63	82
18		2.82	.77	201
19		2.63	.78	191
20		1.83	.88	287
21		3.21	.69	89
22		3.59	.70	61
25		2.14	.81	168
28		3.52	.63	92
29		2.67	.74	180
36		1.88	.74	205

Figure 4 - Summary of 1985 Data

PANEL RATING vs MAYS METER



The following equation (plotted in Figure 5) is the 'best fit' curve for the combined data:

$$\text{PSR} = 5.0 * e^{0.7035 * (-0.0175 * \text{Mays})}$$

This curve tends to obey 'Fechner's law', wherein small increases in road roughness at the smooth end of the Mays scale cause greater decreases in the subjective rating than the same amount of change at the higher end. Put simply, people are more sensitive to smaller differences of road roughness on smoother roads than they are on rougher ones (5).

3.3.4 Other Analyses

The significant of the several candidate variables in explaining the PSR ratings were determined through an analysis of variance. (See Appendix 4). These variables included pavement type, rating, vehicle, position of the rater in the test vehicle, driving experience of the rater, and the sex of the rater.

Two considerations made this a nonstandard analysis. First, the PSR-Roughness relationship was recognized to be nonlinear, whereas analysis of variance techniques assumed a linear combination of variable effects. Second, it was recognized that bituminous pavements tended to be smoother than concrete pavements. These considerations lead to the development of a new variable, (PREDPSR), which accounts for both the nonlinear PSR-Roughness relationship and also distill from the variable pavement type. The roughness-related effects of PREDPSR was simply the predicted average PSR value associated with each level of roughness regardless of pavement type. PREDPSR was thus a calculated variable whose value was estimated with nonlinear regression. This distilling procedure accounted for the roughness offset of the various pavement types and gave an opportunity to distinguish other factors potentially affecting the observed the relationships. These included such items as pavement color, harmonic effects associated with rigid pavement joints, and distress manifestations particular to each pavement type.

The principal finding of this analysis was that roughness level (i.e., PREDPSR) was the predominant influence on PSR. This variable overwhelmed all other factors. Pavement type was found to be nonsignificant once separated from roughness level. Also significant but having a smaller impact on reducing the unexplained error were vehicle type and rater position in the test vehicle. This finding suggests that future panel rating studies might benefit from conducting the work with both vehicle sizes and varying the rater position, although the practical impact of this consideration is expected to be small. And, finally, using the preferred statistical evaluation criteria (TYPE III Sum of Squares), the significance of the remaining variables was not testable in this experimental design.

3.4 Shortcomings and Questions of 1985 Study

A review of the results of the 1985 project revealed a number of shortcomings and questionable conclusions. The following is a summation of these problem areas.

1. The available data supported only a single PSR relationship for both pavement types. Since this result was unexpected, it was considered suspect.

2. Raters who selected the "undecided" option on the ride acceptability question were disqualified from the logit analysis used to determine the terminal serviceability indices. (Only a "yes" or "no" answer was valid.) This condition caused a severe reduction in the amount of usable data.

3. The lack of mays roughness data in the 300 to 700 in./mile interval raised questions as to the adequacy of the estimated relationship in this range.

4. The use of one roughness measurement device limited the generality of the developed relationship to a particular mechanical unit.

4.0 OVERVIEW OF THE 1986 PANEL STUDY - NCHRP 1-23 (2)

4.1 Objectives of the 1986 Panel Study

The Department's specific objectives for this study were as follows:

1. To rectify the perceived shortcomings of the experimental design used in the earlier study

2. To verify the PSR relationship developed in the 1985

study, and to develop similar relationships for the ARAN and the Profilometer.

3. To determine the terminal serviceability level for bituminous, composite and concrete pavements.

In addition, participation in the NCHRP Study afforded the Department the opportunity to correlate its model(s) with those of four other participating states.

The tasks performed in the three phases of the 1985 study were repeated in this study. However, because the details of this study had to conform to the consultant's experimental design, certain modifications were required in each of the phases. The following sections outline these changes and the results obtained.

4.2 Phase I - Preliminary Work

The following changes to the 1985 experimental procedure were necessary to conform to the new experimental design.

The Weaver-AASHO direct scale was again chosen to collect the user's opinion. However, as Figure 6 illustrates, the form includes the 0-5 numeric scale. The "undecided" category was eliminated and the ride quality question was modified to determine at what point the users felt that the pavement needed improvement.

The test site selection procedure was identical to the initial study with a few exceptions. Composite pavement sections (bituminous overlaid concrete pavements) were now included. The number of test sites increased from 48 in the 1985 study to 69. Of these, 62 sections were ultimately used in the analyses. The test loops were not purely bituminous or concrete pavement sections. Finally, the length of each section was increased to approximately one-half mile.

A northern and a southern route were created from the list of verified test sections. The level of roughness and the pavement type were randomized as much as possible along the route. Appendix 5 contains the finalized list of sites along the northern and southern routes.

The 48 raters (plus alternates) were selected randomly from lists of available personnel submitted by various units throughout the Department. The job classifications of the panelists included engineers, secretaries, etc. Panelists were assigned to test vehicles on a random basis. They were allowed to select their seat position, but retained that position for the remainder of the testing.

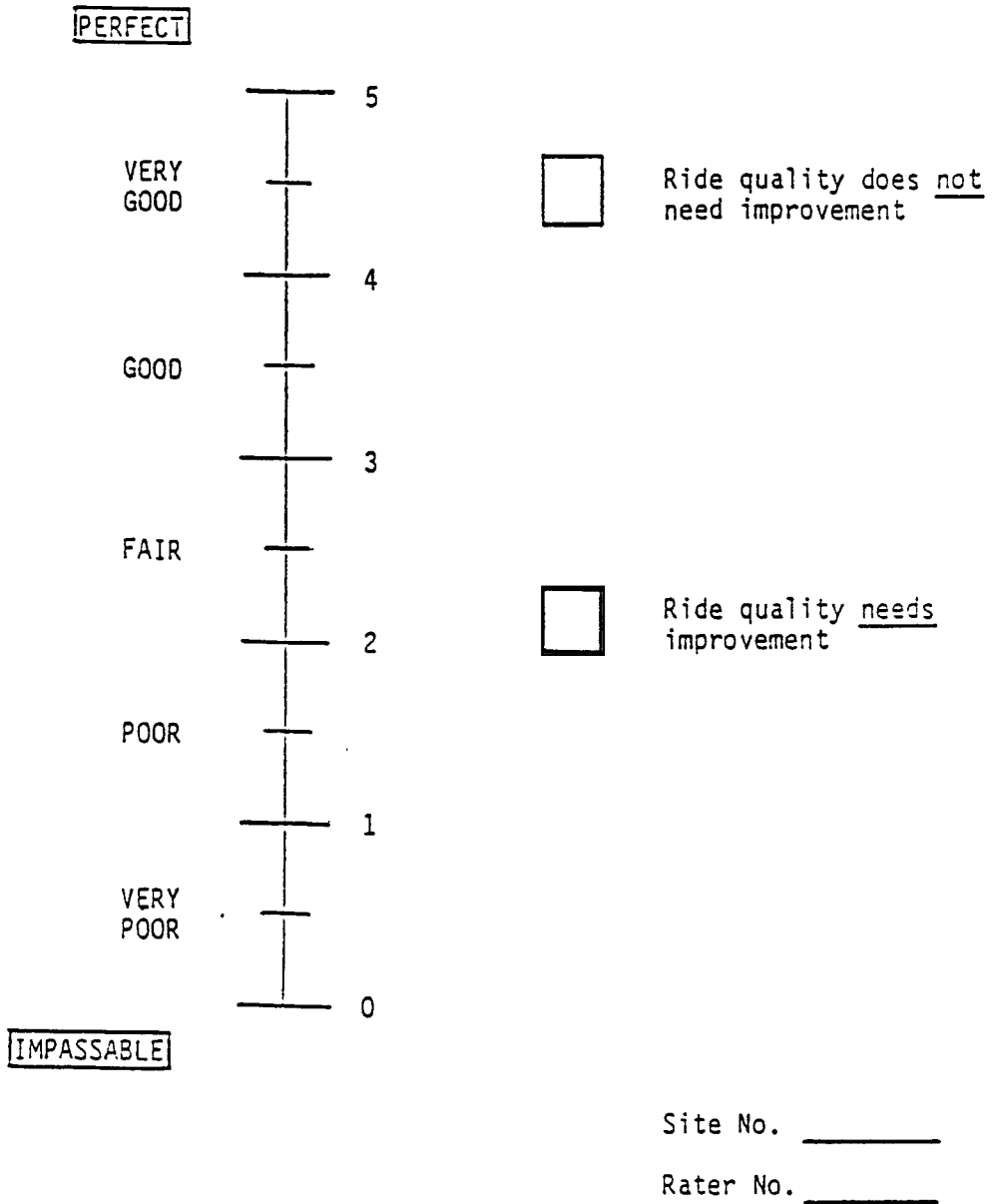


Figure 6 - Weaver ASSHO Rating Scale

4.3 Phase II - Testing Phase

Prior to exposure to the test sites, the panelists were given oral and written instructions by Mr. Michael Janoff, the NCHRP principal investigator. (Appendix 6 contains a copy of the written panel instructions.) Mr. Janoff did not feel that the panelist needed to be driven over sites to calibrate their senses to various roughness levels. The testing and experimental test procedures outlined earlier were also used in the 1986 study.

4.4 Phase III - Data Analyses

1. The relationships for transforming Mays Meter, ARAN and Profilometer values into estimates of user opinion are the primary products of the data analyses.

2. The terminal serviceability indices for the three pavement types were also estimated.

3. The relationships developed from the 1986 data analyses were compared to the 1985 relationship.

4.4.1 Data Reduction

The data was reduced in the same manner as described in section 3.3.1 above.

4.4.2 Data Base

The 1986 panel study information was placed in a Ramis data base with the fields shown in Figure 7. A summary of the data is provided in Figures 8, 9, and 10.

4.4.3 Regression Analyses

Scatter diagrams of rater opinion vs. mechanical measurement device (Mays Meter, ARAN, and Profilometer) were plotted over the model fit by the SAS (nonlinear) package.

As cited earlier, the form of the model was considered to be critical in the developing the appropriate relationship. The form of the model discussed in section 3.3.3 was retained after consideration of the physical constraints imposed by the model and a scatter plot analysis. Subsequently analyses again determined that unique curves for each pavement type were not justified.

The equations plotted in Figures 11, 12, and 13 are the 'best fit' curves for the combined pavement data for each roughness measuring device. These curves also obey Fechner's law.

RAMIS PANEL2 FILE FIELDS

<u>LIST</u>	<u>FIELDNAME</u>	<u>EXAMPLES</u>
1	Site Number	1, 4, etc.
2	Pavement Type	BC, CO, RC
3	Mays	Mays values for each site
4	Profilometer	Profilometer values for each site
5	ARAN	Aran values for each site
6	Rater Number	1-55
7	Driver Experience	Year with a license
8	Sex	M F
9	Panelist Test Vehicle	Plate Number
10	Position in Vehicle	Right front, Right Rear, Left Rear
11	Panel Rating	0-5
12	Improvement Required Question	Yes or NO

Figure 7 - Ramis Panel2 File Fields

PAVE	SITE	AVE RATING	STD RATING	AVE TD401	AVE ARAN	AVE PROF
BC	2	1.07	.55	669	1023	.147
	9	1.41	.60	445	950	.112
	43	2.16	.59	311	579	.079
	49	4.14	.56	47	162	.018
	61	3.79	.53	76	226	.022
	62	3.02	.54	127	445	.028
	63	2.58	.55	244	568	.049
	64	3.75	.45	93	218	.023
	65	4.06	.50	43	215	.020
	69	2.77	.61	108	429	.047
	72	4.28	.46	27	151	.015
	73	4.20	.55	25	143	.016
	77	3.59	.65	63	169	.019
	78	3.09	.58	129	256	.037
	89	3.65	.54	58	300	.027
	99	3.91	.60	68	165	.021
	100	3.65	.56	73	213	-
	101	3.65	.54	81	228	.029
	110	3.49	.50	84	283	-
	111	3.24	.70	104	256	-

Figure 8 - Summary of 1986 Data for Bituminous Pavements

PAVE -----	SITE -----	AVE RATING -----	STD RATING -----	AVE TD401 -----	AVE ARAN -----	AVE PROF -----
RC	1	3.48	.73	27	314	.029
	4	2.59	.57	201	657	-
	48	3.75	.64	50	339	.021
	50	3.52	.67	56	308	.021
	51	3.38	.57	56	453	.026
	54	3.56	.60	78	267	.026
	55	3.59	.57	86	289	.026
	74	3.48	.69	92	282	.030
	75	3.68	.51	46	296	.022
	81	1.89	.71	183	663	.074
	82	2.19	.70	212	690	.064
	83	3.46	.59	69	311	.025
	84	3.30	.67	74	294	.028
	85	3.71	.53	-	283	-
	86	2.73	.71	162	528	-
	87	3.59	.48	88	256	.025
	97	3.35	.63	62	367	.023
	105	2.50	.81	160	655	.053
	106	2.33	.69	246	856	.063
	108	2.54	.72	97	474	.040
	109	2.35	.68	-	545	-
	112	2.61	.69	-	660	-
	113	2.44	.73	-	767	-
	114	2.60	.73	-	732	-
	117	3.39	.63	102	324	.033

Figure 9 - Summary for 1986 Data for Concrete Pavements

PAVE	SITE	AVE RATING	STD RATING	AVE TD401	AVE ARAN	AVE PROF
-----	-----	-----	-----	-----	-----	-----
CO	5	3.27	.47	131	424	-
	6	3.06	.62	103	506	-
	45	3.26	.59	81	-	.031
	46	3.54	.67	92	445	-
	47	3.65	.63	82	204	-
	52	3.74	.55	34	223	.025
	56	3.42	.61	62	322	.032
	58	2.43	.59	144	391	.046
	66	3.18	.62	82	308	.031
	67	3.02	.58	62	400	.035
	70	3.96	.46	72	280	-
	79	2.46	.66	133	428	.048
	80	3.27	.59	84	284	.032
	88	3.96	.49	50	221	-
	102	2.61	.78	95	630	-
	103	2.61	.77	49	670	-
	116	3.49	.62	53	180	.022

Figure 10 - Summary of 1986 Data for Composite Pavements

A comparison of the 1985 and 1986 predictive models (see Figure 14) indicate very close agreement.

4.4.4 Terminal Serviceability Indices

The third objective of this study was to determine the terminal serviceability index for each pavement type. Logit analyses were performed on the rehabilitation-question data. The average PSR rating for each site was paired with the percentage of raters who indicated that the pavement should be rehabilitated. The estimated relationship of the present study are graphically presented in Figures 15 through 18.

These analyses indicate that the terminal serviceability levels for the concrete and composite pavements are very similar and that both are different from the level for bituminous pavements. Concrete and composite pavements are estimated to fail at a PSR level of approximately 2.5, while the level for bituminous pavements is estimated to be approximately 2.0. Practical considerations suggest that these point estimates may be precise to within one-quarter of a PSR unit.

Note that generally similar findings have been reported elsewhere (ref. Janoff's NCHRP 308, pages 14 and 15), as well as in the pilot panel rating study.

A similar analyses using the average Mays Meter values of each site and the percentage of raters indicating that the pavement needed repair is presented in Appendix 7. Here the terminal serviceability levels were estimated to be 2.6 for concrete and composite pavements, and 1.9 for bituminous pavements. This particular analysis indicates the significance level for the difference in terminal serviceability is smaller than $C = 0.01$. Also, the 95 percent confidence level for the bituminous terminal serviceability levels nominally claimed to have a total range of 0.1 PSR units. Several assumptions were required to perform this analysis, however, such as no error in the independent variable (Mays, ARAN, or Profilometer data) and a known transform between the objective measurement and the PSR units, potentially introducing error to an unquantifiable degree. While these potential errors are thought not to change the principal findings, they may degrade the nominal precision asserted by the technique.

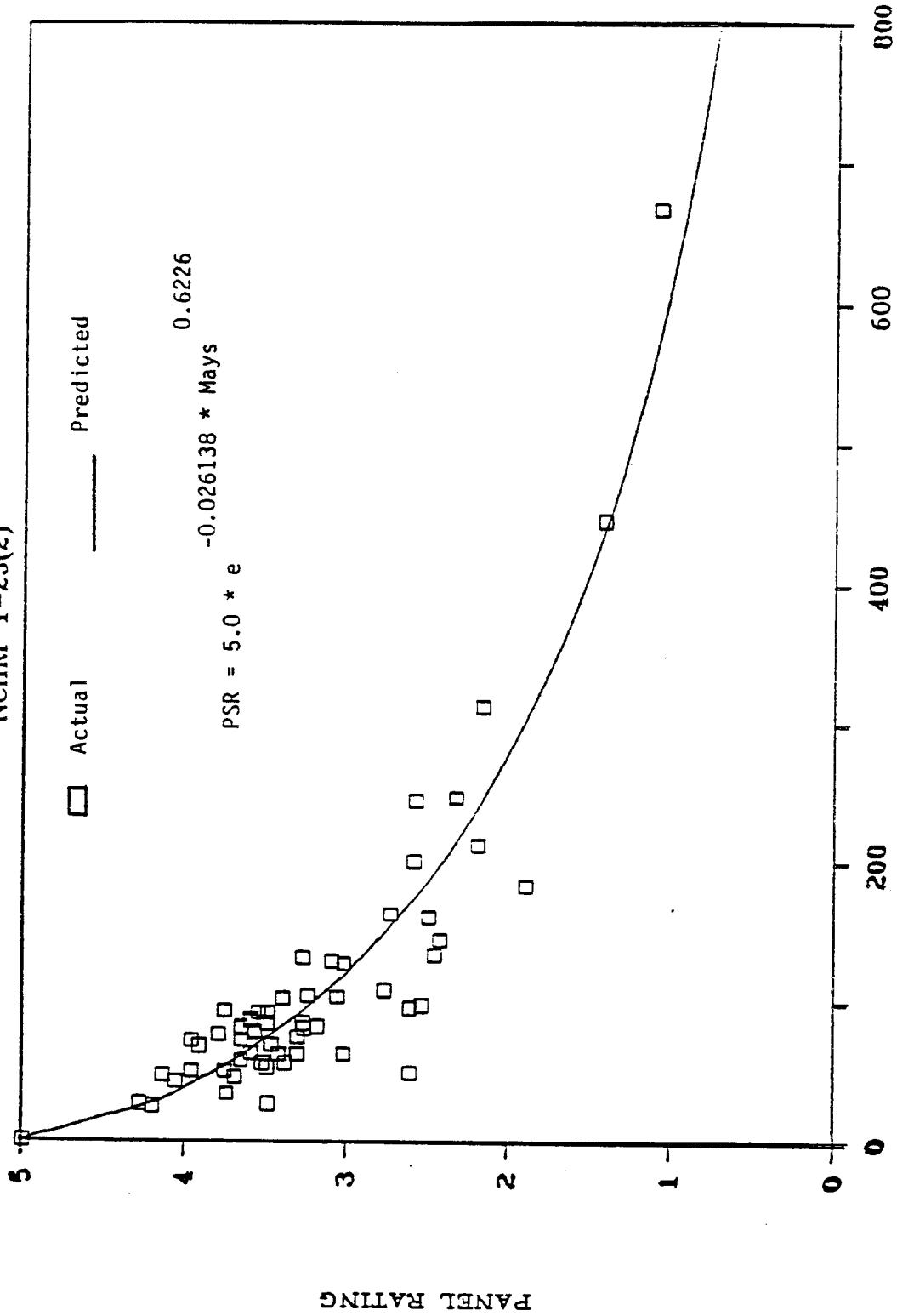
The relative values of the bituminous and concrete-composite pavement indices were unexpected. It had been assumed that the traveling public was more tolerant of short-term roughness associated with the concrete and composite pavement joints. These results suggest just the opposite. Users are apparently more tolerant of the randomly distributed roughness, typical of the bituminous pavements,

than they are of the sudden and more abrupt roughness associated with the joints of concrete and composite pavements.

These results have had a dramatic effect on the pavement rehabilitation prioritization listing. The emphasis for rehabilitation, due to unacceptable ride quality, has shifted from the bituminous pavements to the concrete and the composite pavement sections.

PANEL RATING vs MAYS METER

NCHRP 1-23(2)



MAYS METER VALUES (in./mile)

Figure 11 - Scatter Plot of (MAYS,PSR) and Predicted Curve.

PANEL RATING vs PROFILOMETER

NCHRP 1-23(2)

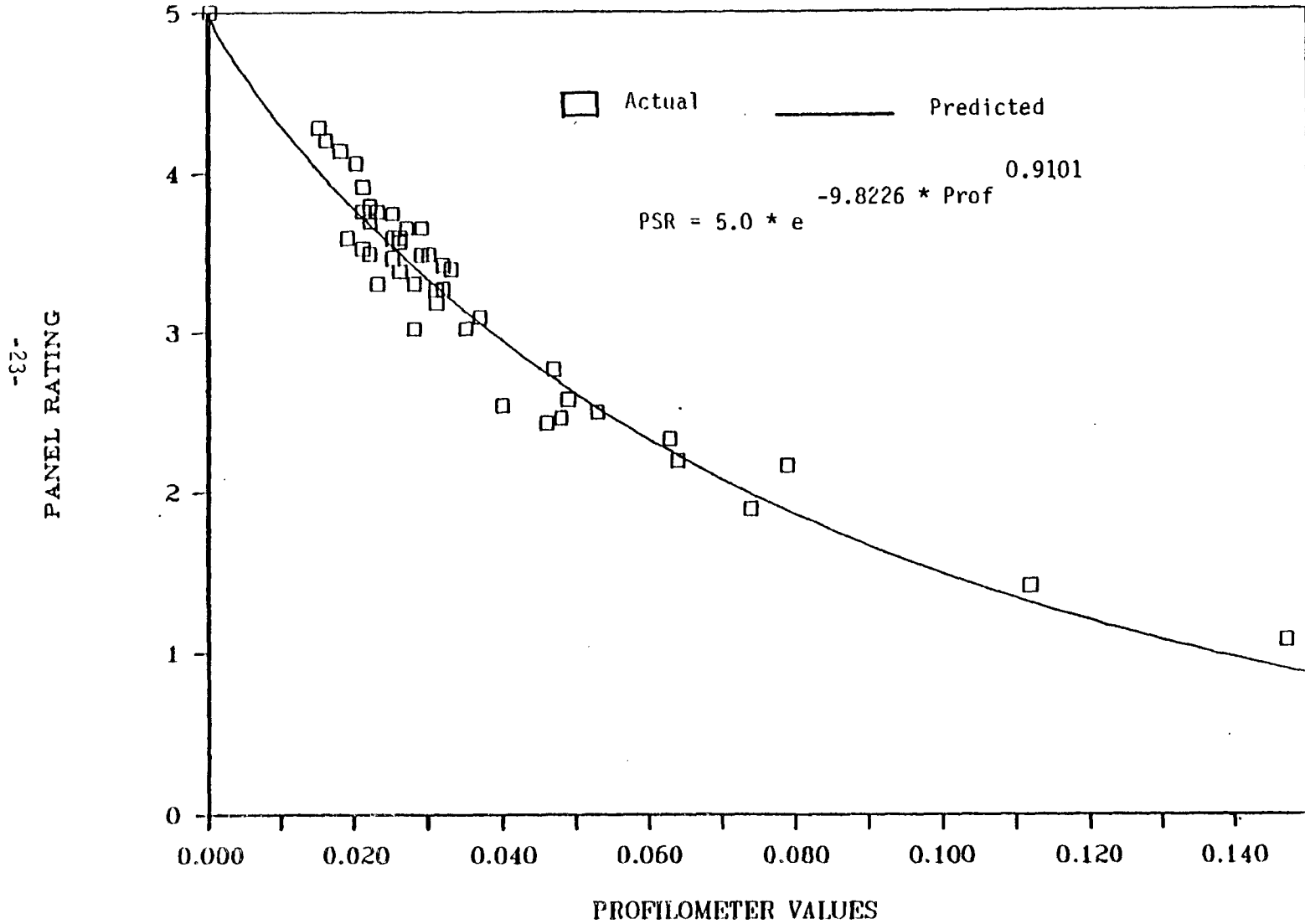


Figure 13 - Scatter Plot of (Profilometer,PSR) and Predicted Curve.

PANEL RATING vs ARAN

NCHRP 1-23(2)

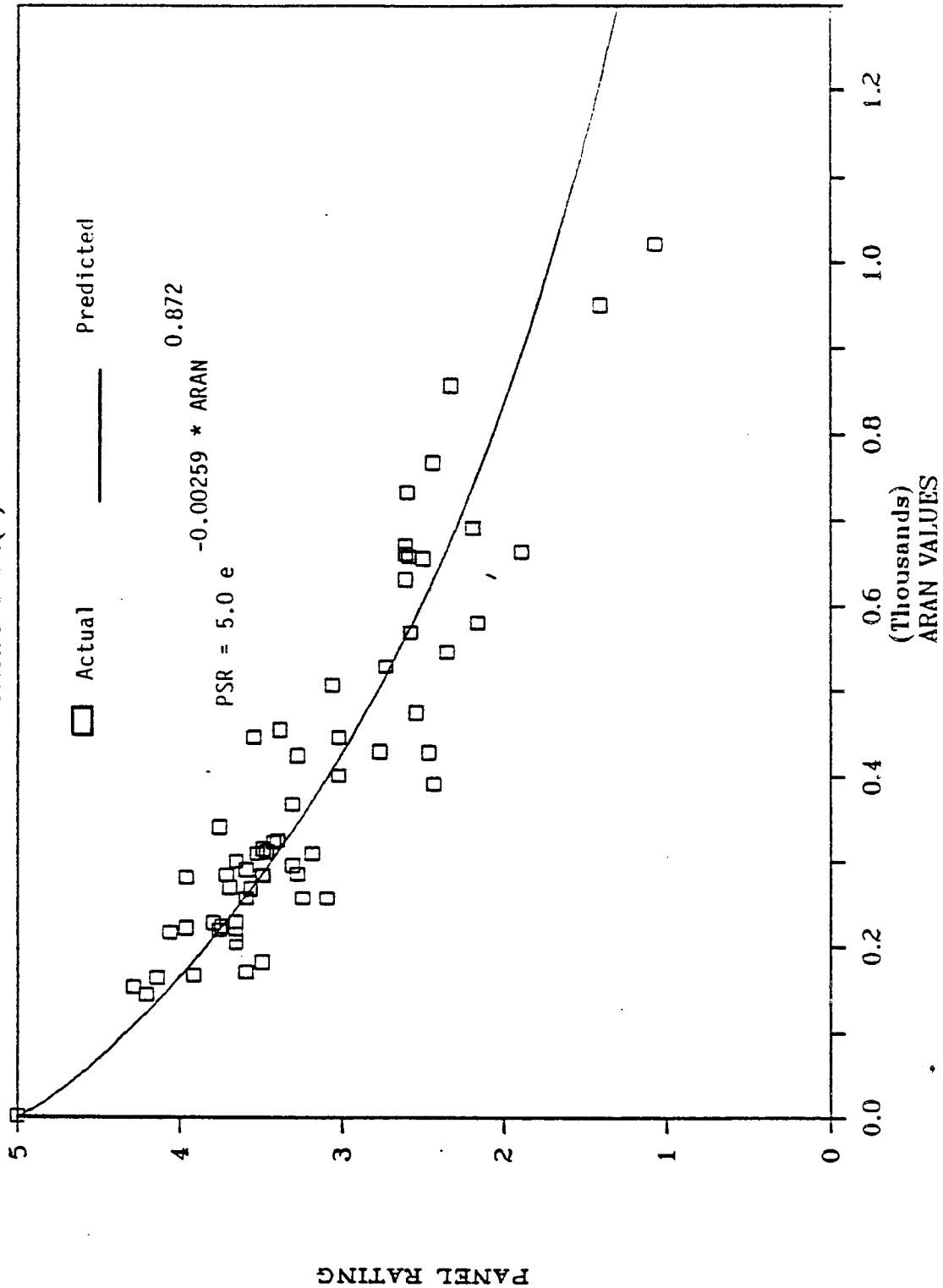


Figure 12 - Scatter Plot of (ARAN ,PSR) and Predicted Curve.

1985 vs 1986 RESULTS

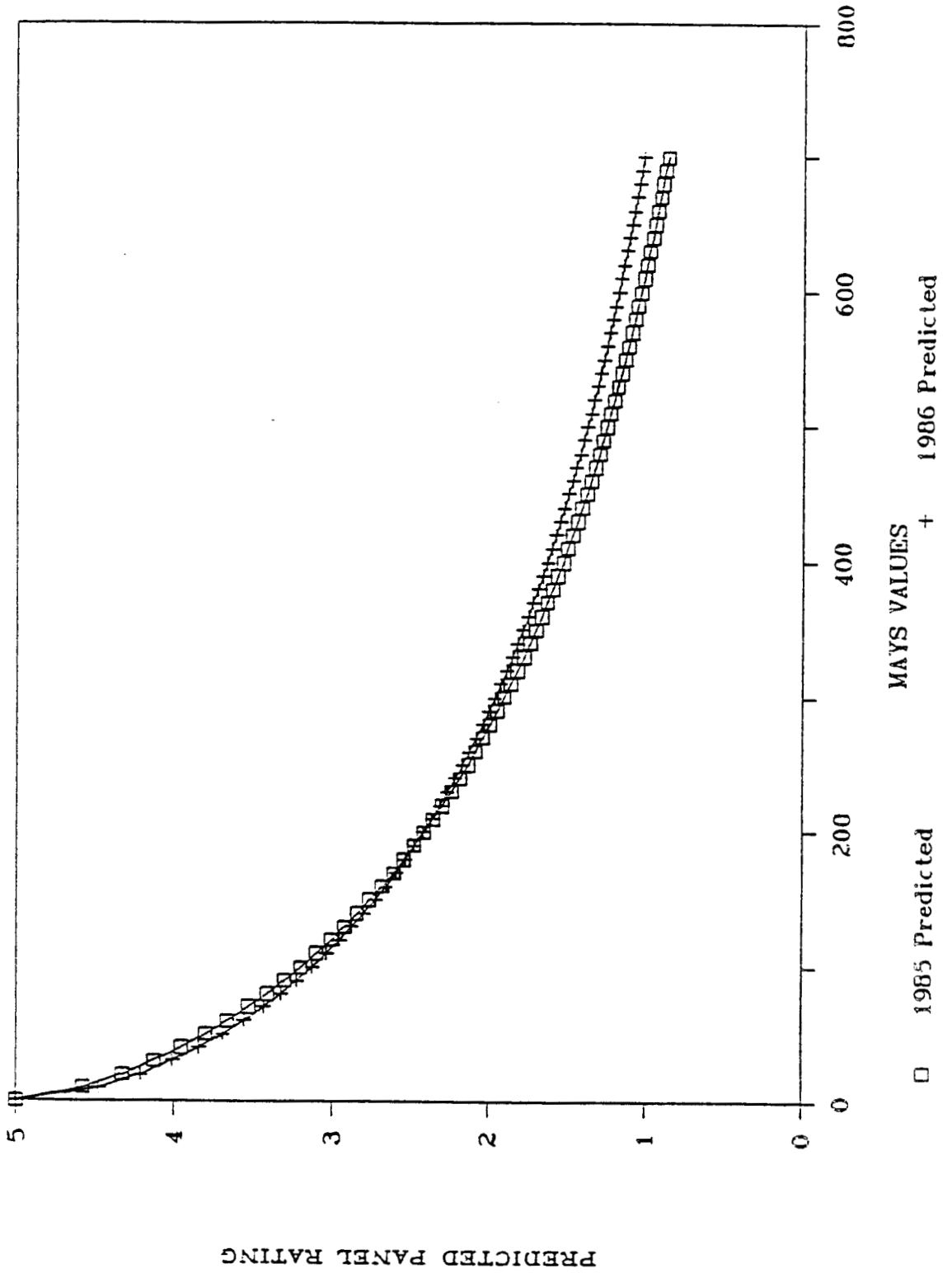


Figure 14 ... Plot of 1985 and 1986 Mays Predicted Curves for All Pavement Types

LOGIT ANALYSES OF THE
TERMINAL SERVICEABILITY INDEX

PV	SITE	RATING	IR	COUNT	PERCENT
BC	2	1.07	Y	46	95.833
BC	9	1.41	Y	36	75.000
BC	43	2.16	Y	18	37.500
BC	49	4.14	Y	1	2.083
BC	61	3.79	Y	3	6.250
BC	63	2.58	Y	13	27.083
BC	64	3.75	Y	0	0.000
BC	65	4.06	Y	0	0.000
BC	69	2.77	Y	11	22.917
BC	72	4.28	Y	0	0.000
BC	73	4.20	Y	0	0.000
BC	77	3.59	Y	0	0.000
BC	78	3.09	Y	2	4.167
BC	89	3.65	Y	0	0.000
BC	99	3.91	Y	0	0.000
BC	100	3.65	Y	3	6.250
BC	101	3.65	Y	2	4.167
BC	110	3.49	Y	2	4.167
BC	111	3.24	Y	5	10.417
CO	5	3.27	Y	6	12.500
CO	6	3.06	Y	5	10.417
CO	45	3.26	Y	4	8.333
CO	46	3.54	Y	2	4.167
CO	47	3.65	Y	2	4.167
CO	52	3.74	Y	1	2.083
CO	56	3.42	Y	1	2.083
CO	58	2.43	Y	26	54.167
CO	66	3.18	Y	3	6.250
CO	67	3.02	Y	8	16.667
CO	70	3.96	Y	0	0.000
CO	79	2.46	Y	23	47.917
CO	80	3.27	Y	3	6.250
CO	88	3.96	Y	0	0.000
CO	102	2.61	Y	21	43.750
CO	103	2.61	Y	24	50.000
CO	116	3.49	Y	1	2.083
RC	4	2.59	Y	21	43.750
RC	48	3.75	Y	0	0.000
RC	50	3.52	Y	3	6.250
RC	51	3.38	Y	4	8.333
RC	54	3.56	Y	0	0.000
RC	55	3.59	Y	1	2.083
RC	74	3.48	Y	4	8.333
RC	75	3.68	Y	0	0.000
RC	81	1.89	Y	41	85.417
RC	82	2.19	Y	35	72.917
RC	83	3.46	Y	2	4.167
RC	85	3.71	Y	1	2.083
RC	86	2.73	Y	18	37.500
RC	87	3.59	Y	0	0.000
RC	97	3.35	Y	2	4.167
RC	105	2.50	Y	28	58.333
RC	106	2.33	Y	31	64.583
RC	108	2.54	Y	20	41.667
RC	109	2.35	Y	32	66.667
RC	112	2.61	Y	17	35.417
RC	113	2.44	Y	24	50.000
RC	114	2.60	Y	17	35.417
RC	117	3.39	Y	5	10.417

Figure 15 - Logit Analyses Data

Figure 16 - Logit Analysis Plot (Bituminous Pavements)

LOGIT ANALYSIS OF 1986 TERMINAL SERVICEABILITY DATA BITUMINOUS PAVEMENTS

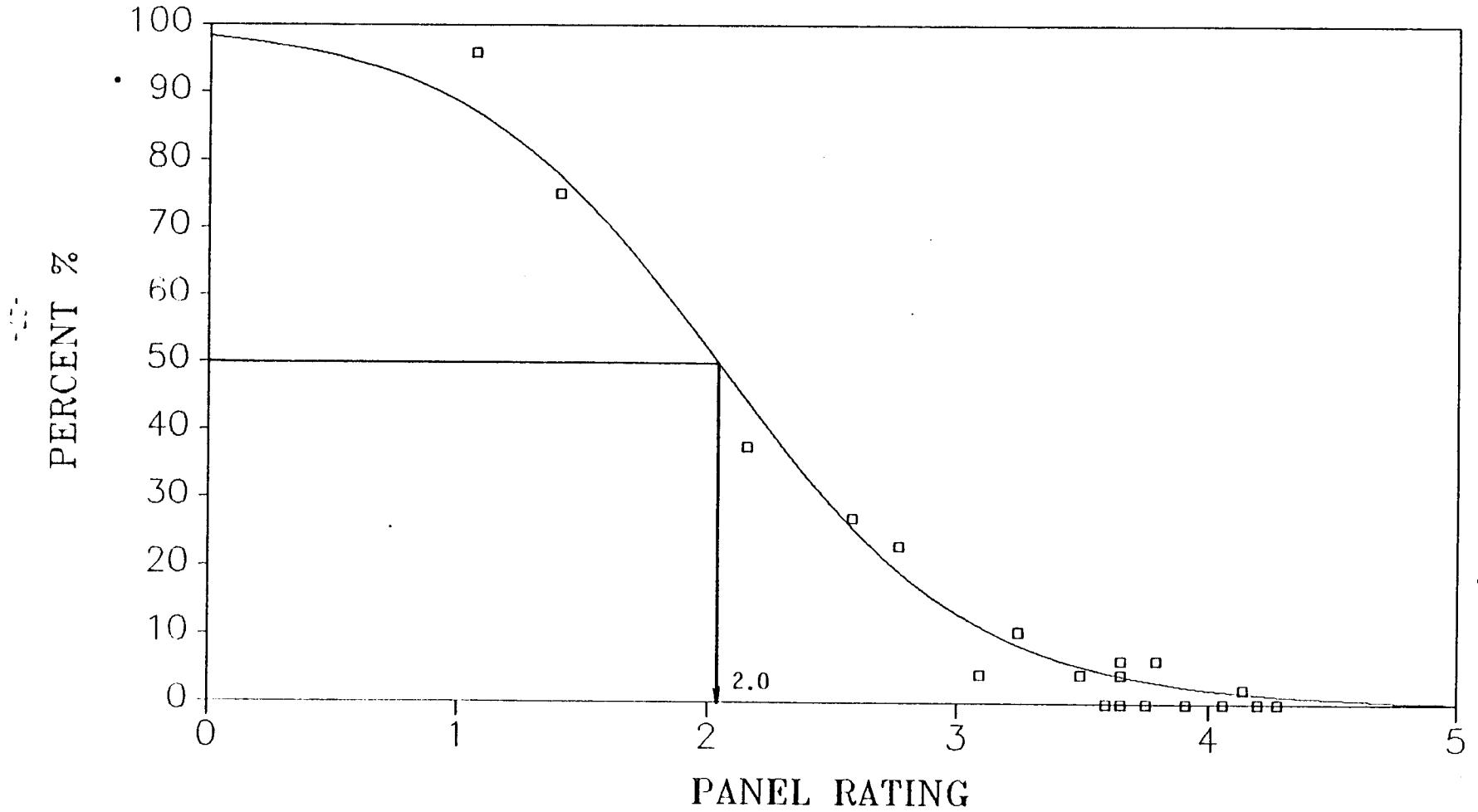


Figure 17 - Logit Analysis Plot (Composite Pavements)

LOGIT ANALYSIS OF 1986

TERMINAL SERVICEABILITY DATA
COMPOSITE PAVEMENTS

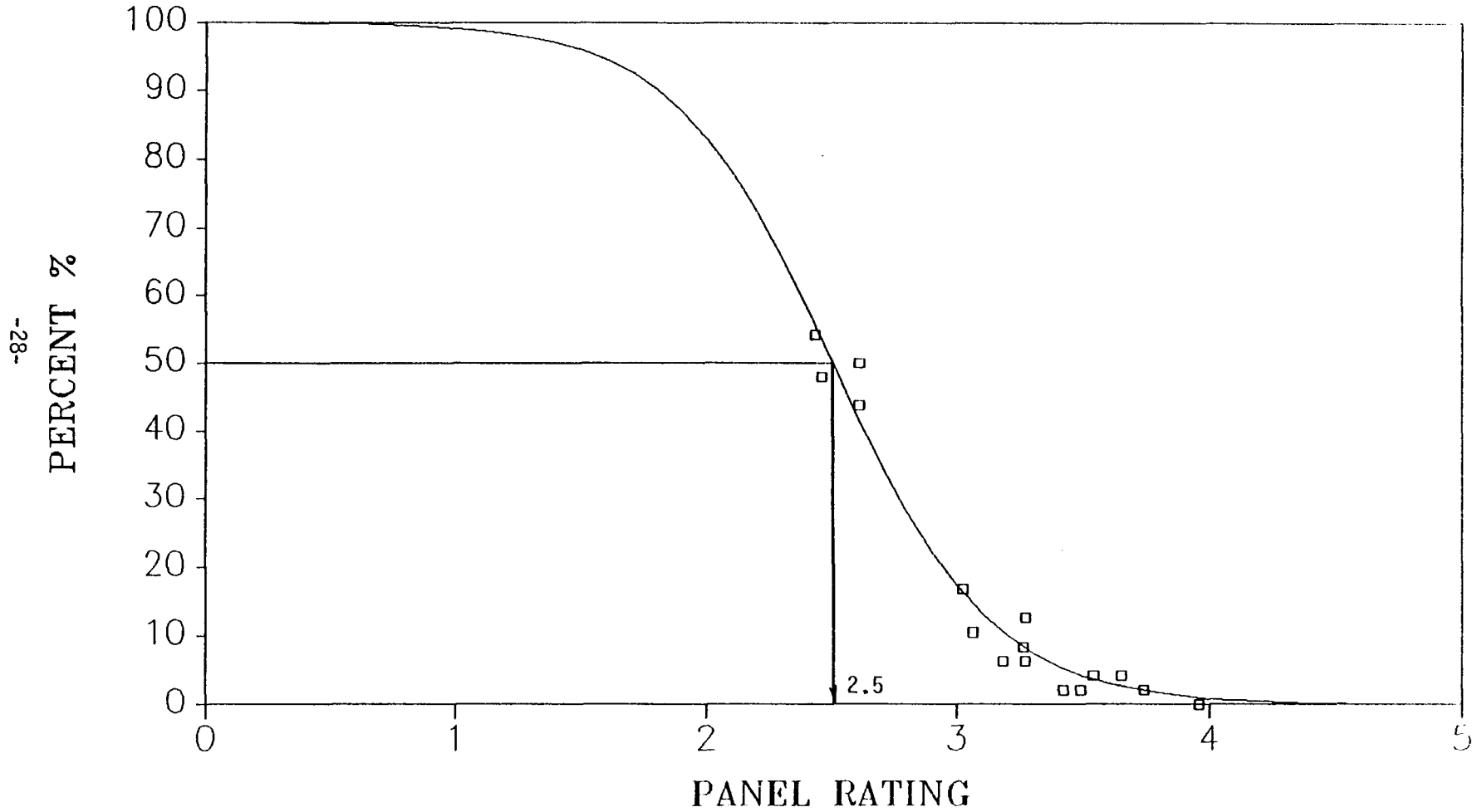
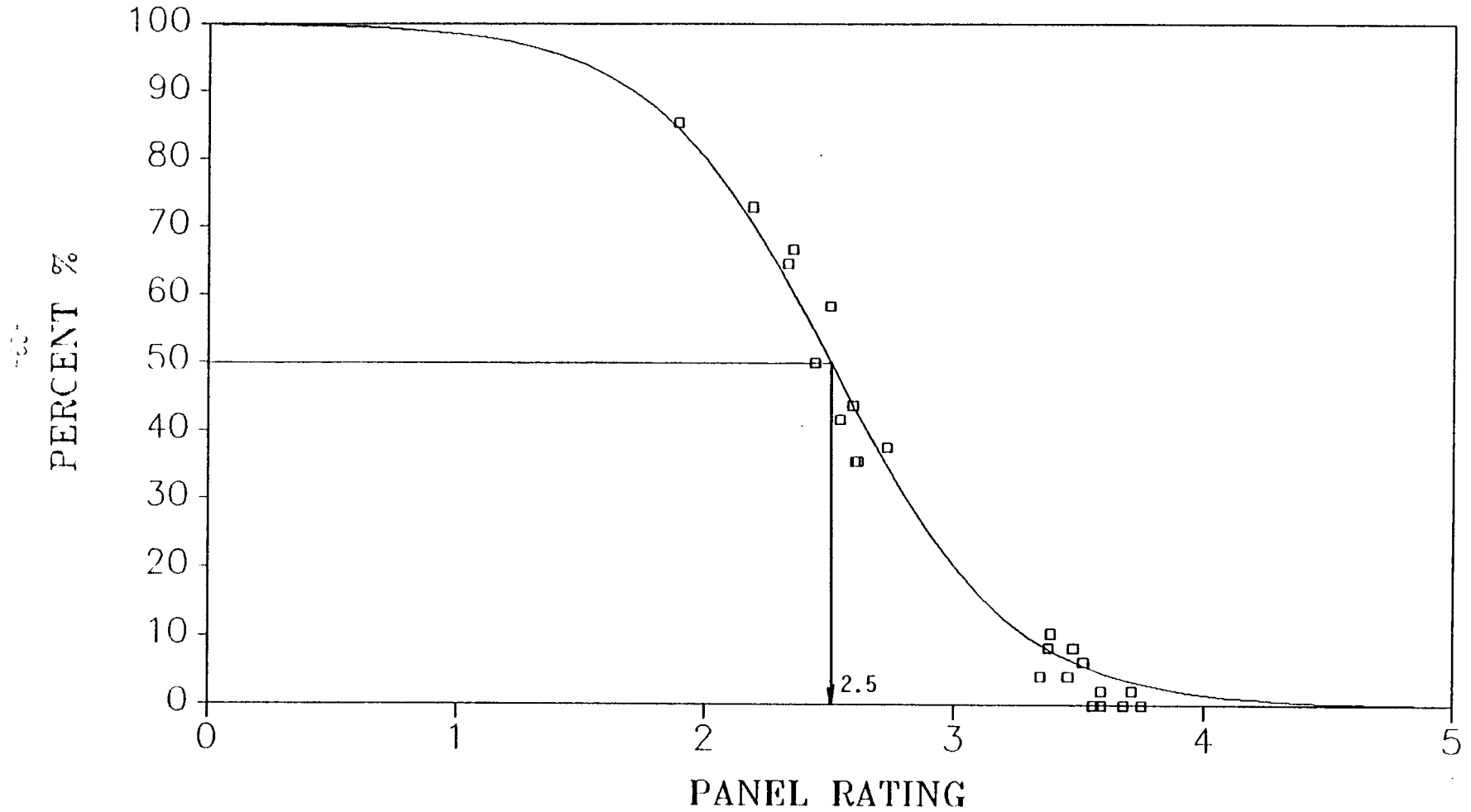


Figure 18 - Logit Analysis Plot (Concrete Pavements)

LOGIT ANALYSIS OF 1986 TERMINAL SERVICEABILITY DATA CONCRETE PAVEMENTS



5.0 CONCLUSION

As a result of the relationships developed in these studies, we can now confidently estimate the ride quality of a pavement section from the objectively measured level of roughness.

We also have New Jersey specific terminal serviceability indices for bituminous, concrete and composite pavements. These values will provide the Department with a gauge to better identify those pavement sections which the traveling public would find unacceptable.

These two findings are of major importance to our Pavement Management System development and refinement.

REFERENCES

1. Janoff, M.S. et al., "Pavement Roughness and Ride Quality," Final Report, NCHRP 1-23, November 1984.
2. Carey, W. N. and Irick, P.E., "The Pavement Serviceability Performance Concept," HBR Bulletin 250, 1960.
3. NCHRP, "Pavement Roughness and Rideability Project 1-23", Project Statement (Undated).
4. Gillespie, T.D. et al., "Calibration of Response-Type Roughness Measuring Systems," NCHRP Report 228, December 1980.
5. Janoff, M.S. and Nick, J.B., et al., "Evaluation and Quantifying User Perception of Pavement Serviceability," Final Report, Pennsylvania Department of Transportation, February 1983.

Appendix 1

Locations of 1985 Panel Test Sites

Appendix 1.
RATING PANEL
FIRST DAY ROUTE

MORNING

Depart main complex North on Parkway Avenue through West Trenton to Rt. 175 North to:

I-95 North

Site 34 Mile 1.00-1.25 and

Site 31 Mile 2.25-2.50

Continue North on I-95 and:

I-295 South

Site 15 Mile 65.50-65.25 and

Site 35 Mile 63.25-63.00

Exit I-295 Left on Kuser Road
Right on White Horse Avenue
Left on Arena Drive
Left on:

I-195 East

Site 32 Mile 3.75-4.00

Site 24 Mile 6.50-6.75

Exit next Interchange and U-turn to I-195 West
Exit Rt. 130 South to:

Rt. 206 South

Site 26 Mile 33.25-33.00

Lunch Break
Meet at Mastoris Diner (Rt. 206 & 130) after lunch.

RATING PANEL
FIRST DAY ROUTE

AFTERNOON

Exit Mastoris Diner on Rt. 130 South to:

I-295 South

Site 21 Mile 54.75-54.50

Continue South on I-295 to Burlington Exit (Rt. 541)
Follow Rt. 541 to:

Rt. 130 North

Site 12 Mile 28.5-28.75

Site 20 Mile 49.75-50.00

Continue North on Rt. 130
Right on Rising Sun Road to Rt. 206 South
Left on:

Rt. 68 South

Site 16 Mile 6.75-6.50 and

Site 19 Mile 5.25-5.00

U-turn to Rt. 68 North to Rt. 206 North
Left on Lalor Street to:

Rt. 29 North

Site 22 Mile 4.75-5.00 and

Site 11 Mile 7.50-7.75

Return to Main Complex

RIDE PANEL RATING
SECOND DAY ROUTE

MORNING

Depart main complex North on Parkway Avenue through West Trenton to:

Rt. 29 South

Site 28 Mile 8.25 to 8.00

Continue South on Rt. 29

Site 17 Mile 5.25 to 5.00

Continue South to Lalor Street to South Broad Street (Rt. 206)

Continue South on Rt. 206 to:

Rt. 130 South

Site 36 Mile 50.00 to 49.75 and

Site 24 Mile 48.75 to 48.5

Continue South on Rt. 130 into Burlington and turn left on Rt. 541.

Follow 541 to:

I-295 North

Site 13 Mile 54.75 to 55.00

Exit I-295 at Rising Sun Road (Signs to Turnpike)
Right turn at Rt. 206 (Move to left lane)
Left turn to Rt. 68 South
U-turn after Mile 5 to:

Rt. 68 North

Site 29 Mile 5.75 to 6.00 and

Site 18 Mile 6.75 to 7.00

Lunch Break

Meet at Mastoris Diner (Rt. 206 & 130) after lunch.

RIDE RATING PANEL
SECOND DAY ROUTE

AFTERNOON

Depart Mastoris Diner on Rt. 130 South to Rt. 206 South
U-turn vicinity Mile 31 to:

Rt. 206 North

Site 27 Mile 32.75-33.00

Continue North on Rt. 206 to Rt. 130 North to I-195 East
U-turn at Exit 7 (Rt. 526) and proceed west

I-195 West

Site 14 Mile 6.75-6.50 and

Site 10 Mile 3.75-3.5

Exit I-195 to Arena Drive North
Right on White Horse Ave.
Left on Kuser Road
Right on:

I-295 North

Site 33 Mile 63.00-63.25 and

Site 30 Mile 65.25-65.50

Continue North on I-295 to:

I-95 South

Site 37 Mile 2.50-2.25 and

Site 23 Mile 1.25-1.00

Return to Main complex

Appendix 2

1985 Instructions for Panel Rating

Appendix 2.

INSTRUCTIONS FOR PANEL RATING

PURPOSE: The purpose of this study is to determine what typical N.J. users think of the ride quality (smoothness or roughness) of our State Highways. The information will be used to determine which N.J. Highways to repair and in which order this should be done given the limited funds which are available.

OBJECTIVE: The main objective of this portion of the study is to get your opinion of the ride quality provided by 28 specific ¼ mile sections of State and Interstate Roads which are located in this general area. Your opinions of the test sections which you will rate will be compared to the values measured with the Department's Mays Ride Meter.

Secondly, we will ask you to pass judgement on the sections you will rate. "Is this ride acceptable" or should tax dollars be spent to improve the ride quality of this road.

RIDE QUALITY SURVEY:

All the roads which you rate will be between two extremes, impassable and perfect.

Impassable: A road which rides so poorly you doubt if you or the car will make it to the other end at the speed you are traveling (like traveling down a railroad track along the ties.

Perfect: A road which is so smooth that at the speed you are traveling you can hardly feel the road. You doubt that anything can be done to improve the ride.

Since these extremes probably do not exist on the N.J. roads which you will be rating, your choices will probably lie somewhere between the two.

In order to help you in making your rating we have included a number of words along the scale which could be used to describe how the riding sensation seems to you. For example, if you should encounter a road for which you describe the ride as FAIR but not quite GOOD, place your mark between the GOOD and FAIR.

NOTE: We are not asking you to replace each section into one of five categories. You should use small differences in the position of your marks on the scale to indicate your opinion as specifically as possible.

ACCEPTANCE SURVEY:

After you have made your rating of the ride quality of a section, we want you to check the appropriate box along the side the rating scale to indicate whether or not you feel this level of ride is acceptable on this section of State or Interstate Highway.

PROCEDURE OF THE SURVEY:

You will be rating 7 quarter mile sections of road each morning and each afternoon.

All the pavements which you rate in the morning or afternoon will be concrete or bituminous (black top).

You will be given a package of 7 forms with the section numbers already filled in. We will review the numbers before the test to be sure you have the proper numbers in the correct order.

The beginning and end of each $\frac{1}{4}$ mile section will be delineated by a orange NJ DOT cone.

As you approach the section the driver will call out the section number as you pass the cone he will tell you to START. Begin concentrating on the feel of the ride. At the second cone the driver will say STOP. At this point place your rating on the form.

Next indicate whether you feel the ride quality is acceptable for this road and speed or whether the ride quality should be improved.

SPECIAL INSTRUCTIONS:

Once you have selected your location in the vehicle, please use the same location for both days.

When making your rating, only consider the ride quality of the pavement within the $\frac{1}{4}$ mile test section.

Concentrate only on the ride quality provided by the roads. Don't let the appearance of the road surface influence your rating. Judge only on how the road feels.

Don't discuss your ratings with the other raters. There are no right of wrong answers. We are interested in YOUR opinion not the average opinion of everyone in the car.

Please bring a clipboard with you.

Appendix 3

Analysis of Rating Results

Appendix 3.

ANALYSIS OF RATING RESULTS

R. Barros
January 10, 1986

Statement of Findings

A pavement user survey conducted in July, 1985, by the Pavement Management Task Force yielded the following findings:

- 1) Precision of New Jersey user opinion, while consistent with that of other studies, was weaker than intuitively expected.
- 2 Terminal serviceability levels for pavement roughness in New Jersey occur at a Mays value of approximately 237 inches per mile. (This corresponds to a PSR value of 2.2 when substituted into the model presented below.)
- 3) The available data supports only a single relationship modeling user opinion as a function of pavement roughness. Both rigid and flexible pavements are adequately represented by this relationship. The current best model is:

$$PSR = 5.0 * e^{-0.0175 * MAYS^{0.7035}}$$

- 4) The inability to distinguish a difference in user opinion between rigid and flexible pavements is recognized to depart from expectations based on earlier work. This finding of no distinction survived extensive checks of both the experimental design and the data collection process.
- 5) It has been suggested that a second pavement survey may be warranted, but this time incorporating Profilometer data as well as Mays readings. (Had pavement roughness been characterized with a Profilometer rather than a Mays Meter, it is believed, the distinction between pavement types would have had an increased opportunity of detection.) Furthermore, if this second survey is properly timed, then measurements with the ARAN unit scheduled for delivery later this year will also be available for study. The findings of a second survey would be expected to both confirm the appropriate statistical model and also provide direct relationships between three instruments considered preeminent in the evaluation of pavement ride and/or condition with New Jersey user opinion.

Discussion

A panel of 23 raters was convened over a two-day period to provide subjective opinions regarding their impression of ride quality on 37 pavement sections. These pavement sections were representatively distributed with respect to the roughness ranges observed systemwide for rigid and flexible pavements, respectively. The 'true' roughness of each section was assumed to be the average Mays reading of the Department's four Mays vehicles, with each vehicle making three passes over each site. And, while it is not yet possible to make temperature corrections to the Mays data, all Mays runs were made on consecutive days under similar, warm weather conditions.

Upon first review of the data, an inescapable observation is the high variability of user opinion. A spread of 2.5 Present Serviceability Rating (PSR) units between the high and low rater was typical, even though the total range of the PSR scale is only 5.0. A reasonableness check with Ketron data from a 1983 study in Pennsylvania indicated that our standard deviation of 0.65 was consistent with theirs, and a second check with a 1963 Purdue study revealed a similar degree of variability. The mean PSR values at each site were substantially less dispersed, of course, and permitted informative relationships to be identified.

A logit analysis was performed on the Acceptable/Not-Acceptable responses of the raters for each pavement section. An S-shaped curve was produced, modeling uniform acceptability when the ride was perfectly smooth, uniform unacceptability when the ride was extremely rough, and allowing for a transition phase in-between. According to AASHTO convention, terminal serviceability occurs when 50 percent of the raters find a pavement to be unacceptably rough. This occurred with our data when the Mays value dropped to the vicinity of 237 inches per mile. This roughness was subsequently determined to correspond to a PSR value of, approximately, 2.2.

It should be noted that logit analyses normally require a large amount of data and, while a reasonably good fit was obtained in our experiment, the available sample size must be considered relatively small. This problem was inadvertently compounded by the form of the question posed to each rater. Rather than force them to choose between "Acceptable" and "Not Acceptable" responses, a third alternative, "Unsure", was also allowed. The logit model requires binary type data and is unable to make use of such intermediate responses. Hence a further reduced sample size was imposed, consisting of only those raters able to reach an extreme decision. It is recommended that the "Unsure" response be omitted from future surveys. The available data yielded a reasonably good fit to the model, nevertheless, with an R-Square value of 0.77.

The proportion of raters expected to find a pavement acceptable may be estimated with the following logit equation:

$$P = \frac{\text{EXP}(B_0 + B_1 \cdot \text{MAYS})}{1.0 + \text{EXP}(B_0 + B_1 \cdot \text{MAYS})}$$

where: $B_0 = 4.97$
 $B_1 = -0.021$

A substantial effort was made in developing, refining, and confirming the statistical model for the (MAYS,PSR) relationship. A critical part of this effort was the determination of the most appropriate form for this model. That is, should the general shape of the fitted curve be a straight line, a parabola, or an exponential function? Do additional criteria exist, relevant to the data's structure, but not wholly described by the sample observations, which should also be considered in the model's evaluation? And, finally, what is the significance and weight assignable to the discrepancies (and similarities) between the model produced and other models found in the literature?

A fundamental theoretical point must be unequivocally established prior to further discussion. Statistical models are simply mathematical functions, $y=f(x)$, used as a convenient surrogate for a large array of (x,y) coordinates. They provide a means to interpolate between observed (x,y) points and filter out 'statistical noise' by locally smoothing the $y=f(x)$ relationship.

The 'best fit' of a model simply minimizes the degree to which some function $y=f(x)$ misses the net array of (x,y) coordinates in a predetermined manner. Regardless of the form of the model selected, however, be it a straight line, a parabola, or an exponential, a (different) 'best fit' will be found for each form of the function $y=f(x)$. Each of these 'best fits' can be expected to model the observed data points reasonably well within the range of observed x values. For example, a straight line may adequately approximate a very flat parabola within a limited range of data.

Selection of the best form of the model requires careful consideration. If one adopts the 'best fit' of a model with an inaccurate form, then latent errors are predestined to surface under certain conditions of the model's subsequent use. Estimated y values calculated with the $y=f(x)$ relationship may substantially differ from their true values and, unfortunately, they will probably differ to a degree understated by the precision estimated with established statistical techniques. Consider the straight line approximating a parabola: the discrepancies will tend to grow as x values approach the extremities of the observed data and, ultimately, diverge completely. Thus, while several forms of a statistical model may appear to be practically indistinguishable within the range of the observed data, selection of that form which is best must also, in some manner, consider the inherent structure of the data collected.

Two boundary constraints exist for the (x,y) coordinates in modeling the (MAYS,PSR) relationship. First it must be acknowledged that both measures of pavement roughness have a fixed extreme value for perfectly smooth pavements. That is, were a Mays value of 0.0 inches per mile ever to be encountered, the PSR measure could never be anything but 5.0. Second, pavement roughness may increase indefinitely without an upper bound. As pavement roughness increases to infinity, a minimum PSR value (0.0) will be approached. On an X-Y, graph such a relationship is modeled by an asymptotic function.

The appropriate statistical model is therefore assumed to be the smooth function fitting both of these boundary conditions, and the 'best fit' of the model determined by those specific parameters which allow the function $y=f(x)$ to most closely reproduce the array of observed (x,y) coordinates. A model of the form

$$y = 5.0 \cdot e^{a \cdot x^b}$$

is an excellent candidate for this task because it can manifest the family of curves shown in Figure 1. Given the general form, i.e., the family of curves, statistical methods are used to identify the specific values of a and b which prescribe the single, most appropriate equation. The parameters a and b may be most meaningfully estimated with nonlinear regression techniques. (The general linear model approach can also be used but is subject to certain drawbacks, as the 'best fit' is arrived at by minimizing the residual error on a transformed scale. This fit may not correspond to the optimum on a scale of the original units.)

Observed (MAYS,PSR) coordinates were recorded preserving the distinction between rigid and flexible pavements. Regression analyses were conducted in a manner which would allow different, individual curves from the family of curves (Figure 1) to be identified for each pavement type if justified by the observed trends. However, the experimental data did not support a distinction between rigid and flexible pavements. The 'best fit' curve for all pavements was found to be :

$$PSR = 5.0 \cdot e^{-0.0175 \cdot MAYS^{0.7035}}$$

A conventional R-Square value is not meaningful when nonlinear regression techniques are used but, as illustrated in Figure 2, this model trends through the mass of the observed data points very well. (Had the general linear approach been taken, where the squared residual errors are minimized on a natural log scale rather than on the direct unit measurements themselves, the R-Square value would be found to be 0.51.)

Figure 3 presents the model in what may be a more informative context. The mean PSR values for each site, plus a range of two standard errors on either side of the mean, are plotted as a vertical line. Rigid pavements are represented by continuous

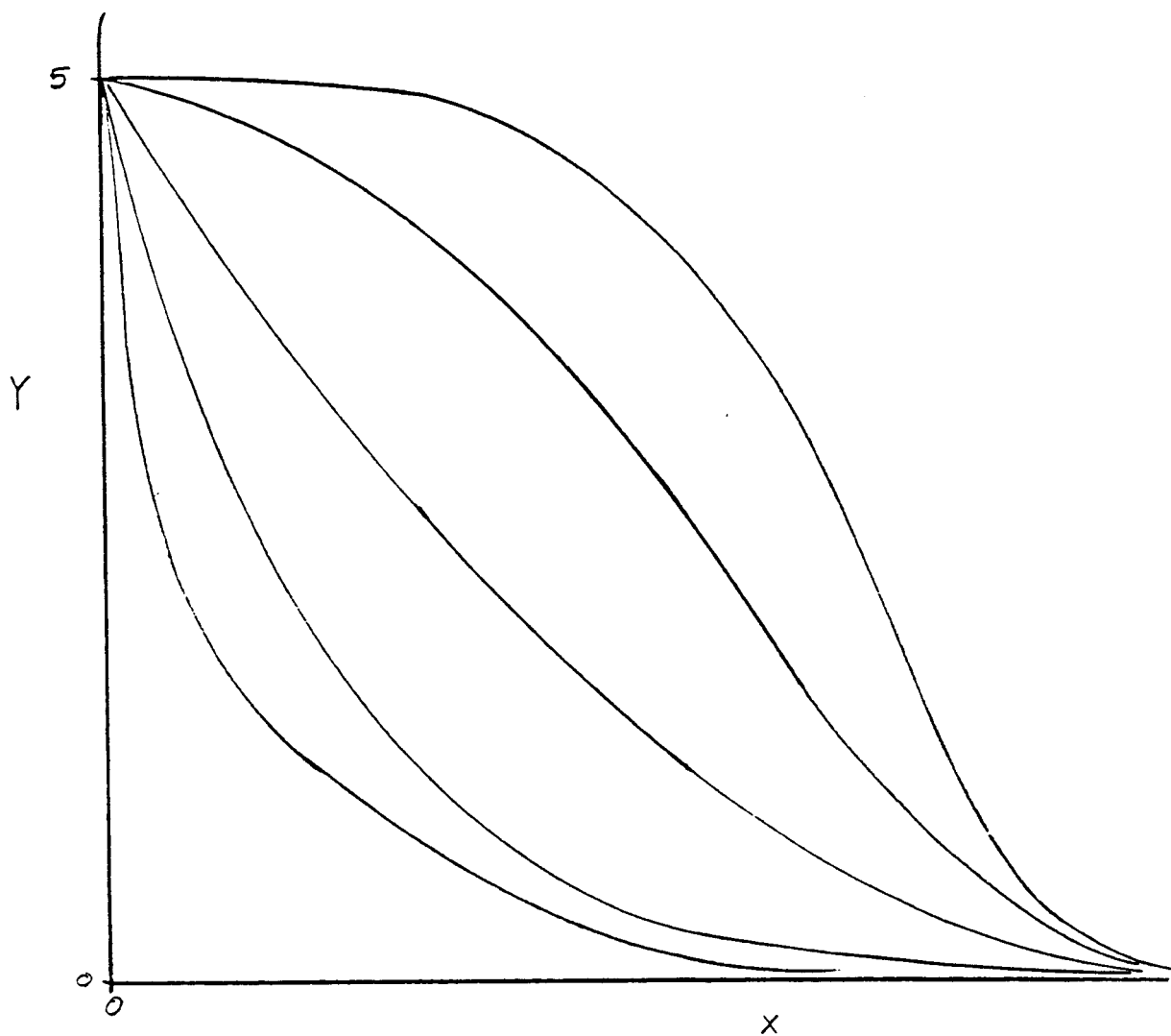


Figure 1. A family of exponential curves.

PSR

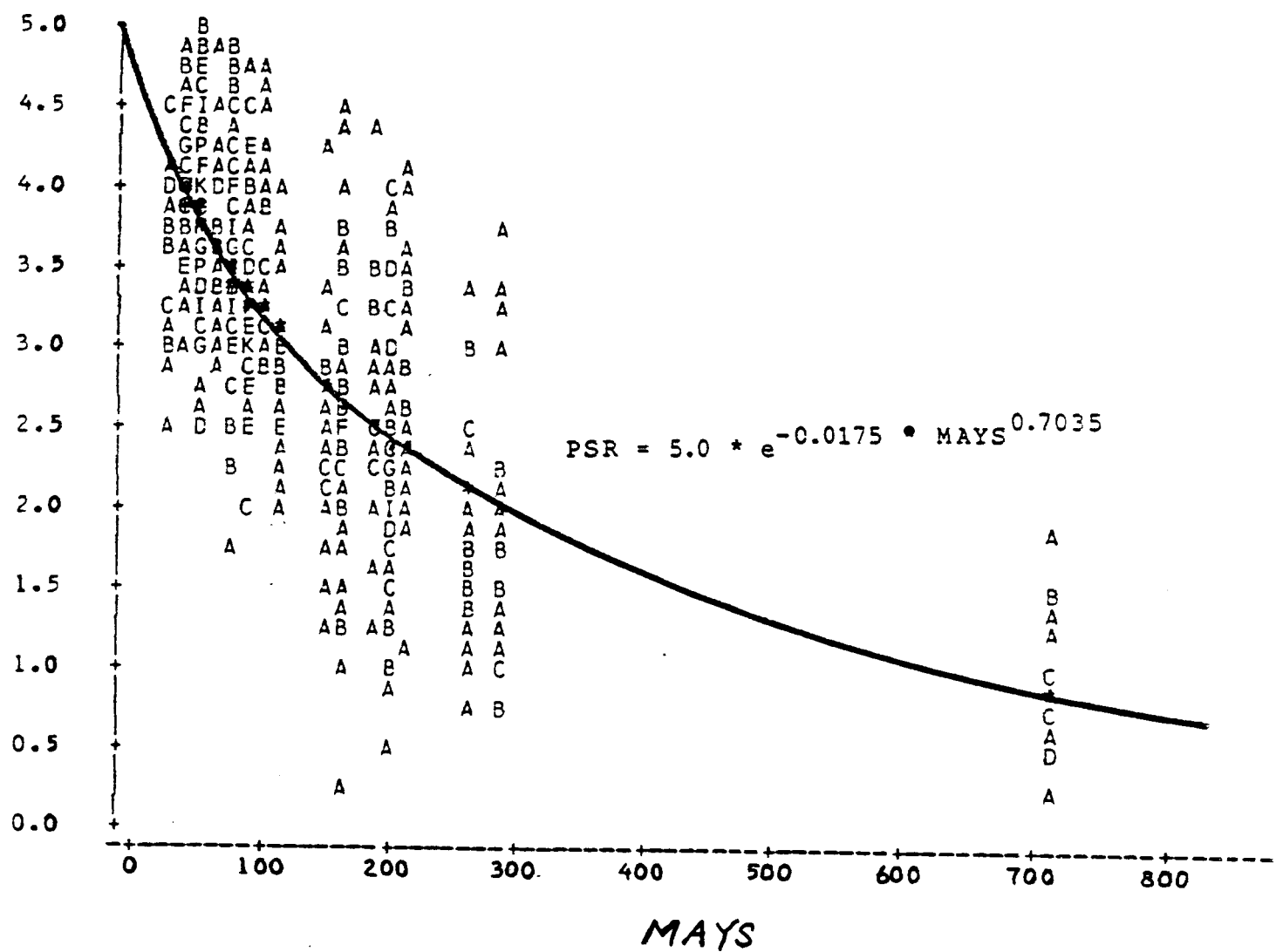


Figure 2. Scatter plot of (MAYS,PSR) and the fitted model.

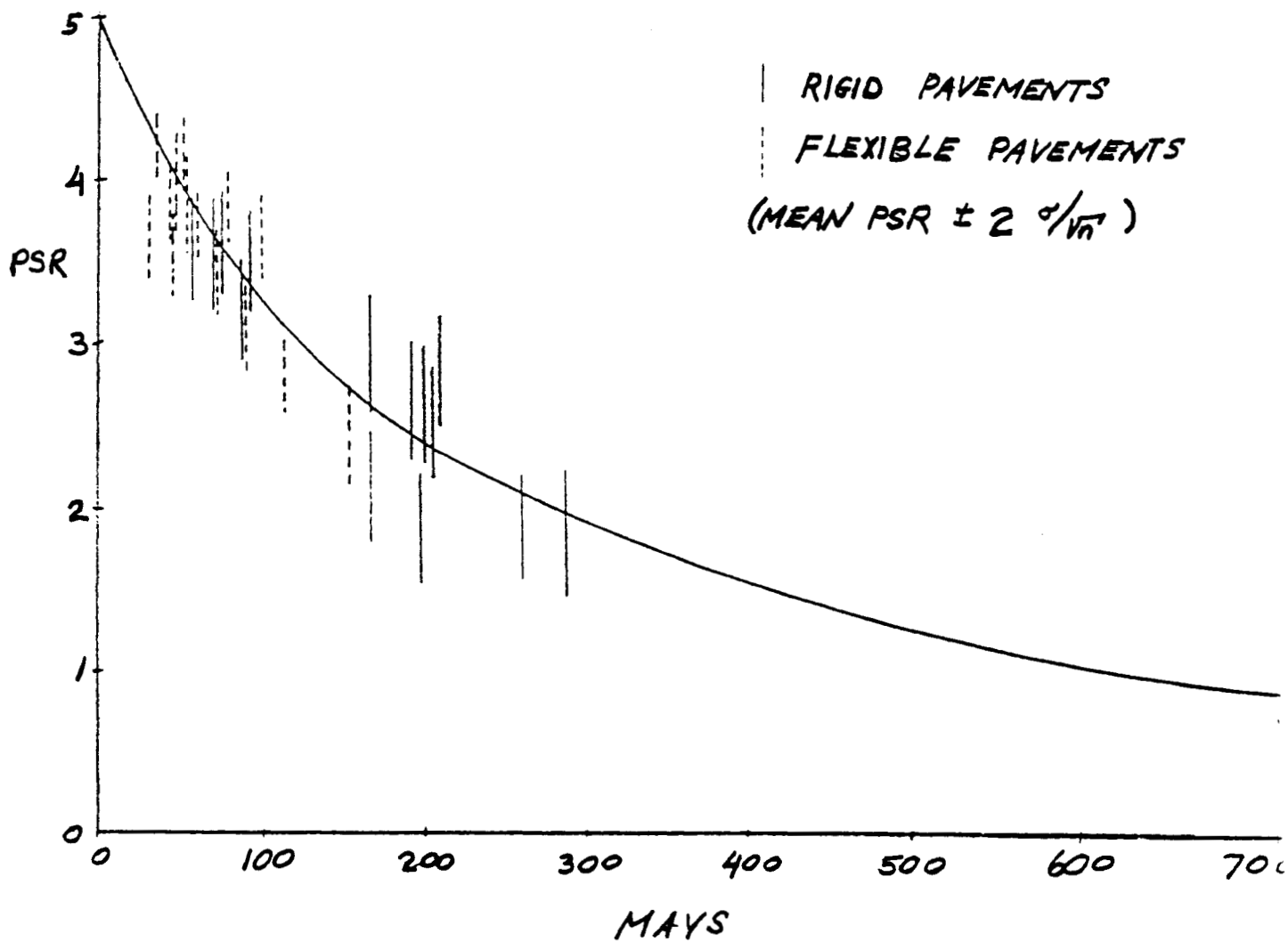


Figure 3. Relationship between mean PSR, fitted model, and pavement type.

lines while flexible pavements are represented by dashed lines. It can be seen that the model does indeed estimate the mean PSR values relatively well, and that rigid and flexible pavements coexist in an overlapping domain of user opinion.

This model differs from others cited in the literature in two respects. First, it incorporates known constraints into the mathematical model whereas earlier work concentrated only on obtaining the 'best fit' of y within the observed range of x . Second, this study was unique in its access to New Jersey user opinion. Thus it was not surprising that the estimates produced by earlier models differed from the estimates produced with this one. Based on the information available at this time, it is the opinion of the Pavement Management Task Force that the above is indeed the most appropriate model for use in New Jersey.

It has been established in the literature that user opinion of ride quality is influenced by pavement type, but leading authorities (i.e., Hudson and Janoff,) independently report that the Mays Meter is incapable of detecting this effect. It appears that the Mays Meter is insensitive to subtle factors which influence user opinion, such as the one-third octave band frequencies Janoff has identified with a Profilometer. It is recognized that this finding of no distinction between pavement types may have significant repercussions upon the Department's Pavement Management System.

If it is important to quantify the difference in New Jersey user opinion between flexible and rigid pavement ride quality, it is possible this may be achieved by conducting a second panel rating survey in which pavement roughness is measured with a Profilometer. Furthermore, since the Department is scheduled to receive an ARAN unit later this year, this panel survey could be timed to incorporate ARAN measurements as well as Mays and Profilometer readings, thus permitting us to establish direct relationships between the various instruments. (It is not expected that Mays readings will be sensitized to the difference between rigid and flexible pavements as a result, however.) These transforms, combined with a direct relationship to user opinion, would assure the development of a well calibrated Pavement Management System.

Appendix 4

Analysis of Variance of 1985 Pavement Roughness Panel Study

TO MEMORANDUM OF RECORD

MEMORANDUM

FROM Ricardo T. BarrosSUBJECT "Analysis of Variance, 1985 NJDOT
Pavement Roughness Panel Survey" DATE 5/23/86 TELEPHONE NO. _____OVERVIEW

This analysis investigated the observed variability in the 1985 pavement roughness panel survey on a substantially more detailed level than previously attempted. While specific influences on the rating results have been identified, these findings remain consistent with previous work. Important conclusions are: pavement roughness is indeed the predominant influence on the reported ratings, pavement type is not a significant consideration after the level of roughness has been screened from the data, and both the individual rater and the vehicle used also significant factors.

DISCUSSION

The July, 1985, pavement roughness panel survey results were investigated with the objective of identifying the specific sources of variability which influence the reported ratings. Analysis of variance (AOV) techniques were applied to test whether the various ways in which the data could be partitioned would survive a test for statistical significance. A finding of statistical significance would indicate that the partitioning criteria meaningfully segregated (at least) two levels of the response variable. For example, pavement sites with roughness levels known to differ elicited a correspondingly varying rating of acceptability from the panel members. Thus, it was not surprising that the factor SITE was found to be statistically significant in explaining the variability observed in RATING.

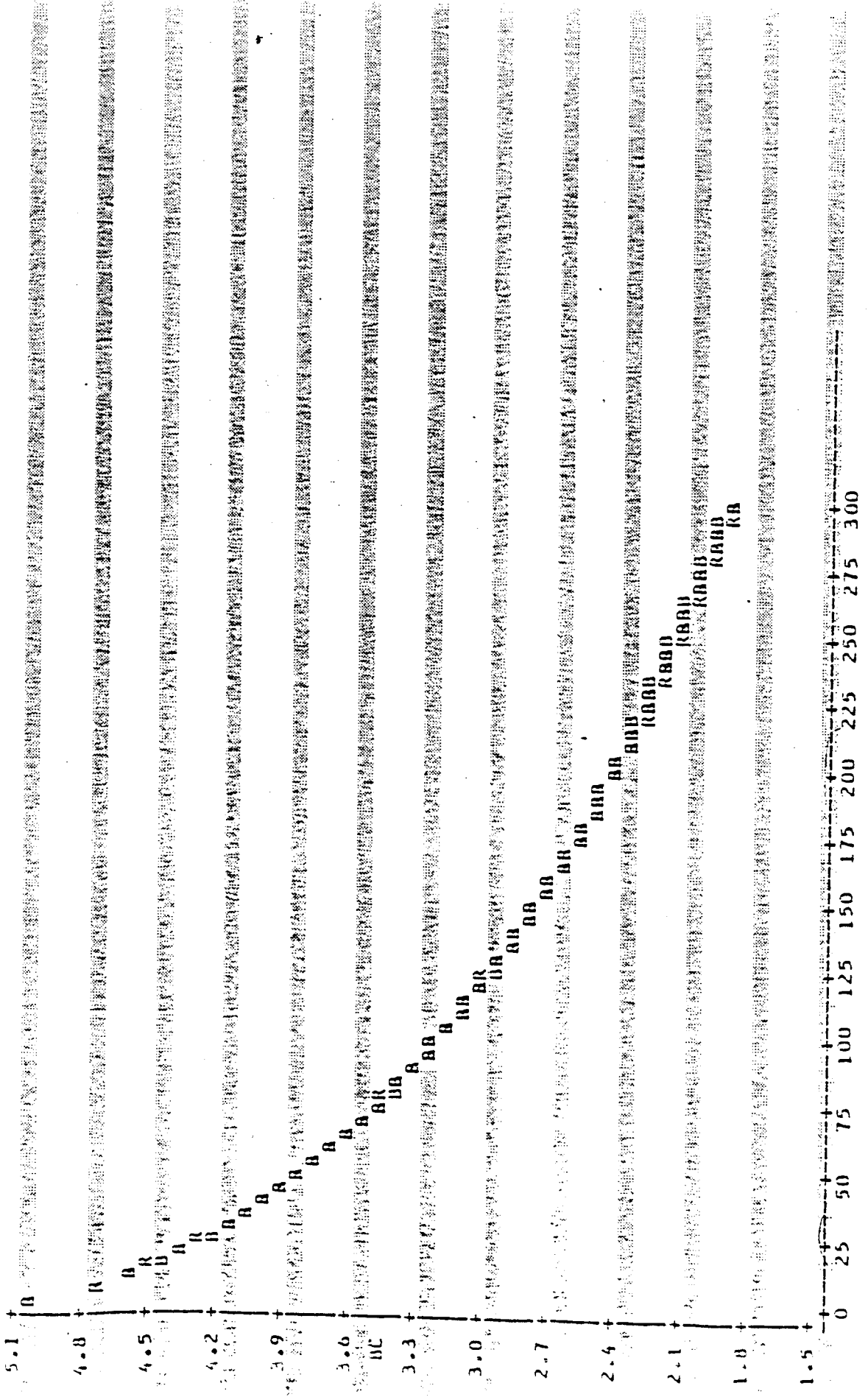
At least four alternative procedures exist with which the test of significance may be applied, not all of which may be appropriate for each experimental design. In the present application, two criteria are possible, those designated by their summation process as Type I and Type III Sums of Squares. The Type III procedure is the more conservative. (It is unaffected by unbalanced sample sizes within the partitioned cells and is independent of the order in which the factors to be tested are listed in the model.) Thus, strong emphasis was placed on the results of this procedure even though the alternative, Type I, allowed a greater number of factors to be tested.

Previous work has concluded that the relationship between the level of pavement roughness (measured by a Mays Meter) and user perception is a nonlinear one ("Analysis of Panel Roughness Rating Results", R. Barros, 2/27/86). Visual inspection of the data clearly indicated that, although the distribution of pavement roughnesses of bituminous pavements is distinctly offset from the distribution of rigid pavement roughnesses, both distributions independently estimate virtually the same Present Serviceability Rating (PSR) — Roughness relationship. This nonlinear relationship is presented in Figure 1. An "R" is printed at the (X,Y) coordinate predicted by the rigid pavement distribution, and a "B" is printed at the analogous (X,Y) coordinate predicted by the bituminous pavement distribution. The agreement between the two nonlinear curves is so close that most predicted points are plotted on top of one another.

Given the knowledge of a distinct offset between roughness distributions of rigid and bituminous pavements, care is required in applying and interpreting AOV analyses. If one forges ahead, then one would find that both Type I and Type III, Sums of Squares, identifies the variable PAVE, for pavement type, as

SAS 11:03 TUESDAY, APRIL 22, 1986

PLOT OF BCXX SYMBOL USED BY IS R
 PLOT OF RCXX SYMBOL USED IS R



X

FIGURE 1. PLOT OF PREDICTED PSR VALUES FOR BITUMINOUS AND RIGID PAVEMENTS.

highly significant in partitioning the levels of PSR, as measured by the variable RATING. In the present case, this does not mean that a different PSR relationship exists for each pavement type, it means that two different aspects of the same relationship have been identified. (Rigid pavements tend to be rougher and are generally associated with lower levels of RATING than bituminous pavements.)

It is possible to quantitatively distill from the variable PAVE the principal influence leading to a significant distinction in the variable RATING. Introduction of a new variable for each site, PREDPSR, reflecting the predicted rating one would expect based exclusively on the roughness level observed at that site, liberates the variable PAVE to exclusively reflect non-roughness type effects. These might include extraneous variables such as pavement color, rutting, and so forth.

Application of a second AOV, but this time incorporating the variable PREDPSR, reveals that the variable PAVE now becomes non-significant under both the Type I and the Type III Sums of Squares testing procedures. The level of significance dropped from 0.0001 to 0.4454. PREDPSR, on the other hand, is significant at the 0.0001 level with the Type I method and deemed untestable with the Type III. The apparent interpretation of these findings is clear. Once the influence of roughness has been filtered from the controlled factor PAVE, pavement type no longer meaningfully assists in explaining the variability observed in the reported user perception of pavement serviceability.

It is recognized that in an ideal analysis, one would first estimate the parameters of the appropriate nonlinear PSR-Roughness model, as has been done,

then apply this model to an independent set of data for the AOV analysis. This was not possible because only one data set was available. Thus, the same data used to estimate the nonlinear parameters of the model was also used to test the explanatory power of the model in the AOV analysis. It is expected that the primary consequence of this lack of independence will be the loss of power in identifying statistical significance. As it turns out, several of the partitioning factors considered were found to be statistically significant nevertheless, suggesting this lack of independence was not overly detrimental in the present application. Furthermore, application of engineering judgment to the information presented in Figure 1 strongly confirms the latter AOV result that the variable PAVE is not an important consideration in partitioning the various levels of RATING throughout the observed range of pavement roughness.

Eight partitioning criteria were tested in the AOV of the panel survey results. These are presented in Table 1. Of these, only four variables, PAVE, VEH, POSITION, and either SITE or PREDPSR may be tested with the Type III procedure. (The remaining variables are considered to have zero degrees of freedom in this experimental design by this procedure.) As shown in Table 2, the factors SITE, VEH, and POSITION were found to very significantly influence the level of RATING.

Taken together, SITE, VEH, and POSITION account for a substantial portion of the observed variability in the reported pavement rating. The R-Square for this model is 0.77. The residual error has a standard deviation of 0.47 units in PSR.

Interpretation of the variables SITE and VEH is relatively straightforward. One predominantly reflects the degree of pavement roughness and the other the

TABLE I
VARIABLES INCLUDED IN PANEL RATING AOV

<u>VARIABLE NAME</u>	<u>DESCRIPTION</u>	<u>COMMENT</u>
RATING	A continuous variable from 0 to 5, with higher numbers reflecting a more favorable user-perception of pavement roughness.	RATING is the response variable in the AOV.
PAVE	Pavement type, either Rigid, Bituminous, or Composite.	
SITE	A unique designation identifying a specific pavement section.	
DRIVEXP	Driver experience, either "LITTLE" if less than 5 years, or otherwise, "LOTS".	
SEX	Sex of rater.	
CATEGORY	"T" for those raters professionally involved in some form of technical diagnostic evaluation of pavements, otherwise "N" for nontechnical.	
VEH	License plate number of vehicle in which rater rode.	
POSITION	Position in vehicle: "RF" for right front, "LR" for left rear, and "RR" for right rear.	Note that because "LR" in one vehicle is not the same as "LR" in another, POSITION is nested within VEH. Note also that since individual raters did not change seats or vehicles, the individual rater effect is confounded within this variable.
PREDPSR	The predicted rating produced with the nonlinear model: $\text{PREDPSR} = 5 * e^{-0.018\text{MAYS}}^{0.703}$	It is recognized that it would have been desirable to independently develop the nonlinear model used to compute PREDPSR. This was not possible in the present case. Thus, a certain degree of overlap in explanatory power may be unavoidable with respect to the variables SITE and PREDPSR.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RATING

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	50	382.58133077	7.65162662	33.94
ERROR	508	114.52723846	0.22544732	PR > F
CORRECTED TOTAL	558	497.10856923		0.0001

R-SQUARE	C.V.	ROOT MSE	RATING MEAN
0.769613	14.9747	0.47481293	3.17076923

SOURCE	DF	TYPE I SS	F VALUE	PR > F
PREDPSR	1	223.94461489	993.33	0.0001
PAVE	1	0.15166536	0.67	0.4125
SITE(PAVE)	25	41.53492619	7.37	0.0001
DRIVEXP	1	3.02692843	13.43	0.0003
SEX	1	1.97605229	8.77	0.0032
CATEGORY	1	1.48325677	6.58	0.0106
VEH	7	34.84181789	22.00	0.0001
POSITION(VEH)	13	75.62206895	25.80	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
PREDPSR	0	0.00000000		
PAVE	1	0.13147245	0.58	0.4454
SITE(PAVE)	25	41.29293923	7.33	0.0001
DRIVEXP	0	0.00000000		
SEX	0	0.00000000		
CATEGORY	0	0.00000000		
VEH	7	31.00938594	19.65	0.0001
POSITION(VEH)	13	75.62206895	25.80	0.0001

TABLE 2. FULL AOV MODEL INCORPORATING BOTH PREDPSR AND SITE.

dampening capability of the vehicle's suspension. Interpretation of the variable POSITION is slightly less clear. It was intended to reflect which passenger seat was occupied by each rater. Raters maintained the same seat within the same vehicle throughout the experiment, however, confounding the rater-to-rater effect with that of POSITION. Rater-to-rater variability must be considered a random (or uncontrollable) effect and, while POSITION may not be random, it can be reasonably approximated as one, thus, this shortcoming was considered to be of limited impact. Both rater-to-rater and the POSITION effects can be justifiably pooled into the term of inherent variability.

The variable SITE is a class, or categorical, parameter uniquely identifying each pavement section and is not a continuous variable. That is, Site 3 is neither lower nor higher than Site 4. Thus it is only partially helpful to know that the sites are significantly different — after all, they were included in the experiment precisely because they were different.

The predominant distinction between the various sites has been assumed to be their level of roughness. Elimination SITE from this model allows PREDPSR, a continuous variable, to assume the role of its surrogate. A key advantage offered by this modification is that, more than knowing that sites affected PSR differently, the model assists in understanding how the sites affected PSR. The equation used to generate PREDPSR can be quantitatively assessed. Table 3 shows that PREDPSR is indeed highly significant provided the SITE is not also in the model, confirming the assumption that the predominant distinction between sites is roughness. The R-Square for this model drops by 0.08 to 0.69, representing the small loss in explanatory power one pays for a quantitatively more clear model under test.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RATING

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	24	341.13518601	14.21396608	48.66
ERROR	534	155.97338322	0.29208499	PR > F
CORRECTED TOTAL	558	497.10856923		0.0001

R-SQUARE	C.V.	ROOT MSE	RATING MEAN
0.686239	17.0447	0.54044888	3.17076923

SOURCE	DF	TYPE I SS	F VALUE	PR > F
PREDPSR	1	223.94461489	766.71	0.0001
VEH	7	33.98837095	16.62	0.0001
POSITION(VEH)	16	83.20220017	17.80	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
PREDPSR	1	221.71448926	759.08	0.0001
VEH	7	33.63691080	16.45	0.0001
POSITION(VEH)	16	83.20220017	17.80	0.0001

TABLE 3. REDUCED AOV MODEL WITH PREDPSR AS A SURROGATE FOR SITE.

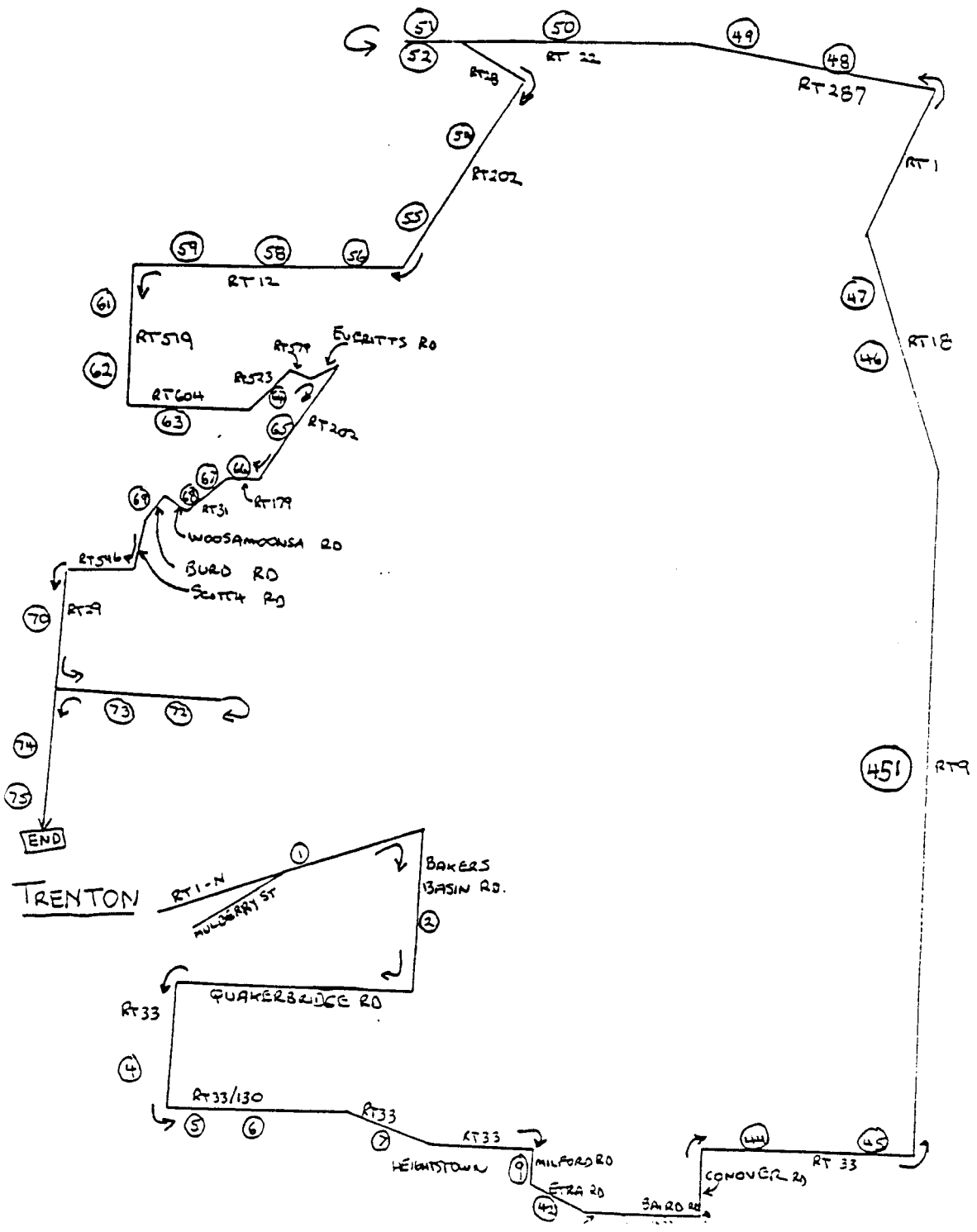
It is interesting to note that, had a Type I AOV analysis been selected, these same conclusions would have been reached. The Type I analysis would have also indicated that the variables DRIVEXP, SEX, and CATEGORY were also significant in partitioning levels of the response variable RATING. The resultant R-Square does not change but remains 0.77, however, suggesting that the additional refinement does not further diminish the residual error from what was previously achieved. Thus, support is generated to accept the simpler, but comparably powerful, Type III analysis.

In summary, a concise model has thus been defined which accounts for nearly 70 percent of the observed variability in PSR. This model is easily interpreted. Aside from pavement roughness, the vehicle used to ride over a pavement and the individual rater has also been found to have a significant effect with a Type III AOV procedure. Pavement type is concluded to be non-significant in influencing user perception of pavement serviceability.

Appendix 5

Locations of 1986 Panel Test Sites

NORTHERN ROUTE (DAY 1)



Appendix 5.
NJ Route/North

Enter Route 1 NB at or south of Mulberry St.

- *1C* Road: Route 1 NB
 Speed: 55 mph
 Warning: Mulberry St. exit
 Start: MP-3
 End: "Whitehead Rd Next Right" sign

- ### Continue NB on US 1
 Turn right onto Bakers Basin Rd/Shell gas station on left/
 at traffic signal.

- *2B* Road: Bakers Basin
 Speed: 35 mph
 Warning: Youngs Rd intersection
 Start: Just past stone house on right at the end of the
 curve
 End: Paint on road/tree overhanging road before curve

- ### Turn right onto Quakerbridge Road

- *3B* Road: Quakerbridge Road
 Speed: 45 mph
 Warning: First traffic signal (must be lead car)
 Start: Paint on first TP at 45 mph sign
 End: Paint on TP (needs more marking)

- ### Left turn onto 33EB

- *4P* Road: 33E
 Speed: 45 mph
 Warning: 45 mph sign past Yardville-Hamilton Sq. Rd
 (must be lead car)
 Start: TP past 45 mph sign
 End: TP on left side at Cenlar Bank

- ### Take left onto 33E/130N

- *5C* Road: 33E/130N
 Speed: 55mph
 Warning: TP at Parker Trailer Service
 Start: MP-63
 End: TP at entrance to Advance Elec/Office Bldg

- *6C* Road: 33E/130N
 Speed: 55 mph
 Warning: "No Stopping/Standing" sign before Amoco
 Start: MP-66
 End: "No Stopping/Standing" sign .4mi E/N
 at electric sub-station

- ### Exit onto 33EB

7B Road: 33E
 Speed: 45 mph
 Warning: Bridge parapet (under 33)
 Start: MP-13
 End: 4th TP past Agway

Proceed through Heightstown on 33E, following NJTPK signs
Turn right onto Milford Rd/3rd intersection past NJTPK
at Exxon station
Note: site immediately after turn

9B Road: Milford
 Speed: 35 mph
 Warning: Right turn onto Milford Rd
 Start: Paint & tape on road
 End: Paint & tape on road

Turn left onto Etra Rd (571) at stop sign

42B Road: Etra/571
 Speed: 35 mph
 Warning: Tape on road just past sign for Roosevelt
 Start: Paint & tape on road before curve
 End: TP past NJDL Supplies

Left turn onto Monmouth Cnty 1/Perrineville Rd

(Additional site deleted)

Go straight where Monmouth Cnty 1 veers right (arrow sign
pointing right)
Go straight at stop sign/Baird Rd

43B Road: Baird
 Speed: 35 mph
 Warning: .2 mi past stop sign/tape on road & TP on left
 Start: .2 mi past warning mark/tape on right & TP on
 left
 End: .35 mi past start/tape on right & tp on left

Left turn onto Conover Rd
Right turn onto 33EB

44C Road: 33E
 Speed: 55 mph
 Warning: 3 TP past MP-22
 Start: 5 TP east/tape on road
 End: 1 TP past Woodward Rd

Stay on 33E (bears right) NOT on Freeway

45C Road: 33E
 Speed: 50 mph
 Warning: 9 TP past traffic signal at Park
 tape on TP
 Start: .2 mi east/tape on TP
 End: "No Litter" sign

Take Route 9 NB at circle (lots of rest stops here)

*451 * Road: 9N
 Speed: 55 mph
 Warning:
 Start:
 End:

Take Route 18 NB (rest stops here)

46C Road: 18N
 Speed: 55 mph
 Warning: MP-32
 Start: Tape & paint on road
 End: Tape & paint on road

(Additional site deleted)

Take US 1 NB
 Take I-287 NB

48P Road: I-287N
 Speed: 55 mph
 Warning: "Durham Av/S. Plainfield 3/4 mile" sign
 Start: "I-287N" sign
 End: MP-4

(Additional site deleted)

Take US 22 WB (exit on left)

50P Road: 22W
 Speed: 55 mph
 Warning: 4 TP before MP-32
 Start: MP-32
 End: "Junction 28" sign

51P Road: 22 W
 Speed: 55 mph
 Warning: TP & tape in parking area across from diner
 Start: MP-28.9
 End: TP & tape before County Line Rd

Make U-turn and proceed EB on 22
 (Note: next site directly across road from previous one)

52C Road: 22E
 Speed: 55 mph
 Warning: TP & tape across from end of last site
 Start: TP & tape at intersection
 End: TP at Royal Diner (Needs tape!)

Exit onto 28

(Additional site deleted)

Take right at circle onto 202SB

54P Road: 202S
 Speed: 55 mph
 Warning: "No Stopping/Standing" sign; Getty station
 on left
 Start: MP-18
 End: .4 mi past MP-18/TP & tape

55P Road: 202S
 Speed: 55 mph
 Warning: "No Stopping/Standing" sign S. of Lynn
 Equipment Co.
 Start: .2 mi S at wood post
 End: MP-15

Take 12WB at circle

56C Road: 12W
 Speed: 50 mph
 Warning: "Hunterdon Cnty Complex" sign
 Start: MP-9
 End: TP & tape opposite Natl Guard Armory

(Additional site deleted)

58C Road: 12W
 Speed: 50 mph
 Warning: TP & tape near "Bridge Freezes Before
 Road Surface" sign
 Start: "Speed Limit 50" sign
 End: 2 TP past MP-6

Note: Next site immediately ahead!

59C Road: 12W
 Speed: 50 mph
 Warning: 5 TP before MP-5
 Start: MP-5
 End: .4 mi west/TP & tape at guardrail

Take left onto 519 at National State Bank (on left)

(Additional site deleted)

61B Road: 519S
 Speed: 45 mph
 Warning: 2nd "45 mph" sign past service station
 Start: 4TP & tape further south
 End: TP & tape on left at beginning of guardrail

62B Road: 519S
Speed: 45 mph
Warning: TP & tape on left after pavement surface
changes
Start: .2 mi TP & tape
End: TP & tape past MP-2

Left onto 604

63B Road: 604
Speed: 45 mph
Warning: 2nd "45 mph" sign
Start: TP & tape on left
End: 2nd TP & tape before MP-1

Left turn onto 523

64B Road: 523
Speed: 50 mph
Warning: MP-4
Start: .2 mi at TP & tape
End: .4 mi at TP & tape

Right onto 579SB and then left onto Everitts Rd
Right onto 31/202

65B Road: 31/202
Speed: 55 mph
Warning: TP & tape across from Luggage Outlet (on left)
Start: "55 mph" sign
End: TP & tape near "Hidden Driveway" sign

Right turn onto 179; Site immediately ahead

66C Road: 179
Speed: 45 mph
Warning: "Entering Ringoes" sign
Start: TP & tape at Scientific Instrument Services
Bldg
End: "Reduced Speed Ahead" sign

Go straight onto 31/579SB

67C Road: 31/579
Speed: 50 mph
Warning: "50 mph" sign after road narrows to two lanes
Start: TP & tape .2 mi south
End: "Cnty Rd 579" sign

Continue on 31SB

68C Road: 31S
Speed: 50 mph
Warning: Cnty Rd 612 near Stage Depot
Start: MP-10
End: "Speed Limit 50" sign

Right turn onto Woosamoonsa Rd then left onto Burd Rd
Note: site immediately ahead!

69B Road: Burd Rd
Speed: 35 mph
Warning: at the left turn
Start: Back of sign on left side
End: 2 TP past Yard Rd

Continue on Burd Rd & it becomes Scotch Rd
Right turn onto 546 (unmarked) at traffic signal
Left turn onto 29S
Note: site immediately ahead!

70C Road: 29S
Speed: 50 mph
Warning: "No Stopping/Standing" sign S of Lafayette Av
Start: TP & tape .2 mi south
End: TP & tape .4 mi south

Follow signs to I-95 NB

(Additional site deleted)

Exit at Scotch Rd and re-enter I-95 SB

72B Road: I-95S
Speed: 55 mph
Warning: "I-95" sign south of Scotch Rd
Start: "55 mph/Entering Ewing" signs
End: Tape on shoulder near inlet

Note: Next site immediately ahead

73B Road: I-95S
Speed: 55 mph
Warning: "55 mph" sign south of Bear Tavern Rd
Start: Tape & paint on shoulder
End: Tape & paint on shoulder

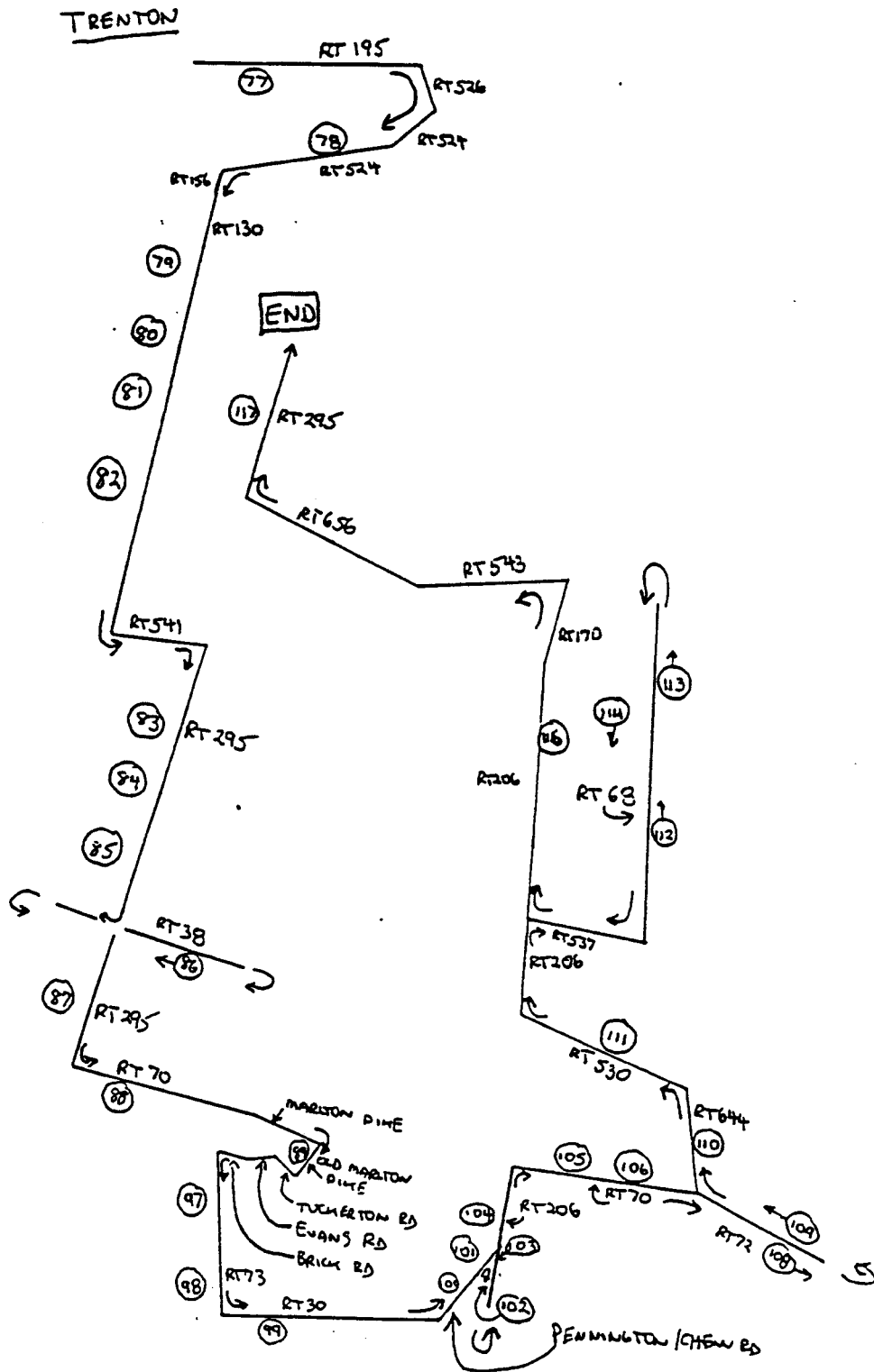
Exit onto 29SB

74P Road: 29S
Speed: 55 mph
Warning: Tape & paint 1/4 mi south of Route 175
Start: Tape & paint on shoulder
End: Tape & paint on shoulder

75P Road: 29S
Speed: 50 mph
Warning: "No Stopping/Standing" sign south of
Parkside Av
Start: "No Stopping/Standing" sign before pedestrian
overpass
End: "No Stopping/Standing" sign before filtration
plant

Return to NJDOT

SOUTHERN ROUTE (DAY 2)



NJ ROUTE/SOUTH

Take I-195 East from Trenton.

77B Road: I-195E; leftmost lane
Speed: 55mph
Warning: Route 130 Interchange
Start: "NJ TPK 3/4 MILE" sign
End: "NJ TPK KEEP RIGHT" sign
Note: Watch for cars entering from right

Exit at Robbinsville/Allentown exit, toward Allentown,
Route 526 East. Right turn onto 524 West, bear right
at William Penn gas station.

78B Road: 524E
Speed: 45mph
Warning: Tape west of Woodys
Start: Tape past Whippanny Drive
End: Merrick Rd.

Turn left onto 156 SB which turns into 130 SB.

79C Road: 130S
Speed: 50mph
Warning: Tape at PSE&G Bldg S of Dunns Mill Rd.
Start: MP-54
End: Tape on TP

80C Road: 130S
Speed: 50mph
Warning: 4th Telephone pole past Roebling sign/
traffic signal - Tape
Start: 2nd Tel Pole South
End: MP-51

81P Road: 130S
Speed: 50mph
Warning: MP-50
Start: Tape at 84 Lumber sign
End: Tape at Fleet Truck Sales

82P Road: 130S
Speed: 45mph
Warning: Tape at traffic signal at Burlington food
market
Start: Tape at "Entering Burlington" sign
End: Tape at phone booth at Amoco

Left onto 541 and South onto I-295

83P Road: I-295S
Speed: 55mph
Warning: First I-295 South sign
Start: MP-47
End: Beginning of guardrail & "Business Center" sign

84P Road: I-295S
Speed: 55mph
Warning: "Willingboro - Mount Holly Exit - 1 Mile" sign
Start: MP-46
End: Tape on shoulder - .4 miles

85P Road: I-295S
Speed: 55mph
Warning: "295S" sign south of Rancocas Woods exit
Start: "55MPH" sign & tape on shoulder
End: Tape on shoulder 100' S of MP-42

Take exit 40 - Route 38, proceed west on 38 and make
U-turn at first traffic signal to go E on 38.
Make U-turn at Getty Gas Station to go W on 38

86P Road: 38W
Speed: 50mph
Warning: Tape west of Medford sign
Start: Tape after 2 TP (telephone poles)
End: 2nd TP west at MP-12(E)

Take right onto I-295 SB

87P Road: I-295S
Speed: 55mph
Warning: "73, TPK, TP Bridge 1 mile" sign
Start: Beginning of guardrail
End: Tape on shoulder 100' S of "73, TPK etc..." exit

Take exit for 70EB

88C Road: 70E
Speed: 50mph
Warning: Sign post on left, tape on right
Start: MP-11
End: Second "No Stopping/Standing" sign

Bear right onto Marlton Pike at Sunoco station,
then take immediate, first right onto Old Marlton
Pike SB (unmarked) at "Harriot's Oil Service" sign

89B Road: Old Marlton Pike SB
Speed: 50
Warning: 4th TP after turn
Start: Tape on left side of road at driveway to Deli
End: "Curve 35MPH" sign

Take Right onto Tuckerton RD, then
left onto Evans Rd. (jughandle), then
right onto Brick Rd. and
left onto 73SB (SITE IMMEDIATELY AHEAD)

97P Road: 73S
Speed: 50mph
Warning: "55 MPH" sign after Evesham Rd. intersection
Start: TP, inlet & tape
End: TP, Avandale Homes sign & tape
Note: Must be lead car at this site

98P Road: 73S
Speed: 50mph
Warning: MP-21
Start: "AC EXPWY" sign
End: "Signal Hill" sign, tape

Take left onto 30 EB

99B Road: 30E
Speed: 50mph
Warning: Blue Mile Motor Inn
Start: 5 TP past motor inn, tape
End: TP past Farm Market

(Additional site deleted)

Left onto Pennington Rd. at Al's Hiway (on left)
Becomes Chew Rd.

100B Road: Chew Rd. .
Speed: 50 mph
Warning: Tape on TP/left side
Start: 2nd TP past warning/left side
End: TP on left side

101B Road: Chew Rd.
Speed: 50mph
Warning: 3rd TP past RR tracks, tape
Start: 3rd TP & 1st in clearing (.2mi)
End: TP near houses

Take left onto 206 NB

(Additional site deleted)

103C Road: 206N
Speed: 50mph
Warning: "No Stopping" sign, tape
Start: Diagramatic, curve sign
End: 2 TP north of MP-7

(Additional site deleted)

(Additional site deleted)

Take right turn onto 70 EB

105P Road: 70E
Speed: 50mph
Warning: Back of "No Passing" sign, E of Traf. Sig. at
Huntingdon Dr.
Start: MP-21
End: Tape at drain furrow; X on pine tree

106P Road: 70E
Speed: 50mph
Warning: Stop sign on crossroad
Start: Beginning of guardrail
End: MP-25

Take 72 EB - SITE IMMEDIATELY AHEAD

108P Road: 72E
Speed: 50mph
Warning: "Do Not Pick Up Hitch Hikers" sign,
new State school
Start: 3 TP past Pizza Shop about 1/2 mile from circle
End: MP-1

Make U turn at Mayo's Halfway House and proceed on 72 WB

109B Road: 72W
Speed: 50mph
Warning: New Lisbon Development sign
Start: MP-1
End: TP in front of pizza shop

At circle, take second right onto 644 (unmarked). Note
signs for Tacony/Burlington-Bristol Bridges

110B Road: 644 (unmarked)
Speed: 50 mph
Warning: TP on left side
Start: "50MPH" sign
End: Sign post on left side, about .5 miles

(Additional site deleted)

Bear left onto 530 WB

111B Road: 530W
Speed: 50mph
Warning: Gulf Station
Start: Pole at Crescent Heights Professional Bldg.
End: TP past Trilco City bus stop

Stay on 530/38, then turn right onto 206N and
right again onto 537

Take left onto 68W

112P Road: 68W
 Speed: 55mph
 Warning: MP-3
 Start: "No Litter" sign
 End: TP with transformer

113P Road: 68W
 Speed: 55mph
 Warning: Tape on shoulder - opposite farm on left
 Start: Tape on shoulder just before farm on right
 at an inlet
 End: Tape on shoulder west of MP-6 (.15mi)

Go further west on 68 and make U-turn; proceed
east on 68

114P Road: 68E
 Speed: 55mph
 Warning: TP at intersection
 Start: MP-5
 End: Tape on shoulder at intersection

Take right onto 537 and then right onto 206N

115C Road: 206N
 Speed: 50mph
 Warning: MP-26
 Start: 1st pole north; sign graphics
 End: TP before Brick Collision Center

116C Road: 206N
 Speed: 50mph
 Warning: "North 206" sign/Columbus food market
 Start: Pole .2 mile north
 End: 4th TP S of MP-30

Take 170 to Columbus, then turn left onto 543. Take right
onto 656 to I-295N

117P Road: I-295N
 Speed: 55mph
 Warning:
 Start: MP56
 End: "Freeway Ends 1500 Ft. Ahead" sign

Return to NJDOT

Appendix 6

1986 Panel Instructions

Appendix 6.
Panel Instructions

HIGHWAY IMPROVEMENT STUDY

Purpose: To survey typical *N.J.* drivers in order to determine what they think of the quality of the ride provided by the roads in the State. *NJDOT* will use this information to help decide which roads they should improve first with the limited funds available to make highway improvements.

Object of the Study:

We are going to drive you over a number of roads which we believe are representative of the roads as they exist throughout the State. We will then ask you to make two judgments concerning each road. First, we want you to rate the roughness or smoothness of the ride provided by each road on a scale of 0 to 5, and second, we want you to indicate whether or not you think an effort should be made to improve the ride quality of each road.

MAKING YOUR RATINGS OF RIDE QUALITY

(A facsimile of the rating scale was shown to the subjects for this section).

The first thing we want you to consider as you drive down a road is the roughness or smoothness of the ride provided by the road and then to rate it on this scale (illustrated) which ranges from 0 to 5. You will indicate your rating by placing a small mark across the vertical line of the scale at the place which you think best describes the ride provided by each road.

DEFINITIONS OF ENDPOINTS

All roads which you drive over in this survey will be between two extremes. That is, somewhere between impassable and perfect.

Impassable: A road which is so bad that you doubt that you or the car will make it to the end at the speed you are travelling--like driving down railroad tracks along the ties.

Perfect: A road which is so smooth that at the speed you are travelling you would hardly know the road was there. You doubt that if someone made the surface smoother that the ride would be detectably nicer.

Panel Instructions(continued)

Since these roads probably do not exist you will probably not consider any road to be worse than impassable or better than perfect.

In order to help you make your rating, we have included a number of words along the scale which could be used to describe how the riding sensation seems to you. For example, if you should encounter a road for which you could describe the ride as FAIR but not quite good, place your mark just below the line labeled "3" (illustrated). On the other hand, if you think the next road is still fair, but somewhat worse than the previous road, place your mark at a point which you think is the appropriate distance down in the FAIR category. To indicate small differences between the ride quality provided by the roads, you may place your mark anywhere you like along the scale.

NOTE: We are not asking you to place roads into one of five categories! You should use small differences in the position of your marks to indicate small differences between the ride quality provided by the roads. You may place your mark anywhere you like along the scale.

INDICATING THE NEED FOR THE IMPROVEMENT

After you have made your rating of the degree of ride quality provided by any particular road; we want you to check the appropriate box alongside the rating scale to indicate whether or not you think the State should improve the ride quality of the road.

When making this decision you should take into account the fact that since the State only has a certain, fixed amount of money each year to make road improvements, it must determine which roads should be improved first. Therefore, before deciding on the need for improvement, you should not only consider how rough a ride is provided by each road, but whether you feel the road is important enough to be placed high on the State's list of roads needing improvement. For example, you may ride across two roads which give identically rough rides but, if you had your choice, you would rather see only one of them improved because the type or character of that road seems to you to make it more worthy of improvement.

PROCEDURE FOR SURVEY

- o For this survey we are going to ask you to evaluate
70 road sections.

Panel Instructions (continued)

NOTE: You will not be rating an entire road for its ride quality. We have carefully selected small test sections to represent each road. It is these sections that we want you to rate for ride quality.

- o As you approach each section, the driver will call out the number of the section. Be sure you have the proper numbered form.
- o When the driver says START, begin concentrating on what the rating of ride quality should be, based on how the ride feels to you.
- o It will only take about 30 seconds to drive over each section, so maintain your concentration until the driver says STOP. At that point, place your rating mark on the scale.
- o Next, while taking into account both the roughness of the ride through the representative test section, as well as the nature and type of the entire road, indicate whether or not you think the ride quality needs to be improved by checking the appropriate box next to the rating scale.
- o Since some sections are only 3-4 minutes apart, make your decisions quickly and pass your forms to the person sitting in the front right seat.
- o This procedure will be repeated for each site.
- o We will be driving over a predetermined course in an ordinary passenger car. The trip will take 6 hours the first day and 5 hours the second.

SPECIAL INSTRUCTIONS

- o When making your rating of ride quality, do not consider any of the road before or after a test section. We are only interested in a rating for a small section of road.
- o When making your decision concerning the need for improvements, assume that the ride provided by the entire road is the same as that for the test section.
- o Concentrate only on the ride quality provided by the roads. Don't let the appearance of the road surface influence your ratings. Judge only how the road feels!

Panel Instructions (continued)

- o Don't be distracted by conversations in the car or by pretty scenery.
- o Don't reveal your ratings to the other raters. There is no right or wrong answer, so don't "cheat". We are interested only in your opinion which is as valid as anyone else's.
- o Be critical about the ride quality provided by the roads. If they are not absolutely perfect as far as you are concerned, be sure to give it a rating on the scale which you think best reflects the diminished quality of the ride.
- o Be aware that there are many ways that the ride could be considered less than PERFECT. The road could
 - a) be so bumpy that it rattles your bones and makes your teeth chatter,
 - b) have bumps or undulations that makes the car heave up and down as if it was a roller coaster, or
 - c) have other imperfections in the surface which you think detract from the ride quality.

Appendix 7

Analysis of 1986 Pavement Roughness Survey

TO Memorandum of Record

MEMORANDUM

FROM Ricardo T. BarrosSUBJECT Analysis of 1986 NJDOT DATE 10/30/86 TELEPHONE NO. 5-3606
Pavement Roughness Survey

A panel study investigating user opinion of pavement roughness was conducted in July, 1986, by the Research Division as part of the Pavement Management effort. This study constituted one part of a larger effort, a national investigation sponsored by the FHWA designated NCHRP 1-23. The NJDOT panel study directly paralleled a previous effort by the Department and readers are referred to that report ("Analysis of Pavement Roughness Rating Results", Barros, 2/27/86) for more detailed background information.

In this 1986 study, 48 panelists evaluated 20 bituminous, 25 concrete, and 18 composite pavement sections for roughness of ride. Each of these sites was also measured with a Mays Meter and a profilometer.

The two principal objectives of this study were to:

- 1) Calibrate user opinion with measurements made by a mechanical device; and
- 2) to estimate the terminal serviceability levels with respect to user opinion of pavement roughness.

Preliminary insights into the above objectives had been provided by the Department's 1985 study. It was a goal of this study to confirm and better estimate the previous findings.

PSR-Mays Relationship

A nonlinear regression model relating the present serviceability rating (PSR) with Mays Meter roughness measurements was estimated. This model was of the form:

$$PSR = 5.0 * e^{\beta_1 * MAYS^{\beta_2}}$$

The β_1 and β_2 coefficients were estimated separately for each of the three pavement types, bituminous (BC), concrete (RC), and composite (CO). Confidence intervals for the three terms thus produced overlapped, failing to support the hypothesis that the three relationships were distinct. This finding, plus the practical observation that the three individual relationships were practically indistinguishable, lead to the conclusion that one PSR-MAYS relationship adequately models user opinion for all pavement types.

Pooling the data together produced the model shown in Figure 1. This model estimates the regression coefficients to be $\beta_1 = -0.038$ and $\beta_2 = 0.557$ and agrees very closely with the 1985 relationship. Because this 1986 study afforded a greater sample size, these results are thought to be more precise and should supercede the 1985 estimated relationship.

Terminal Serviceability

A logit analysis was performed regressing the proportion of raters indicating pavement rehabilitation was required against the Mays roughness value for each section. This analysis indicated that RC and CO pavements were perceived without distinction, but that BC pavements were perceived differently. This difference was statistically significant at the 0.01 level of risk. These estimated relationships are presented in Figure 2.

The relative position of the RC and BC curves in Figure 2 was unexpected. This data indicates that users are more critical of RC roughnesses than BC roughnesses, a finding contrary to prior assumptions. A check of the data failed to detect any obvious irregularities and also that, in the 1985 study, this same relative positioning was present. Thus, because of apparently error-free data and the independent confirmation, the two distinct curves of Figure 2 were accepted.

The proportion of raters calling for a pavement's rehabilitation is estimated by the following model.

$$\text{PROPORTION} = \frac{e^{\beta_0 + \beta_1 \text{MAYS}}}{1 + e^{\beta_0 + \beta_1 \text{MAYS}}}$$

where: $\beta_0 = -3.08$

$\beta_1 = 0.018$ for RC and CO pavements,
and

$\beta_1 = 0.009$ for BC pavements.

The 1985 logit analysis was based on a substantially smaller sample size and asked a subtly different question than that posed in the 1986 study. (Adequacy of ride was asked rather than inadequacy.) Consequently, the logit models were not compared between the two years.

Terminal serviceability is conventionally defined to be that roughness for which 50 percent of the raters find the ride objectionable. Terminal Mays values were found to be 172 inches

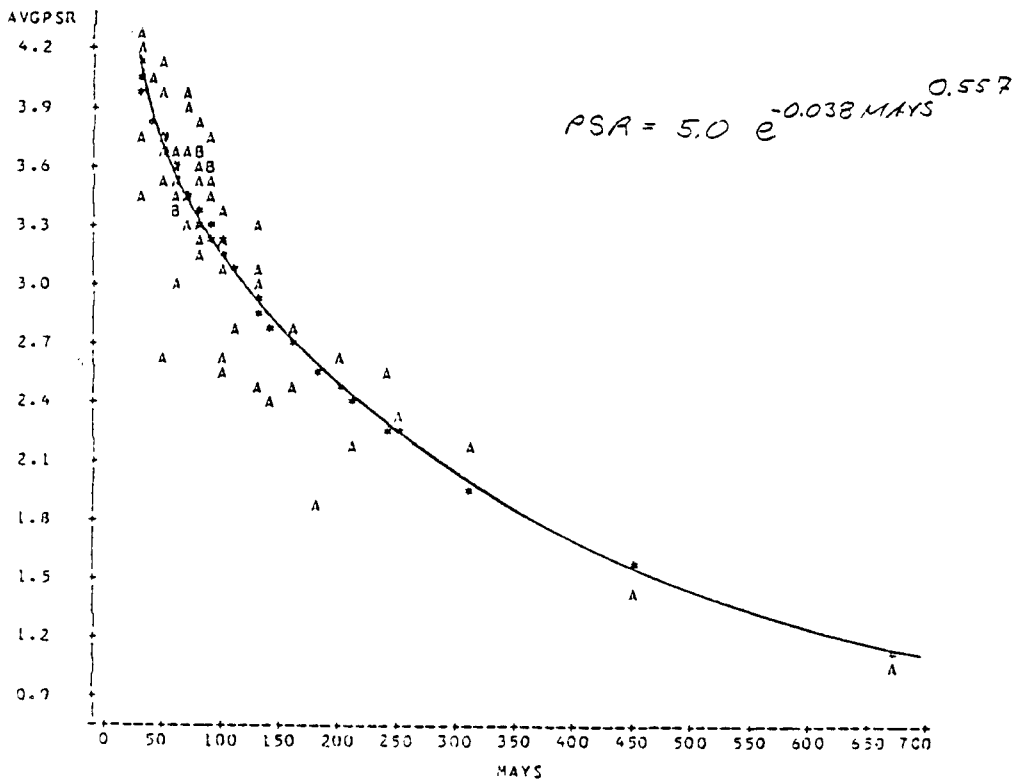


Figure 1. Estimated PSR-MAYS relationship, 1986 NJDOT study.

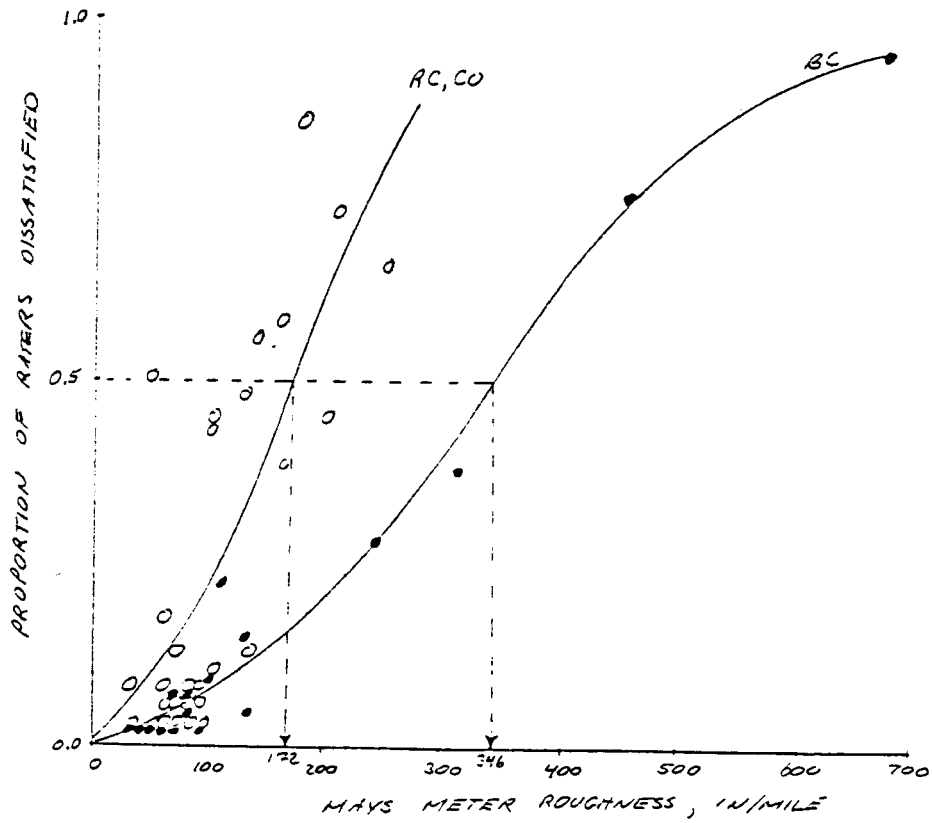


Figure 2. Estimated logit relationships, 1986 NJDOT study.

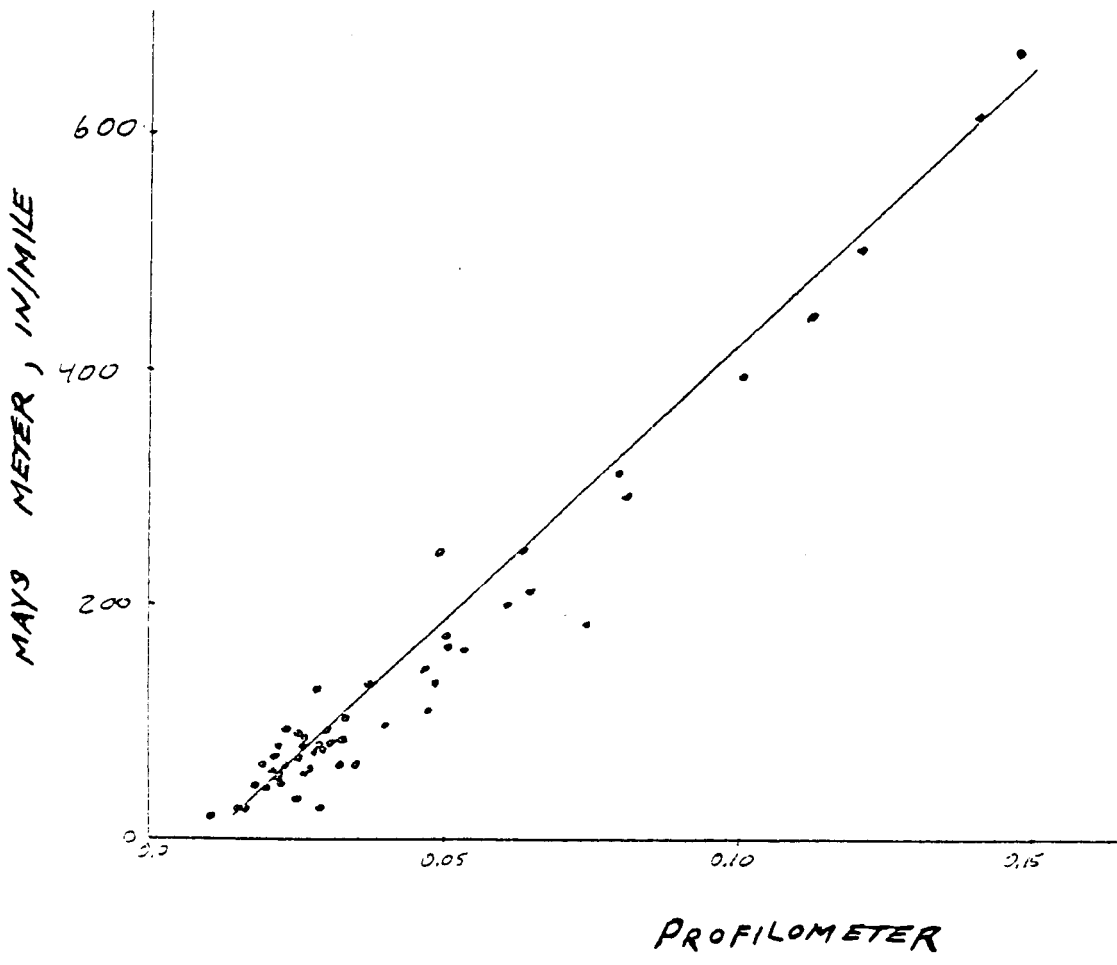


Figure 3. Estimated Profilometer - Mays Meter relationship.

per mile for RC and CO, and 346 inches per mile for BC pavements. Substitution of these values into the PSR-MAYS relationship identifies the terminal serviceability levels to be 2.6 and 1.9 PSR, respectively.

Profilometer Data

Profilometer data, linearly scaled, agreed so closely with Mays Meter measurements that it provided no additional insights. A plot of the Profilometer vs. Mays relationship is presented in Figure 3. Although a parabolic model may be more appropriate, a straight line fit produces an R-Square value of 0.93. Analysis of the Profilometer vs. PSR relationships also failed to distinguish a difference between pavement types.

Summary and Conclusions

The 1986 NJDOT pavement rating survey produced three measures of pavement roughness: a PSR value, a Mays Meter value, and a profilometer value. Analysis of the Mays and PSR data produced very similar results to those observed in the 1985 NJDOT survey. As before, one PSR-MAYS relationship is thought to be sufficient for all pavement types. Logit analyses indicate that users are more tolerant of BC pavement roughnesses than those of RC and CO. This finding is supported by both the 1985 and the 1986 studies. Terminal serviceability levels are 1.9 PSR for BC pavements and 2.6 PSR for RC and CO pavements. Profilometer measurements were observed to be virtually a linear translation of the Mays Meter measurements and did not contribute additional information.



Ricardo T. Barros