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16. Abstract

Two methods are examined which provide objective pavement performance information about the Texas highway system. These methods are sampling surveys and a complete inventory of all pavements. A sampling survey has been conducted in all twenty-five SDHPT districts and results from the survey are discussed. These results include measures of roughness, visual condition, and deflection for four years of collected data. The optimum number of required highways for conducting such a survey are determined. A performance inventory for all pavements in District 21 is discussed. Procedures are developed which can assist in the planning of future state-wide performance inventories currently being planned by the SDHPT.

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MEASUREMENTS OF PAVEMENT PERFORMANCE USING STATISTICAL SAMPLING TECHNIQUES

by

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Research Report Number 207-2

Flexible Pavement Evaluation and Rehabilitation

Research Project 2-8-75-207

Conducted for

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and Public Transportation

in cooperation with the
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by the

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March 1978

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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LIST OF REPORTS

Report No. 207-1, "Determining Stiffness Coefficients and Elastic Moduli of Pavement Materials from Dynamic Deflection," by C. H. Michalak, D. Y. Lu, and G. W. Turman, is a summary in one document of the various methods of calculating in situ stiffness coefficients and elastic moduli in simple two-layer and multi-layer pavement structures using surface pavement deflections.

Report No. 207-2, "Measurements of Pavement Performance Using Statistical Sampling Techniques," by J. P. Mahoney and R. L. Lytton, examines two methods for obtaining performance related data on the Texas highway system and the associated results of using the methods.

SUMMARY

Cost-effective, objective performance information obtained on a highway network better enables highway maintenance managers to make informed decisions. Three methods which can be used to obtain such objective information are: mass inventory, partial, and sampling surveys. Of the three, sampling surveys and a mass inventory of data available from District 21 are examined in depth.

Five types of sampling surveys are described including examples for each. Of the five, a stratified two-stage sample survey was elected for use in Texas. The sample was obtained by first randomly selecting counties within each highway district then randomly selecting two-mile highway segments within each county. Approximately one percent of the total statewide centerline mileage was sampled using this technique.

Various kinds of data were obtained for each of the sampled highway segments with Serviceability Index, Pavement Rating Score, and Surface Curvature Index examples used to demonstrate the kinds of inferences which can be made. Sampling and year-to-year variations of these data types are discussed and recommendations are made which will improve the consistency of the data obtained with the visual condition evaluation procedure. The questions of what kind and how large of a sampling survey which should be used are examined.

Available data from District 21 were used in conjunction with a simulation procedure to obtain possible answers to these questions. The simulation study results and a utility theory analysis procedure revealed that two-stage sample sizes generally of about two percent of the total centerline mileage provided optimally cost-effective estimates for determining

roughness, visual condition, deflection and skid.

An extensive examination of performance related data obtained in District 21 and two procedures which can be used to determine the required data sampling within highway segments are provided to assist in the planning and development of the statewide condition inventory currently being planned by the SDHPT.

IMPLEMENTATION STATEMENT

For the first time statewide estimates of performance related information are presented for immediate use. This information is of a general nature and can be used as a check on similar data to be collected in a statewide inventory to be conducted by the SDHPT.

Analysis of the available data indicates that the visual condition rating system should be revised. A possible revision is shown. The errors involved in collecting Serviceability Index data indicate a better calibration procedure is warranted for the Mays Ride Meter or, alternatively, a new roughness measuring device could be developed.

Procedures are presented which can be used to assist in determining the required data sampling frequency within highway segments for the upcoming statewide condition inventory of all state-maintained Texas pavements.

The first uses of the data collected on the 250 randomly located highway segments are reported here and many additional uses will be addressed in subsequent research reports.

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INTRODUCTION

In order to allocate highway rehabilitation and maintenance funds fairly and consistently, the highway administrator needs information about the actual condition of the road network for which he is responsible. He can get this information in a variety of ways, some of which are more costly than others. This report presents two information gathering methods that were applied to the pavements in Texas.

There are two broad categories of pavement condition information: subjective and objective. In the first mentioned class fall the routine or regular visual inspections of the roadways. The "objective" measurements are made with machines or with the aid of mechanical devices and include several methods. In addition, combinations of subjective and objective information are often made.

One of the objective methods is the use of "mass inventory" surveys (1). These surveys are used to obtain extensive data on all highways in a given area (state, district, county, etc.). The primary advantage of this type of survey is that all segments of the highway system are carefully surveyed thus indicating all the weaknesses in a given highway. Presumably, the highway with the greater number of weaknesses would receive corrective maintenance sooner than other pavements serving the same function. Also, this survey method allows for general inferences to be made about the complete highway system. The most obvious problem with this type of survey is the cost associated with the data collection, reduction, and interpretation of the results. An inventory of such data was obtained by District 21 personnel and will be examined in this report.

A method used to obtain both subjective and objective data are "partial" surveys. A partial survey occurs where some type of preliminary routine visual examination of the highway system is made. The visual examination is used to identify those highway segments for which additional, more detailed information is required. For example, a highway segment may be identified as being severely cracked and thus some type of deflection survey is made to determine the load carrying capability of the pavement section. The deflection survey may then be used to assist in making the proper maintenance decision.

One advantage of a partial survey is that it generally results in a low cost. The disadvantage is that the data obtained do not allow general inferences to be made about the total highway network (state or district).

The disadvantage of a partial survey leads to a third type of survey which is the major topic of this report - the "sampling survey". This method of obtaining objective data on a highway system has a number of characteristics which can be of value to highway departments.

Characteristics and Types of Sampling Surveys

The purpose of a sample survey is to make inferences about the sampled "population" (4). The population in this case denotes the state maintained highway network.

In any sampling process, two factors affect the usefulness of the data contained in the sample: the size of the sample and the variability of the data within the sample. The goal of most sampling surveys is to keep the sample size as low as possible while keeping the variability of the data below some maximum acceptable limit.

To accomplish the above goal, careful consideration should be given to the sample survey design. Such surveys are generally inexpensive when compared to other data collection procedures but can still represent a significant investment. Enough emphasis cannot be placed on the design of a sampling survey in order to minimize costs while maximizing the information gained with the survey. Some of the sample survey methods available are (2, 3, 4):

1. Simple random sampling
2. Stratified random sampling
3. One-stage cluster sampling
4. Multi-stage cluster sampling (Multi-stage sampling)
5. Systematic sampling

A brief description and example of each of the above sampling methods follows:

1. Simple random sampling. This method provides that every sample has an equal probability of being chosen from a population.

   Example: If all highways in a given geographic area were divided into equal lengths (segments), then each highway segment would have an equal chance of being chosen for the required sample size.

2. Stratified random sampling. This is the sampling process whereby a population is divided into strata and then random samples are obtained within the described strata.

   Example: If a given state is divided into a number of highway department districts and data estimates were required for each district, then each district could be considered a stratum and individual highway segments could be randomly selected within each district.

3. <u>One-stage cluster sampling</u>. This process first groups elements within a population together and then the elements are randomly sampled.

   Example: If data estimates are required for a state, counties could be randomly selected throughout the state. Within each selected county all highway segments would be sampled. The pavement segments surveyed are considered to be "clustered" within the selected counties.

4. Multi-stage cluster sampling (Multi-stage sampling). This method is similar to one-stage cluster sampling but takes the process further. Multi-stage clustering allows for larger areas to be clustered together and then randomly sampled. The elements within these clusters are also randomly sampled.

   Example: Again, as for the previous example, if data estimates are required for a given state, then counties within a district can be randomly selected and within those selected counties pavement segments may be randomly selected. This would constitute a two-stage cluster sample if all data within the pavement segment are sampled. If the data are only sampled within the pavement segment, this is simply referred to as a two-stage sample. A three-stage sample would be randomly selecting highway department districts within a state, then counties within the selected districts, then pavement sections within the selected counties.

5. Systematic sampling. This process samples every K-th element of a set of data.

   Example: If data estimates are required for a state and assume this state has 100 counties, then every tenth county from a listing of all counties could be selected for a total of ten counties. Within each county selected all highway segments would be sampled in the data collection effort.

In addition to the above sampling methods, combinations of the five presented can be created. For example, a stratified two-stage cluster sample can be taken. Other combinations are possible.

A properly designed highway sample survey can provide the following:

1. Inexpensive indication of statewide, district, or county pavement performance.
2. Year-to-year differences in pavement performance.
3. Valuable research tool for various statistical pavement experiments.
4. Expansion or reduction to accommodate changing needs.
5. More detailed objective data may be obtained since the amount of pavement being surveyed is much smaller than in a mass inventory survey.

TEXAS SAMPLE SURVEY

Introduction

The sampling survey has been used on Texas pavements to bring together extensive information on a number of highway segments distributed throughout the state. This report will show only part of the kind of information which can be obtained from the selected highway segments. Later reports will further expand the applications and uses of such data.

A statistically random selection of two-mile long Interstate (IH), United States and State (US & SH), and Farm-to-Market (FM) highway segments was made during 1973. A "stratified two-stage sample" was utilized for this purpose. The stratification comprised dividing the highway network into the twenty-five SDHPT districts. This was done because separate data estimates were required for each district since each is considered to have its own unique characteristics (soils, traffic, etc.). The two-stage sample was obtained by first randomly sampling counties within each district and then randomly sampling the two-mile highway segments within each county. This stratified two-stage sample was accomplished for the three state maintained highway types with each considered to be a separate population. Figure 1 is a depiction of how this sampling process was performed. In the figure a given SDHPT district is assumed to have nine counties. One of the counties, County 2, is initially selected at random from the nine. Then one US highway and one FM highway is selected by using a random selection of map coordinates. The actual two-mile segments are field located to the nearest mileposts or other significant physical features. Using a repetition of this sequence, all the required segments in a district are selected. Generally, about four counties in each district are required to achieve the

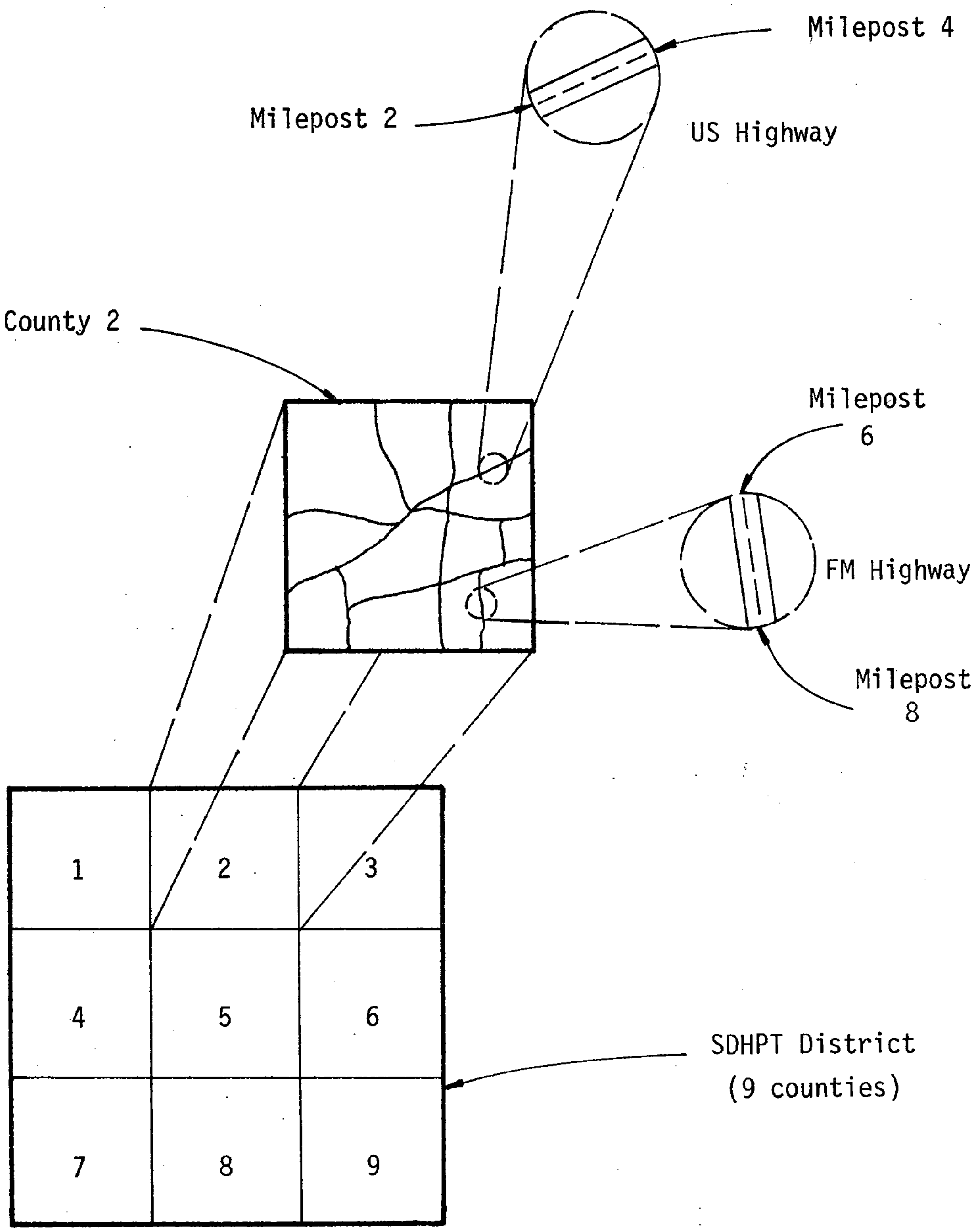

Figure 1 . Depiction of Two-Stage Random Sampling Procedure for Two-Mile Highway Segments.

desired sample size. Since this procedure allowed for the random selection of counties as well as highway segments, IH highways in some districts were not sampled because the appropriate counties were not selected by the random process. Currently, the number of pavement segments and the percentage of centerline miles sampled for the three types of highways for each district and statewide are shown in Table 1. For the 1977 survey, the number of IH highway segments in the study were increased to approximately a five percent sample. This reflects the added importance of this highway type. Results of the increased sample size will be presented in a later report.

The statewide percentages in Table 1 reflect the importance placed on each kind of highway and are the result of the sampling method. A total of 250 highway segments were initially selected using this process. A listing which provides location information for the random highway segments and others is contained in Appendix A. Figure 2 shows the approximate locations of pavement segments involved in the study.

Several kinds of data have been collected on the highway segments selected. Most of the data is updated annually with the same highway segments being used each year. The following list briefly describes the kinds of data collected:

1. Construction information: Includes layer thickness, widths, and available material properties along with dates and types of all major maintenance which currently represent the pavement segment cross section.
2. Traffic histories: Includes Average Daily Traffic and 18 kip equivalent axle loads applied with time.

Table 1. Number of Two-Mile Segments and Percent of the Centerline Mileage Represented by the Segments for the Three Highway Types in Each District

District	Highway Type					
	IH		US&SH		FM	
	Number of Segments	Percent of ℄ Mileage	Number of Segments	Percent of ℄ Mileage	Number of Segments	Percent of ℄ Mileage
1	1	3.6	4	1.1	6	0.7
2	1	2.5	5	1.4	4	0.7
3	0	-	4	0.9	4	0.6
4	3	4.0	6	1.0	5	0.5
5	0	-	9	1.4	8	0.5
6	2	1.3	5	1.1	6	0.9
7	0	-	5	1.1	4	0.6
8	2	3.1	4	0.8	4	0.4
9	2	4.9	4	1.0	6	0.7
10	0	-	3	0.6	7	0.7
11	0	-	4	0.9	5	0.7
12	2	3.8	4	1.3	5	0.8
13	0	-	4	0.8	6	0.8
14	0	-	4	0.8	4	0.5
15	3	2.1	4	1.0	4	0.5
16	1	2.9	5	1.2	4	0.6
17	0	-	4	0.9	4	0.5
18	1	1.8	3	1.3	7	1.2
19	0	-	4	1.0	4	0.6
20	1	3.3	3	0.9	4	0.8
21	0	-	4	0.9	4	0.6
22	0	-	4	0.9	4	0.8
23	1	5.6	4	0.9	4	0.6
24	1	1.2	5	1.3	3	1.1
25	0	-	4	0.9	4	0.6
Statewide	21	1.8	109	1.0	120	0.6

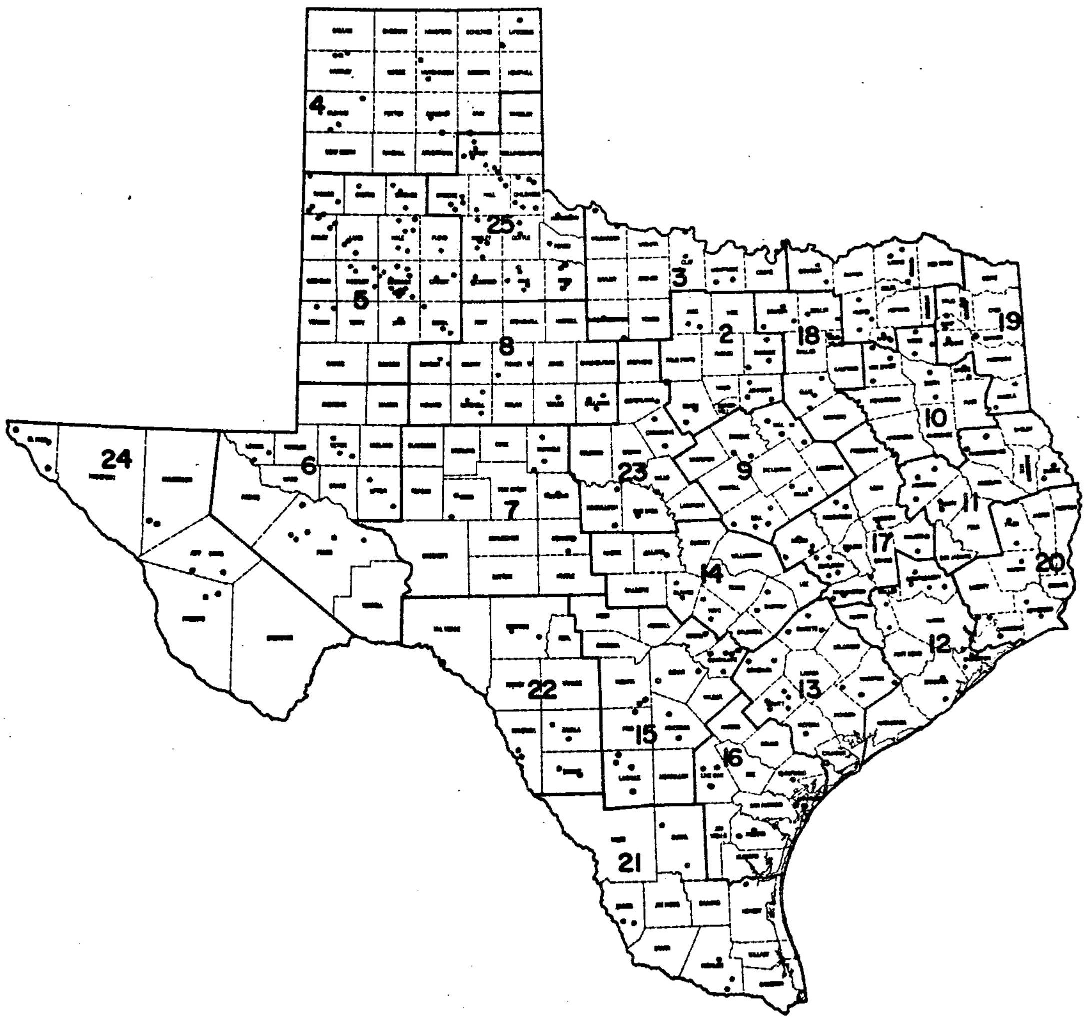

Figure 2. Locations of Project Pavement Segments

3. Climate data: Monthly rainfall and temperatures, freeze-thaw cycles, Thornthwaite indexes.

4. Roughness: Serviceability Indexes (SI) obtained with the Mays Ride Meter (5).

5. Visual condition: Distress manifestations obtained primarily by use of a visual process (6).

6. Deflection: Obtained using the Dynaflect.

7. Rut depth measurements.

8. Skid Number (SN) @ 40 mph.

Examples of estimates which can be produced from such data will be shown in this report. Such data as listed above can also be used to assist in the development of pavement management systems, regression derived performance models, and other uses. Data obtained from this sample survey has been used in the planning and development of the RAMS (Rehabilitation And Maintenance Strategies) computer program. This program was developed to serve as a management tool for district SDHPT personnel to optimally allocate the required maintenance and rehabilitation for highway segments within each district (7, 8). A subsequent report will provide more information about RAMS. Additionally, it is planned to use data from this sample survey to provide new, improved performance models for Texas pavements.

Three estimates of pavement performance were calculated from the statewide sample survey. These estimates are: Serviceability Index, Pavement Rating Score, and Surface Curvature Index. Other estimates for Skid Number can be calculated but were not ready at the time this report was prepared.

Serviceability Index is an indication of road roughness and is based on a scale which ranges from 5 to 0 and was initially developed at the AASHTO Road Test (9). A value of 5 represents a road which is perfectly smooth and 0 indicates a road which is virtually impassible. For the Texas sample survey, the car-mounted Mays Ride Meter was used to determine Serviceability Index (5). This instrument accumulates roughness over a 0.2 mile distance thus ten Serviceability Index values are obtained in each of the two-mile highway segments. The instrument provides a raw value which is reduced to the 5 to 0 scale by a table which is obtained from SDHPT calibration procedures. The data sheet which is used to record the raw data readings for the sample segments is shown as Figure 3.

The Pavement Rating Score is an indication of visually determined distress manifestations present on the pavement surface. The evaluation procedure was developed and implemented by TTI for the SDHPT in 1973-1974 (6, 10, 11). This procedure produces a score which ranges from 100 (perfect pavement-no observable distress) to 0 (or less, indicates an extreme amount of distress is present on the pavement surface). Figure 4 is a copy of the rating form and it shows that the evaluation procedure is composed of nine different distress types. Each distress type is evaluated by determining the "area" and "severity" for each. The Pavement Rating Score is determined by subtracting deduct points from 100 for each area-severity combination for each of the nine distress types.

The Surface Curvature Index is obtained by use of the Dynaflect. This instrument is a small, two wheel trailer which applies a peak-to-peak dynamic force of 1,000 lbs at a fixed frequency of 8 Hz. The resulting deflections (in milli-inches) are measured at five locations spaced at one foot intervals on the axis of symmetry which passes between

Figure 3. Recording Form for Mays Ride Meter

SECTION ID NUMBER	HIGHWAY CLASS	COUNTY NUMBER	HIGHWAY NUMBER	DATE (MO-DAY-YR)	BEGINNING MILEPOST	ENDING MILEPOST	LANE	DIGITAL READINGS PER 0.2 MILES

Figure 4. Visual Condition Evaluation Form for Flexible Pavements

DISTRICT NO. [1–2]

RATERS [5–28]

[31–51]

DATE MONTH [60] DAY [65] YEAR [70]

LOCATION

SIDNO	COUNTY NO.	HIGHWAY NO.	DATE	FROM	TO	LANE

PAVEMENT

MAYS METER			
RUTTING	%AREA	①1-15 ②16-30 ③>30	SLIGHT / MODERATE / SEVERE
RAVELING	%AREA	①1-15 ②16-30 ③>30	SLIGHT / MODERATE / SEVERE
FLUSHING	%AREA	①1-15 ②16-30 ③>30	SLIGHT / MODERATE / SEVERE
CORRUGATIONS	%AREA	①1-15 ②16-30 ③>30	SLIGHT / MODERATE / SEVERE
ALL GATOR CRACKING	%AREA	①1-5 ②6-25 ③>25	SLIGHT / MODERATE / SEVERE
LONGITUDINAL CRACKING	LIN FT PER STA/LN	①10-99 ②100-199 ③>200	SLIGHT / MODERATE / SEVERE
TRANSVERSE CRACKING	NO PER STA	①1-4 ②5-9 ③>10	SLIGHT / MODERATE / SEVERE
CRACKS		(1)SEALED (2)PARTIALLY SEALED (3)NOT SEALED	
PATCHING	%AREA	①1-5 ②6-15 ③>16	GOOD / FAIR / POOR
FAILURES/MILE		①1-5 ②6-10 ③>10	

SHOULDER

PAVED	RIDE / CONTRAST / PAVEMENT EDGE / SHOULDER EDGE / CRACKS / RAVELING / VEGETATION
UNPAVED	PAVEMENT EDGE / RUTTING, CORRUGATIONS, LOOSE ROCK

ROADSIDE AND DRAINAGE	LITTER / MOWING / VEGETATION / SLOPE EROSION / CULVERTS / DITCHES, OUTFALL, CHANNELS / ROADSIDE DRAINAGE
TRAFFIC SERVICE	GUARDRAILS / SIGNS / DELINEATORS / STRIPING / AUXILIARY MARKINGS
OTHER	

the load wheels. The Surface Curvature Index is the difference in measured deflections between the first and second deflection sensors. This index is a measure of the structural adequacy of a pavement. An "acceptable" range of these values is not available but Surface Curvature Indices greater than about 1.0 milli-inch are generally considered indicative of low load capacity pavements.

Tables 2 and 3 show district and statewide estimates of Serviceability Index for 1973, 1974, 1975, and 1976. The estimates of the means are listed in Table 2 and the associated standard errors in Table 3 for each of the three highway types. A similar presentation is made for Pavement Rating Score data in Tables 4 and 5 and Surface Curvature Index in Table 6. The equations which are used to produce all such estimates are discussed later in the report.

Serviceability Index

For the statewide estimate of Serviceability Index, the mean for IH highways ranges from 3.9 to 4.0 for the 1973 to 1976 period with these values representing a relatively smooth condition. US & SH highways have mean values which range from 3.5 to 3.6 and FM highways from 2.8 to 3.0. Thus the statewide value for this data type has been relatively consistent for at least four years.

More notable differences in Serviceability Index means are observed for the individual districts. For IH highways, the maximum range in Serviceability Index means for a district for the four year period varied from a maximum of 0.6 units to a minimum of 0 with an average of 0.2 for the thirteen districts in which highway segments were sampled. The average for the maximum change in one year is also 0.2 units. Seven districts

Table 2. Estimated District and Statewide Serviceability Index Means.

District	IH 73	IH 74	IH 75	IH 76	US & SH 73	US & SH 74	US & SH 75	US & SH 76	FM 73	FM 74	FM 75	FM 76
1	3.4	3.4	3.4	3.4	3.6	3.6	3.7	3.7	2.6	2.5	2.4	2.2
2	3.1	3.1	3.1	3.7	3.7	3.7	3.7	3.7	2.6	2.4	2.2	2.1
3	-	-	-	-	3.5	3.5	3.5	3.3	3.0	3.2	3.1	3.0
4	3.9	4.4	4.3	4.3	3.8	3.8	3.8	4.0	3.2	3.2	2.9	3.0
5	-	-	-	-	3.2	3.2	3.1	2.9	3.3	3.2	3.1	3.3
6	4.2	4.3	4.2	4.4	4.3	4.3	4.3	4.5	3.6	3.6	3.7	3.7
7	-	-	-	-	3.9	3.9	3.8	3.9	3.2	3.2	3.2	3.3
8	4.5	4.6	4.4	4.6	2.9	2.9	2.8	2.7	3.1	3.0	2.7	2.5
9	4.6	4.7	4.6	4.5	3.7	3.5	3.6	3.5	2.8	2.8	2.7	2.5
10	-	-	-	-	2.9	3.0	2.7	2.7	2.7	2.7	2.6	2.4
11	-	-	-	-	3.3	3.4	3.1	3.0	2.2	2.0	1.7	1.3
12	4.2	4.2	4.2	4.3	4.2	4.3	4.3	4.2	3.4	3.4	3.5	3.7
13	-	-	-	-	3.8	3.8	3.8	4.0	2.6	2.4	2.4	2.2
14	-	-	-	-	3.9	3.8	3.7	3.7	3.0	2.8	2.8	2.8
15	3.4	3.4	3.3	3.4	3.2	3.3	3.1	3.4	3.0	2.9	2.7	2.9
16	3.8	3.8	3.5	3.5	3.5	3.4	3.5	3.4	3.3	3.1	2.9	2.9
17	-	-	-	-	3.2	3.2	3.2	3.2	2.6	2.5	2.2	2.0
18	3.5	3.4	3.3	3.4	3.9	3.9	3.7	4.0	3.0	2.9	2.8	2.8
19	-	-	-	-	3.5	3.5	3.4	3.7	3.0	3.1	2.7	2.6
20	4.6	4.6	4.6	4.7	3.6	3.6	3.4	3.4	3.3	3.3	3.4	3.3
21	-	-	-	-	3.6	3.6	-	3.7	3.0	2.8	-	3.1
22	-	-	-	-	3.3	3.4	3.6	3.8	3.5	3.4	3.5	3.9
23	4.0	4.3	4.3	4.5	4.0	3.7	3.9	4.0	2.8	2.6	2.4	2.2
24	4.4	4.4	4.4	4.4	3.5	3.4	3.4	3.2	2.7	2.5	2.6	2.4
25	-	-	-	-	2.9	3.1	2.7	2.6	3.2	3.0	3.1	3.1
Statewide	3.9	4.0	3.9	4.0	3.6	3.5	3.5	3.5	3.0	2.9	2.8	2.8

Table 3 . Estimated District and Statewide Serviceability Index Standard Errors

District	Highway Type and Year											
	IH				US & SH				FM			
	73	74	75	76	73	74	75	76	73	74	75	76
1	-	-	-	-	0.1	0.1	0.1	0.2	0.3	0.2	0.3	0.4
2	-	-	-	-	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.1
3	-	-	-	-	0.3	0.3	0.3	0.4	0.4	0.2	0.2	0.4
4	0.5	0.1	0.2	0.3	0.2	0.3	0.4	0.4	0.1	0.2	0.2	0.4
5	-	-	-	-	0.1	0.1	0.2	0.3	0.1	0.2	0.2	0.3
6	-	-	-	-	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3
7	-	-	-	-	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2
8	-	-	-	-	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.5
9	-	-	-	-	0.2	0.4	0.4	0.4	0.3	0.3	0.3	0.3
10	-	-	-	-	0.2	0.2	0.1	0.2	0.3	0.3	0.4	0.4
11	-	-	-	-	0.2	0.2	0.3	0.4	0.2	0.2	0.2	0.2
12	-	-	-	-	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.2
13	-	-	-	-	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
14	-	-	-	-	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
15	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.3
16	-	-	-	-	0.1	0.1	0.2	0.2	0.1	0.2	0.3	0.3
17	-	-	-	-	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
18	-	-	-	-	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
19	-	-	-	-	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4
20	-	-	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
21	-	-	-	-	0.1	0.1	-	0.1	0.2	0.4	-	0.6
22	-	-	-	-	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2
23	-	-	-	-	0.2	0.3	0.3	0.3	0.1	0.1	0.1	0.2
24	-	-	-	-	0.3	0.3	0.3	0.4	0.2	0.4	0.3	0.6
25	-	-	-	-	0.2	0.6	0.6	0.7	0.2	0.3	0.3	0.5
Statewide	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.4

Table 4. Estimated District and Statewide Pavement Rating Score Means

District	Highway Type and Year											
	IH				US & SH				FM			
	73	74	75	76	73	74	75	76	73	74	75	76
1	76	76	76	76	96	79	72	71	78	82	71	75
2	65	65	85	53	94	95	82	76	76	88	76	75
3	-	-	-	-	90	92	75	70	80	85	81	69
4	98	100	90	82	73	80	72	81	72	78	80	70
5	-	-	-	-	56	66	73	47	79	79	77	53
6	88	99	97	91	91	88	92	83	88	87	91	82
7	-	-	-	-	84	84	89	84	87	87	90	80
8	100	98	89	56	78	62	74	66	82	69	77	71
9	96	96	93	84	82	88	72	63	85	87	84	69
10	-	-	-	-	87	89	68	84	64	69	65	58
11	-	-	-	-	80	80	67	83	57	62	53	76
12	83	90	76	87	87	88	76	84	79	79	82	80
13	-	-	-	-	94	93	87	92	78	88	83	86
14	-	-	-	-	89	92	82	88	85	91	82	85
15	80	85	82	74	89	83	73	70	90	91	69	80
16	100	100	98	100	92	96	96	86	84	85	87	78
17	-	-	-	-	76	80	66	57	67	75	57	76
18	89	82	85	84	85	82	84	75	84	92	90	82
19	-	-	-	-	89	87	50	67	92	87	70	82
20	100	100	100	100	91	82	83	72	89	86	89	95
21	-	-	-	-	76	85	-	76	74	76	-	75
22	-	-	-	-	87	91	88	68	86	87	77	80
23	100	98	100	85	83	88	75	91	74	80	77	46
24	83	83	83	76	85	84	80	70	81	89	93	88
25	-	-	-	-	60	77	74	54	76	79	81	79
Statewide	87	90	87	79	82	83	77	74	80	82	79	74

Table 5 . Estimated District and Statewide Pavement Rating Score Standard Errors

District	IH				US & SH				FM			
	73	74	75	76	73	74	75	76	73	74	75	76
1	-	-	-	-	2	6	4	3	4	4	8	4
2	-	-	-	-	3	1	1	3	15	2	6	6
3	-	-	-	-	2	2	6	4	3	1	2	7
4	2	0	8	5	7	5	13	4	3	4	7	8
5	-	-	-	-	4	4	4	6	4	4	3	10
6	-	-	-	-	6	4	4	4	2	2	2	2
7	-	-	-	-	2	2	2	3	10	10	5	4
8	-	-	-	-	6	2	9	3	7	7	4	10
9	-	-	-	-	8	5	8	10	5	4	5	12
10	-	-	-	-	6	2	8	5	13	12	13	11
11	-	-	-	-	10	5	12	6	8	5	7	4
12	-	-	-	-	3	2	3	3	12	7	8	8
13	-	-	-	-	4	3	3	1	8	5	7	3
14	-	-	-	-	3	3	3	2	3	1	2	3
15	10	19	9	11	6	11	9	6	2	4	12	4
16	-	-	-	-	3	2	1	1	2	2	4	3
17	-	-	-	-	3	4	1	6	6	8	4	3
18	-	-	-	-	7	4	4	8	7	2	2	4
19	-	-	-	-	3	2	11	4	1	6	11	5
20	-	-	-	-	2	6	3	4	1	1	1	2
21	-	-	-	-	10	3	-	10	1	1	-	7
22	-	-	-	-	2	1	3	4	4	4	5	7
23	-	-	-	-	6	5	16	5	1	4	3	7
24	-	-	-	-	2	2	4	3	11	1	1	2
25	-	-	-	-	5	9	7	11	5	2	6	4
Statewide	6	5	7	10	5	5	7	6	6	5	6	7

Highway Type and Year: IH, US & SH, FM

Table 6. Estimated District and Statewide Surface Curvature Index Means and Standard Errors

District	Highway Type					
	IH		US&SH		FM	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
1	0.03	-	0.23	0.12	0.89	0.21
2	0.23	-	0.44	0.05	0.44	0.05
3	-	-	0.44	0.12	0.61	0.06
4	0.14	0.04	0.45	0.07	0.84	0.08
5	-	-	0.56	0.04	0.69	0.06
6	0.05	-	0.34	0.16	0.44	0.05
7	-	-	0.57	0.06	0.84	0.11
8	0.19	-	0.49	0.06	0.66	0.02
9	0.13	-	0.27	0.06	0.59	0.04
10	-	-	0.52	0.09	0.69	0.09
11	-	-	0.43	0.04	0.52	0.05
12	0.03	-	0.14	0.05	0.51	0.06
13	-	-	0.30	0.08	0.73	0.18
14	-	-	0.45	0.13	0.70	0.07
15	0.17	0.06	0.14	0.03	0.92	0.21
16	0.18	-	0.61	0.11	1.01	0.06
17	-	-	0.32	0.09	0.66	0.06
18	0.26	-	0.13	0.11	0.44	0.11
19	-	-	0.29	0.03	0.64	0.03
20	0.21	-	0.37	0.11	0.50	0.01
21	-	-	0.50	0.05	0.77	0.11
22	-	-	0.57	0.18	0.61	0.14
23	0.04	-	0.32	0.06	0.46	0.01
24	0.13	-	0.55	0.05	0.80	0.01
25	-	-	0.76	0.29	0.72	0.07
Statewide	0.14	0.05	0.42	0.11	0.68	0.10

increase in mean Serviceability Index between 1973 and 1976, three decreased, and three had no change. For US & SH highways, the maximum range in Serviceability Index means for a district for the four year period varied from a maximum of 0.5 units to a minimum of 0 with an average for all twenty-five districts of 0.2. Again, as was observed for IH highways, the average for the maximum change in one year is also 0.2 units. Nine districts showed increases in mean SI between 1973 and 1976, eleven decreased, and five indicated no change. For FM highways, the maximum range in Serviceability Index means for the four year period varied from a maximum of 0.9 units to a minimum of 0.1 with an average for all twenty-five districts of about 0.4. Again, as was observed for the two other highway types, the average for the maximum change in one year was about 0.2 units. Four districts showed increases in mean Serviceability Index between 1973 and 1976, eighteen decreased, and three had no change.

From the preceeding discussion for the years 1973 to 1976 the following observations can be made:

1. IH highways have become slightly smoother,
2. US & SH highways stayed about the same,
3. FM highways have become slightly rougher,
4. Few large differences occurred when comparing one district's Serviceability Index means on an annual basis,
5. The differences in district Serviceability Index means are almost as likely to occur in one year as over a period of four years.

The first three observations are reasonable only if no provision is made for instrument, measurement, and calibration errors. Unfortunately, exclusion of such errors is not reasonable and can normally be expected to range 0.1 to 0.3 Serviceability Index units per reading as is discussed in Reference 5.

To provide additional information on such errors, Figures 5, 6, and 7 were prepared. The data for these Serviceability Index histograms were obtained from the sampled two-mile segments for each of the three highway types. These figures are of specific value in examining year-to-year Serviceability Index variations.

Figure 5 contains histograms of the Serviceability Index means obtained from all of the sampled highway segments for 1973, 1974, 1975, and 1976. With the exception of IH highways, these data verify the trends in Table 2 in that the roughness of the pavement segments tend to increase from 1973 to 1976. What needs to be determined is whether this is a "true" indication that US & SH and FM highways are becoming rougher or is this some type of instrument or calibration related anomaly. To help examine this question, Figures 6 and 7 were prepared.

Figure 6 is the same kind of plot as Figure 5 with the difference being that the highest 0.2 mile accumulated Serviceability Index value from each of the sampled segments was used to construct the histograms in lieu of mean values. This data indicates that the number of highest Serviceability Index values tended to increase from 1973 to 1976 for all three highway types and is particularly apparent for FM highways. For this highway type, about twelve percent of the highest Serviceability Index values fell within the range of 4.0 to 5.0 in 1973 and increased to forty-three percent in 1976. A similar trend is observed in Figure 7 which shows histograms of the lowest Serviceability Index value for each of the sampled segments. The frequency of these Serviceability Index values increased from 1973 to 1976 for the lower Serviceability Index

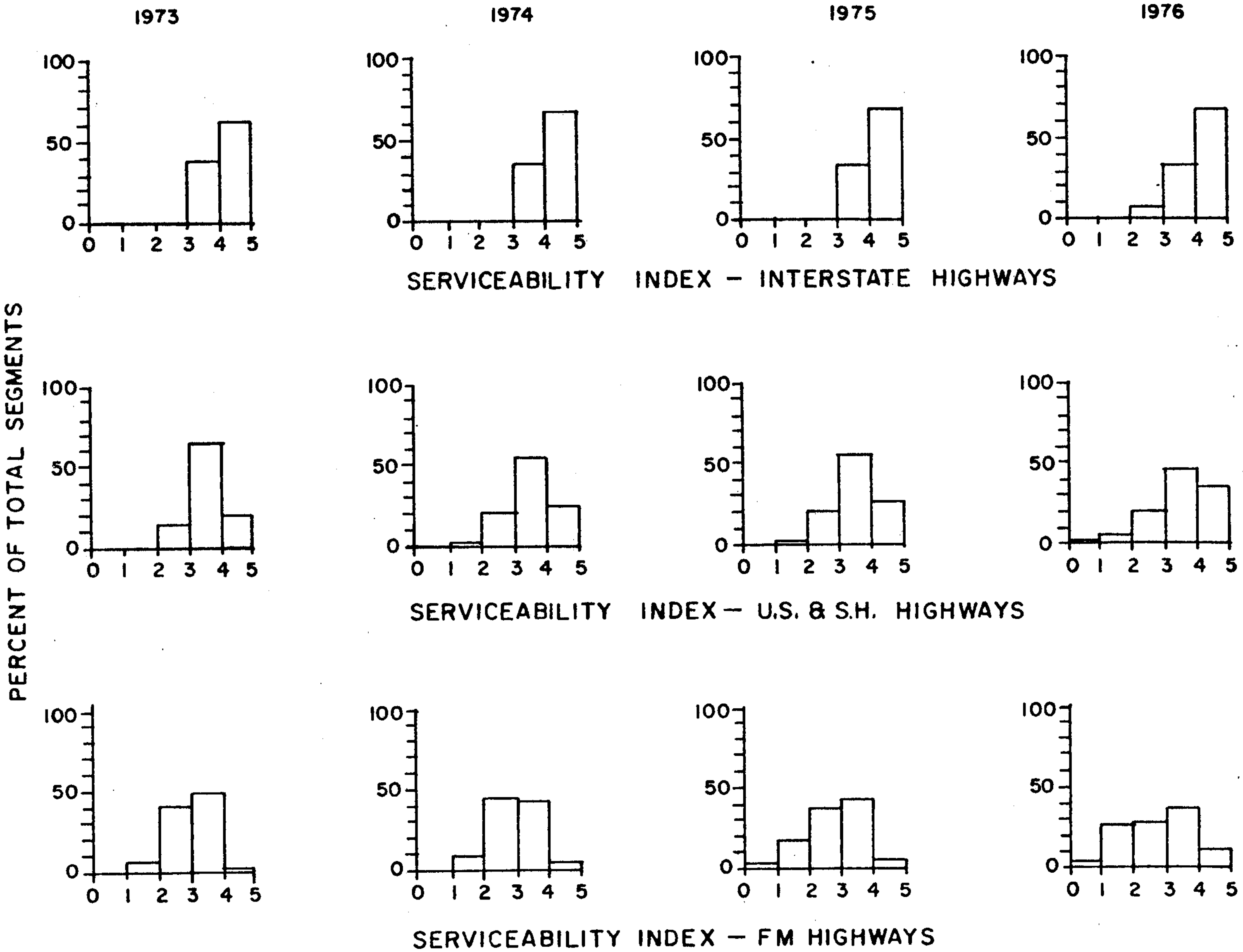

Figure 5. Histograms of Yearly Serviceability Index Means for Statewide Two-Mile Highway Segments

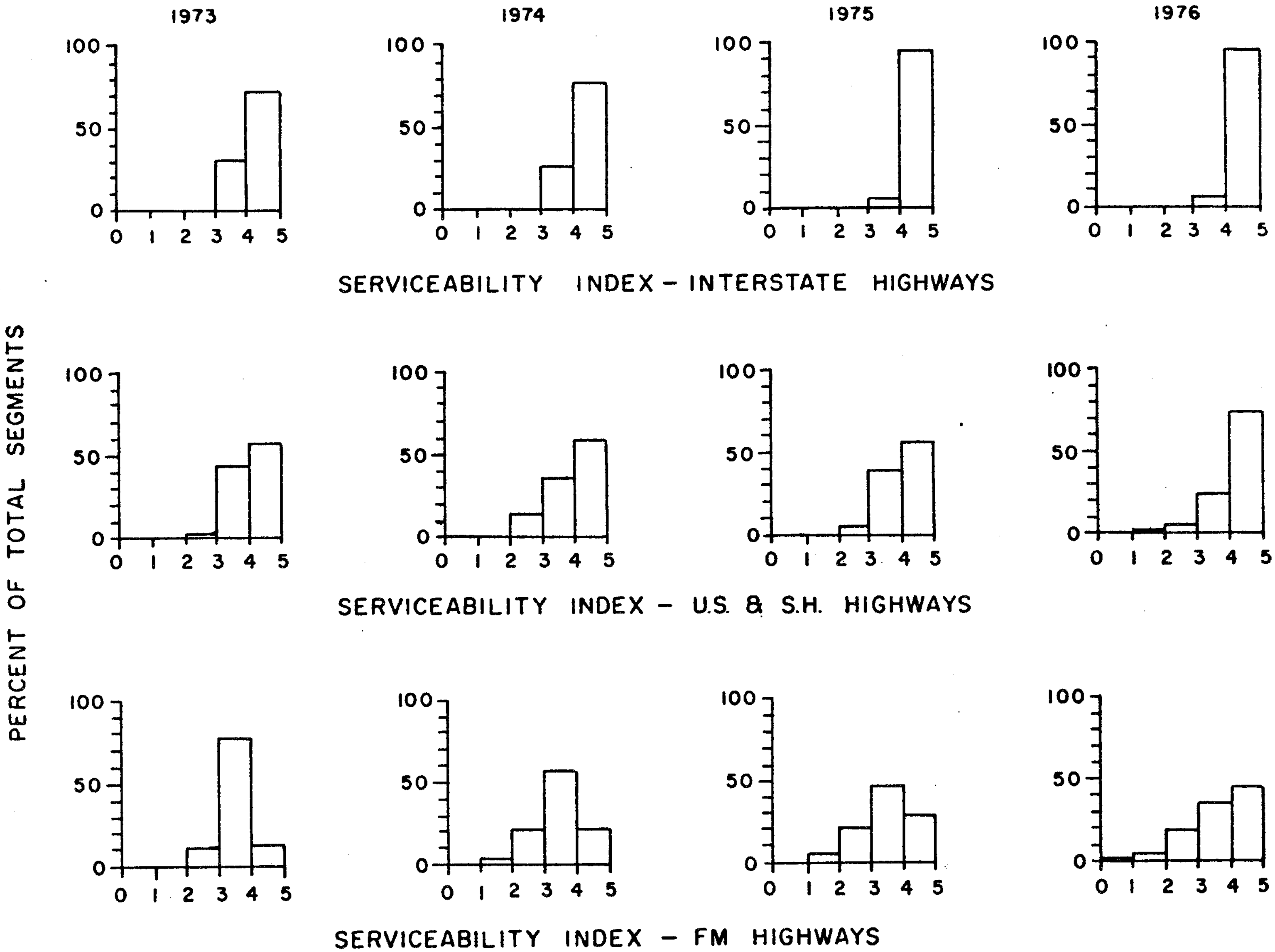

Figure 6. Histograms of Yearly Highest Serviceability Index Values for Statewide Two-Mile Highway Segments

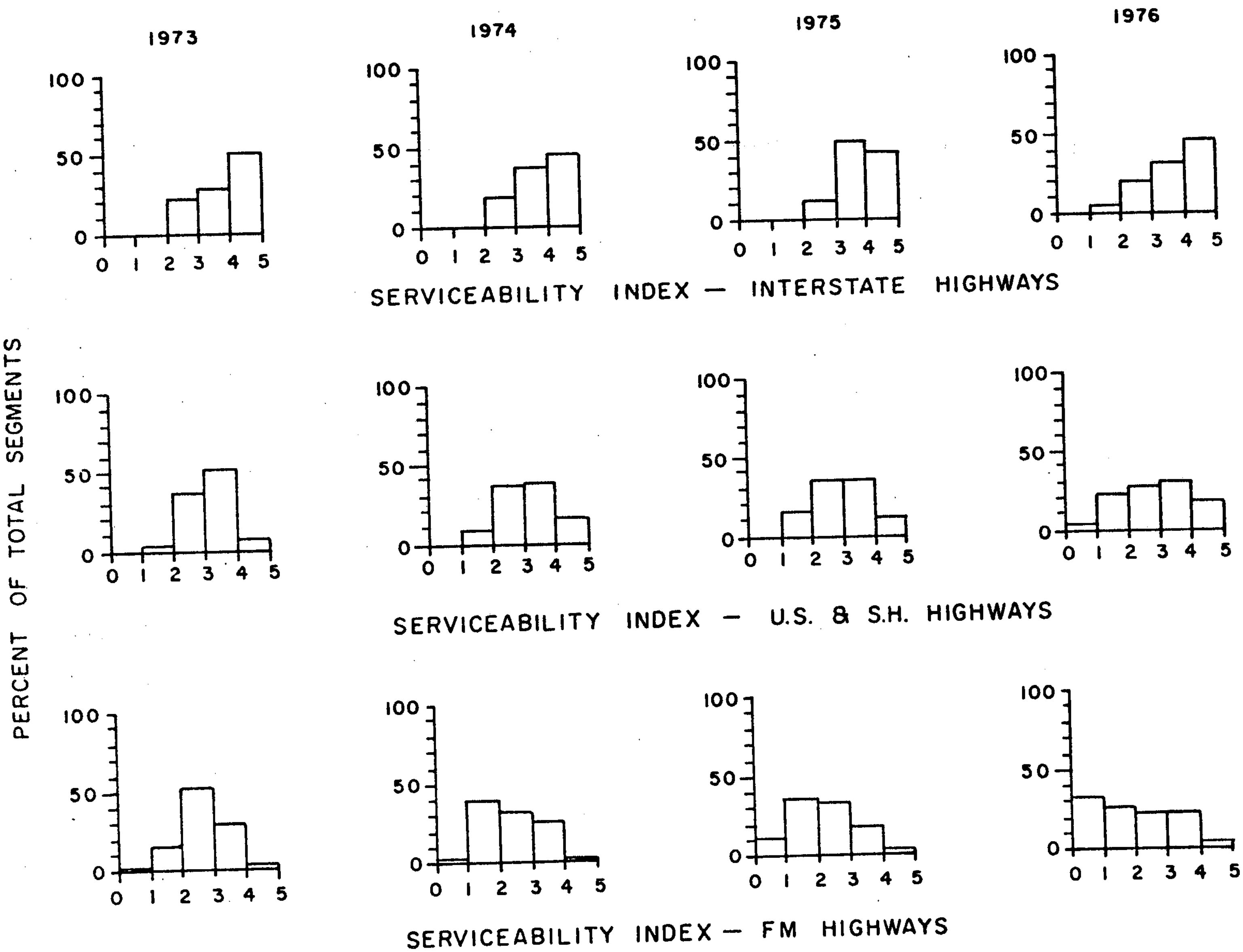

Figure 7. Histograms of Yearly Lowest Serviceability Index Values for Statewide Two-Mile Highway Segments

ranges. Again, this is most apparent for FM highways. For this highway type, about one percent of the lowest Serviceability Index values fell within the range of 0 to 1.0 in 1973 and increased to about thirty-two percent in 1976.

It is unlikely that the highway segments used in the study would improve and deteriorate at the rates shown in Figures 6 and 7 due to effects of environment, traffic, maintenance, etc. It is more likely that the sensitivity of the data is most heavily influenced by the Mays Ride Meter and its calibration.

To examine for possible calibration errors, Tables 7 and 8 were prepared. Table 7 shows how the unreduced Mays Ride Meter digital readings for various levels of Serviceability Index have changed over a period of about three years. These calibrations were obtained using standard SDHPT procedures for the Mays Ride Meter installed in the TTI 1975 Ford LTD. The data indicates that fairly large changes in the calibration have taken place particularly for the lower Serviceability Index region. These changes occurred even though significant efforts were made to keep the vehicle in a standard operating condition. Table 8 is a partial listing of the Serviceability Indices obtained by use of the Surface Dynamics Profilometer (SDP) for the SDHPT calibration sections. These sections are used to calibrate all SDHPT and TTI Mays Ride Meters. Some of the observed Serviceability Indices that increase with time are due to pavement maintenance. The decreases that occur over short periods of time are of more interest and may be due to instrument or related correlation errors. Additionally, the standard error of the residuals for the TTI Mays Ride Meter calibrations have ranged from 0.35 to 0.69. This observed range of variability could obscure year-to-year differences for any of the

Table 7. TTI Mays Ride Meter Calibrations Over a Three Year Period

Calibration Date	Raw Mays Ride Meter Digital Reading For Various Levels of Serviceability Index					
	5.0	4.0	3.0	2.0	1.0	0.5
May 13-16 1975	0.2	63.5	129.5	223.0	389.4	565.2
Sept. 23-24 1975	0.5	81.4	137.5	203.3	301.6	391.2
Sept. 24-25 1975	0.3	71.4	127.5	196.9	306.1	409.9
March 10-11 1976	0.8	81.9	128.9	180.2	252.3	314.5
June 17 1976	1.0	85.8	130.8	178.5	243.5	298.5
July 28 1976	1.3	88.6	130.3	172.9	229.4	275.8
Aug. 30-31 1976	1.1	90.3	135.2	182.1	244.9	297.3
Oct. 28-29 1976	0.6	70.7	115.3	165.9	239.3	304.4
July 21-22 1977	0.4	82.0	144.4	220.7	338.9	449.9
Sept. 22-23 1977	0.4	81.8	147.1	228.3	356.5	478.8
Feb. 24 1978	0.5	91.6	154.9	229.1	339.8	440.5
Range	0.2-1.3	63.5-91.6	115.3-154.9	165.9-229.1	229.4-389.4	275.8-565.2
Mean	0.6	80.8	134.7	198.3	294.7	384.2
Standard Deviation	0.4	8.9	10.9	23.8	55.8	93.7
Coefficient of Variation (0/0)	66.7	11.0	8.1	12.0	18.9	24.4

Table 8. Serviceability Indices Obtained for the SDHPT Calibration Sections With the Surface Dynamics Profilometer.

Section Number	Serviceability Index for Various Dates						
	1/78	7/77	4/77	8/76	4/76	1/76	7/75
1	3.3	3.1	3.1	3.6	3.5	3.5	4.1
2	2.0	1.9	1.9	--	1.7	1.7	1.4
3	3.8	--	3.5	2.9	3.3	3.1	3.1
5	3.2	3.2	3.2	3.4	3.6	3.5	3.5
7	3.8	4.5	4.5	4.1	4.2	4.4	4.2
8	3.3	3.3	3.4	3.8	3.8	4.0	3.4
9	3.9	4.0	4.2	4.0	3.9	4.0	4.0
10	--	4.2	4.2	4.7	4.5	4.6	4.4
11	--	4.3	4.2	4.8	4.9	4.7	4.3
12	--	2.9	3.4	2.5	2.9	2.9	3.0
13	3.2	2.9	3.2	3.2	3.1	3.1	3.0
14	3.6	3.7	3.7	3.2	3.2	3.4	3.5
15	3.7	3.5	3.6	3.9	4.3	4.2	3.4
19	3.6	3.4	3.7	3.2	3.3	3.4	3.5
23	3.5	3.5	3.3	3.2	3.4	3.5	3.4
28	3.8	3.8	3.9	4.2	4.0	4.2	3.8
32	--	3.7	4.1	3.9	3.9	3.9	3.9
33	--	2.8	2.9	2.8	3.0	3.0	3.1
34	--	3.0	3.3	2.5	2.4	2.3	2.9
35	2.6	--	2.3	2.1	1.8	1.6	1.3
36	4.4	4.3	4.6	4.4	4.4	4.5	4.4
37	3.5	3.5	3.6	3.7	3.6	3.6	--
39	1.9	1.7	1.9	1.2	1.2	1.1	1.6
40	3.7	3.7	3.8	3.6	3.6	3.9	3.8
41	2.6	2.6	2.5	2.2	2.2	2.1	2.6

pavement segments being studied.

An additional source of error involved in making such estimates is the sampling error. Since the estimates are based on sample sizes ranging from almost 2 percent to 0.5 percent, the sampling error varies for each district and highway type. The standard error is an indication of the magnitude of the sampling error. Individual estimates for each district and the statewide case are shown. But, the standard errors contained in Table 3 are based on small sample sizes and therefore are not preferable to use in estimating confidence limits. Standard errors obtained from a population of Serviceability Index data in District 21 have been used instead. The development of these standard errors will be discussed in more detail later in the report.

Confidence limits using the District 21 population derived standard errors and sample estimated means for each district were used in developing the information contained in Tables 9 through 11. These confidence limits are intervals which are expected to contain the "true" population means for the given probability. The sample Serviceability Index means are at the centers of the intervals. The three tables are developed for each of the separate highway types for 1976 survey data. It is observed that for the higher confidence probabilities (95 and 99 percent) the intervals for Serviceability Index become quite large.

To verify the statewide random sampling estimates, continuous sampling of Serviceability Index data was made during 1977 and early 1978 with the Mays Ride Meter. This sampling procedure required the evaluation teams to drive 50 mph and record the roughness while traveling between the two-mile highway segments in the study. By obtaining additional Serviceability Index data in this manner, larger statewide sample sizes were ob-

Table 9. Estimated District Serviceability Index Confidence Limits for Sampled Interstate Highway Segments... 1976.

District	Confidence Probability (%)									
	50		80		90		95		99	
	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit
1	3.5	3.3	3.6	3.2	3.6	3.2	3.7	3.1	3.8	3.0
2	3.8	3.6	3.9	3.5	4.0	3.4	4.0	3.4	4.1	3.3
3	-	-	-	-	-	-	-	-	-	-
4	4.4	4.2	4.5	4.1	4.5	4.1	4.5	4.1	4.7	4.0
5	-	-	-	-	-	-	-	-	-	-
6	4.6	4.2	4.7	4.1	4.8	4.0	4.9	3.9	5.0	3.8
7	-	-	-	-	-	-	-	-	-	-
8	4.7	4.5	4.8	4.4	4.8	4.4	4.9	4.3	5.0	4.2
9	4.6	4.4	4.6	4.4	4.7	4.3	4.7	4.3	4.8	4.2
10	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-
12	4.4	4.2	4.5	4.1	4.5	4.1	4.5	4.1	4.6	4.0
13	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-
15	3.5	3.3	3.6	3.2	3.7	3.1	3.7	3.1	3.8	3.0
16	3.6	3.4	3.7	3.3	3.7	3.3	3.8	3.2	3.9	3.1
17	-	-	-	-	-	-	-	-	-	-
18	3.5	3.3	3.6	3.2	3.7	3.1	3.8	3.0	3.9	2.9
19	-	-	-	-	-	-	-	-	-	-
20	4.8	4.6	4.9	4.5	4.9	4.5	5.0	4.4	5.0	4.3
21	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-
23	4.6	4.4	4.6	4.4	4.7	4.3	4.7	4.3	4.8	4.2
24	4.6	4.2	4.7	4.1	4.8	4.0	4.9	3.9	5.0	3.7
25	-	-	-	-	-	-	-	-	-	-

Table 10. Estimated District Serviceability Index Confidence Limits for Sampled United States and State Highway Segments...1976.

District	Confidence Probability (%)									
	50		80		90		95		99	
	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit
1	3.9	3.5	4.0	3.4	4.1	3.3	4.2	3.2	4.4	3.0
2	3.9	3.5	4.0	3.4	4.1	3.3	4.2	3.2	4.3	3.1
3	3.5	3.1	3.7	2.9	3.8	2.8	3.9	2.7	4.0	2.6
4	4.2	3.8	4.4	3.6	4.5	3.5	4.5	3.5	4.7	3.3
5	3.1	2.7	3.2	2.6	3.3	2.5	3.4	2.4	3.5	2.3
6	4.7	4.3	4.8	4.2	4.9	4.1	5.0	4.0	5.0	3.8
7	4.1	3.7	4.2	3.6	4.3	3.5	4.4	3.4	4.6	3.2
8	2.9	2.5	3.1	2.3	3.2	2.2	3.3	2.1	3.5	1.9
9	3.7	3.3	3.9	3.1	4.0	3.0	4.0	3.0	4.2	2.8
10	2.9	2.5	3.1	2.3	3.3	2.1	3.4	2.0	3.6	1.8
11	3.2	2.8	3.4	2.6	3.5	2.5	3.6	2.4	3.7	2.3
12	4.4	4.0	4.5	3.9	4.6	3.8	4.7	3.7	4.8	3.6
13	4.2	3.8	4.4	3.6	4.5	3.5	4.6	3.4	4.8	3.2
14	3.9	3.5	4.1	3.3	4.2	3.2	4.3	3.1	4.5	2.9
15	3.6	3.2	3.8	3.0	3.9	2.9	3.9	2.9	4.1	2.7
16	3.6	3.2	3.7	3.1	3.8	3.0	3.9	2.9	4.1	2.7
17	3.4	3.0	3.6	2.8	3.7	2.7	3.8	2.6	3.9	2.5
18	4.2	3.8	4.3	3.7	4.4	3.6	4.5	3.5	4.6	3.4
19	3.9	3.5	4.1	3.3	4.2	3.2	4.2	3.2	4.4	3.0
20	3.6	3.2	3.8	3.0	3.9	2.9	4.0	2.8	4.1	2.7
21	3.9	3.5	4.1	3.3	4.2	3.2	4.3	3.1	4.4	3.0
22	4.0	3.6	4.2	3.4	4.3	3.3	4.4	3.2	4.5	3.1
23	4.2	3.8	4.4	3.6	4.5	3.5	4.6	3.4	4.7	3.3
24	3.4	3.0	3.5	2.9	3.6	2.8	3.7	2.7	3.8	2.6
25	2.8	2.4	3.0	2.2	3.1	2.1	3.2	2.0	3.3	1.9

Table 11. Estimated District Serviceability Index Confidence Limits for Sampled Farm-to-Market Highway Segments...1976.

District	Confidence Probability (%)									
	50		80		90		95		99	
	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit
1	2.4	2.0	2.7	1.7	2.8	1.6	2.9	1.5	3.1	1.3
2	2.3	1.9	2.6	1.6	2.7	1.5	2.8	1.4	3.0	1.2
3	3.3	2.7	3.5	2.5	3.6	2.4	3.8	2.2	4.0	2.0
4	3.3	2.7	3.5	2.5	3.7	2.3	3.8	2.2	4.1	1.9
5	3.6	3.0	3.8	2.8	4.0	2.6	4.1	2.5	4.4	2.2
6	3.9	3.5	4.1	3.3	4.2	3.2	4.3	3.1	4.5	2.9
7	3.6	3.0	3.8	2.8	3.9	2.7	4.1	2.5	4.3	2.3
8	2.8	2.2	3.1	1.9	3.2	1.8	3.4	1.6	3.7	1.3
9	2.7	2.3	3.0	2.0	3.1	1.9	3.2	1.8	3.4	1.6
10	2.6	2.2	2.9	1.9	3.0	1.8	3.1	1.7	3.3	1.5
11	1.5	1.1	1.8	0.8	1.9	0.7	2.0	0.6	2.2	0.5
12	3.9	3.5	4.1	3.3	4.2	3.2	4.3	3.1	4.6	2.8
13	2.4	2.0	2.6	1.8	2.7	1.7	2.8	1.6	3.1	1.3
14	3.1	2.5	3.3	2.3	3.5	2.1	3.6	2.0	3.9	1.7
15	3.2	2.6	3.4	2.4	3.6	2.2	3.7	2.1	4.0	1.8
16	3.2	2.6	3.4	2.4	3.5	2.3	3.7	2.1	3.9	1.9
17	2.3	1.7	2.5	1.5	2.7	1.3	2.8	1.2	3.1	0.9
18	3.0	2.6	3.1	2.5	3.2	2.4	3.3	2.3	3.4	2.2
19	2.9	2.3	3.1	2.1	3.2	2.0	3.4	1.8	3.6	1.6
20	3.5	3.1	3.7	2.9	3.8	2.8	3.9	2.7	4.2	2.4
21	3.4	2.8	3.6	2.6	3.7	2.5	3.9	2.3	4.1	2.1
22	4.1	3.7	4.3	3.5	4.4	3.4	4.5	3.3	4.8	3.0
23	2.5	1.9	2.7	1.7	2.8	1.6	3.0	1.4	3.2	1.2
24	2.6	2.2	2.7	2.1	2.8	2.0	2.9	1.9	3.1	1.7
25	3.4	2.8	3.6	2.6	3.7	2.5	3.9	2.3	4.1	2.1

tained for the three highway types. The data so obtained are relatively unbiased and can be considered to be randomly collected. The form used to record the raw Mays Ride Meter data is shown as Figure 8. This information was keypunched to provide for computer processing.

The primary goal of each evaluation team was to obtain the required information (Serviceability Index and visual condition surveys) on the two-mile highway segments. Therefore, travel to these segments were via the shortest routes which were most often IH or US & SH highways. This fact is reflected in Table 12 which shows the percentage of centerline mileage sampled in each district and statewide. The IH highways have the highest percentage of sampling with 25.2 percent, US & SH highways were next with 9.7 percent, and FM highways last with 1.2 percent. Most of the mileage reflected in the above percentages were obtained by traveling a highway in one direction. The only major exceptions to this occurred on IH highways in Districts 2, 9, and 18. For these three districts, some of the data were obtained on opposite sides of the same highway.

Figure 9 and Table 13 are summaries of the Serviceability Indices obtained by the continuous sampling procedure. Figure 9 is composed of three histograms - one for each highway type with each showing how the data were distributed. Table 13 is a statistical summary showing the sampled mileage, mean, standard deviation, low, and high values for each of the highway types. The means in this table were weighted by the amount of mileage in each district to reduce the effects of unequal sample sizes in the individual districts. Additionally, the standard deviations were calculated by pooling the variances from each of the district estimates.

An examination of the means in Table 13 show that they compare quite favorably to the estimates shown in Table 1 obtained for the statewide

Figure 8. Form Used for Collection of Continuously Sampled Mays Ride Meter Data

SECTION ID NUMBER	CARD NUMBER	COUNTY NUMBER	HIGHWAY TYPE & NUMBER	DATE (MM DD YY)	SURFACE TYPE	SECTION MILEAGE	LANE (R OR L)	SECTION LOCATION DESCRIPTION

Table 12. Percentage of Centerline Mileage Sampled by Continuous Mays Meter Operation for Each District and Statewide.

District	Percentage of Centerline Mileage Sampled by Continuous Mays Ride Meter Operation		
	IH	US & SH	FM
1	25.6	3.5	0.4
2	76.5	2.4	0.3
3	-	0.6	-
4	23.8	4.7	2.3
5	-	-	-
6	20.2	2.5	1.6
7	7.9	14.4	-
8	21.7	13.2	0.9
9	100.0	11.8	1.2
10	16.3	1.2	-
11	-	16.1	-
12	7.5	19.2	3.1
13	25.4	5.0	2.6
14	10.9	27.4	-
15	-	7.9	0.8
16	-	21.0	3.1
17	-	31.8	2.7
18	100.0	8.4	1.3
19	69.5	4.5	0.3
20	22.8	15.4	2.7
21	-	21.5	2.0
22	-	3.2	3.6
23	23.2	11.1	1.9
24	26.3	9.4	-
25	-	5.7	-
Statewide	25.2	9.7	1.2

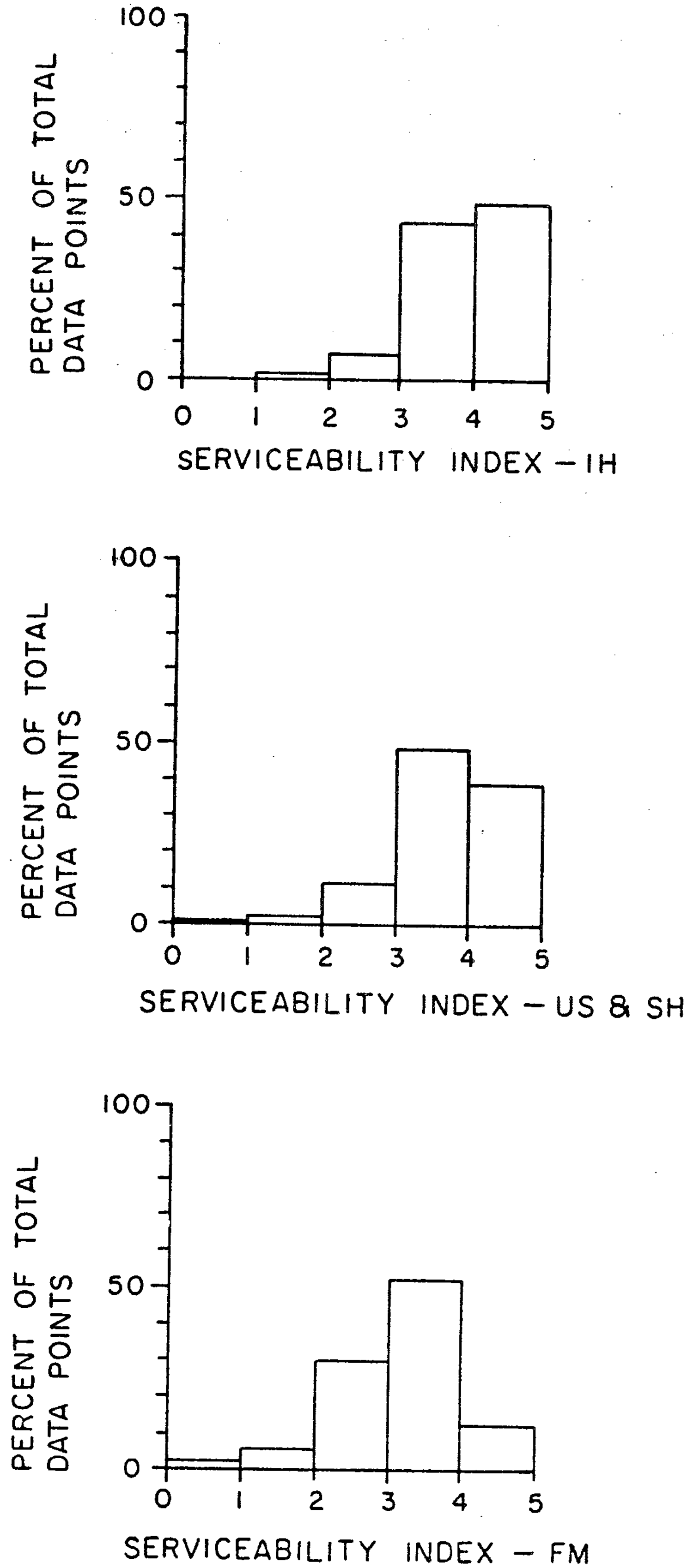

Figure 9. Histograms for Statewide Continuously Sampled Serviceability Index Data

Table 13. Statewide Serviceability Index Statistical Summary Based on Continuous Sampling With the Mays Ride Meter

Highway Type	Mileage	Serviceability Index			
		Mean	S.D.	Low *	High
IH	597	3.99	0.48	1.1	4.9
US&SH	2113	3.57	0.58	0.5	4.9
FM	435	3.10	0.64	0.5	4.7

* A Serviceability Index value of 0.5 is the lowest value used for Mays Ride Meter data

two-mile segments. The minor exception to this is FM highways. The continuously sampled mean for this highway type was 3.1 and from Table 1 it was 2.8 for 1976. It should be noted that the two sample sizes are not greatly different. The continuously sampled data in this case are somewhat biased since eight of the district estimates are based on data obtained on only one FM highway and in eight more districts no continuous data was obtained. Thus, the estimate of statewide Serviceability Index for FM highways contained in Table 1 should be more reliable.

Pavement Rating Score

Tables 4 and 5 show district and statewide estimates of Pavement Rating Score for 1973, 1974, 1975, and 1976. The estimates of the mean are shown in Table 4 and the associated standard errors are shown in Table 5 for each highway type.

For the statewide estimate of this score, the mean for IH highways ranges from 87 to 79 for the 1973 to 1976 period. For the same period, US & SH highways decreased from 82 to 74 and FM highways from 80 to 74. Figure 10 verifies these data trends by use of histograms of Pavement Rating Score means. Both Table 4 and Figure 10 tend to indicate that the distress manifestations evaluated by the rating procedure have been increasing with time thus decreasing the Pavement Rating Score. Again, as was observed for Serviceability Index data, this trend may or may not be valid due to a number of factors which will be discussed subsequently.

More notable differences in Pavement Rating Score means are observed for the individual districts. For IH highways, the maximum range in Pavement Rating Score means for a district for the four-year period varied from a maximum of 44 PRS units to 0 with an average for the thirteen

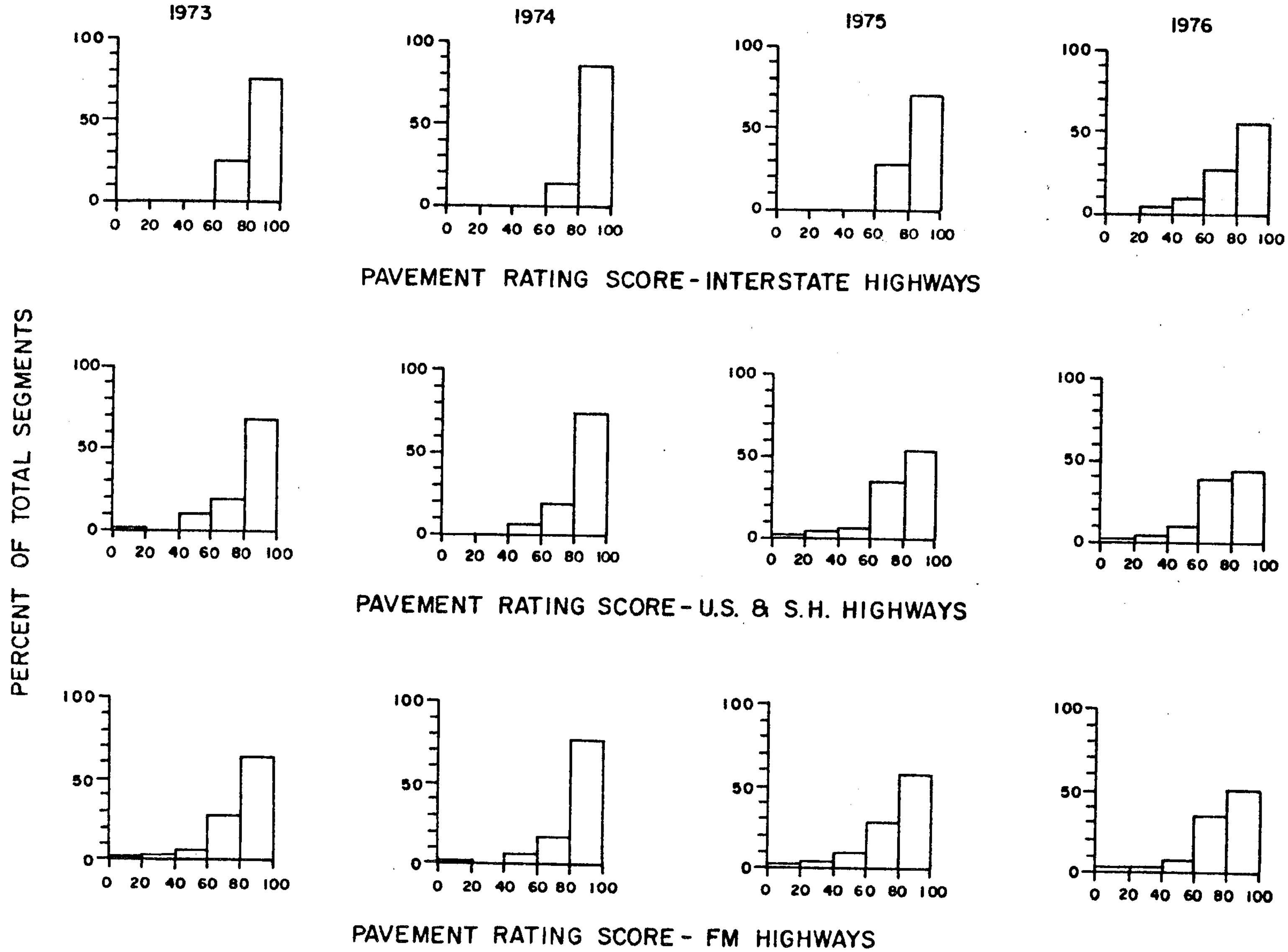

Figure 10. Histograms of Yearly Pavement Rating Score Means for Statewide Two-Mile Highway Segments

districts of 13. The average for the maximum change in one year is 11 PRS units. Only two districts showed increases between 1973 and 1976, eight decreased, and three indicated no change. For US & SH highways, the maximum range in Pavement Rating Score means for a district for the four year period varied from a maximum of 39 PRS units to a minimum of 5 with an average for all twenty-five districts of 17. The average for the maximum change in one year was 14 PRS units. Three districts showed increases between 1973 and 1976, twenty decreased, and two indicated no change. For FM highways, the maximum range in Pavement Rating Score means for the four year period varied from a maximum of 34 PRS units to a minimum of 3 with an average for all twenty-five districts of about 14. The average for the maximum change in one year was about 13 PRS units. Seven districts showed increases between 1973 and 1976, seventeen decreased, and one did not change.

The following observations can be made based on the above discussion:

1. Large differences can occur when comparing one district's Pavement Rating Score means on an annual basis,
2. The large differences in district Pavement Rating Score means are almost as likely to occur in one year as in four years,
3. The general trend in Pavement Rating Score means (district and statewide) has decreased during the 1973 to 1976 period.

The variation observed in the Pavement Rating Score data can be separated into two types: sampling error and year-to-year variation. The sampling error occurs because the segments used represent an approximation of the population mean for each district and this type of error can affect the magnitude of the means reported. The year-to-year differences are those which were discussed in the preceeding paragraphs. Fortunately, the sampling error (as measured by the standard error) does not contribute to the year-to-year variation. This holds since the sample of highway segments was selected only once and are used each year for the annual measurements.

The most obvious way to decrease sampling error is to increase the sample size (number of segments) and a detailed discussion of this will be made later in this report. The year-to-year variation for a district is somewhat more complex since there are a number of factors involved.

Four major contributing factors which have caused year-to-year variation in Pavement Rating Score are:

1. Rater error: The inability of a rater(s) to replicate an evaluation on a given pavement. Previous research has shown that individuals, if properly trained, can attain agreement within ± 10 PRS points about 68 percent of the time (11). Additionally, the rating personnel in this study were not encouraged to use prior year evaluations.
2. Evaluation procedure change: Starting with the 1976 survey, rut depth measurements were made on all highway segments in the study. Prior to this survey rut depth was visually estimated. This resulted in more points being deducted from the Pavement Rating Score
3. Variation within the highway segment:

   (a) Pavement distress variation within highway segments often causes the rater difficulty in arriving at a "composite" rating which is representative of the whole highway segment being evaluated.

(b) Pavement distress variation within highway segments also causes the evaluation to be somewhat dependent upon where the rater stops to make the evaluation. It is felt that this is one of the largest causes of errors in year-to-year evaluations for any highway segment. A further examination of this variation source is contained in Appendices B, C, and D.

4. True year-to-year differences: major maintenance (such as overlays) and minor maintenance (such as patching, crack sealing, etc.) are performed annually on many of the pavement segments. Both types of maintenance can cause significant annual changes in the Pavement Rating Score.

The first three of the four above stated factors which contribute to Pavement Rating Score year-to-year variation should be reduced or eliminated. The fourth factor is the one that is actually sought. A number of relatively simple techniques can be used to reduce these undesirable variations. Some of the possible techniques are:

1. If prior year rating information is available, the rater(s) should use such data while conducting the current evaluation.
2. Each year the rater(s) should stop at the same location within each segment. At each stop, the rater should walk at least 50 feet in front of and behind the parked vehicle.
3. Analysis of data obtained in District 21 indicates that the number of rating locations (stops) should be made every mile to one-half mile (Appendix D).
4. The rating for each segment should be obtained by a consensus of at least two raters whenever possible.

5. Alterations can be made to the current evaluation procedure which will simplify its use (Appendix C).

Additional treatment of year-to-year differences in both Serviceability Index and Pavement Rating Score data will be made when the 1977 survey data are available.

Surface Curvature Index

Table 6 shows district and statewide estimates of Surface Curvature Index. These data are unlike the other two types previously discussed in that it was obtained for only one year. Thus, year-to-year variation cannot be examined. Figure 11 is also provided to show the statewide distributions of Surface Curvature Index means for the three highway types.

For the statewide estimate of Surface Curvature Index, IH highways are 0.14, US & SH highways 0.42, and FM highways 0.68. The smaller values are indicative of the stronger (and generally newer) pavement cross sections. Thus, the ordering of the values are as one would expect.

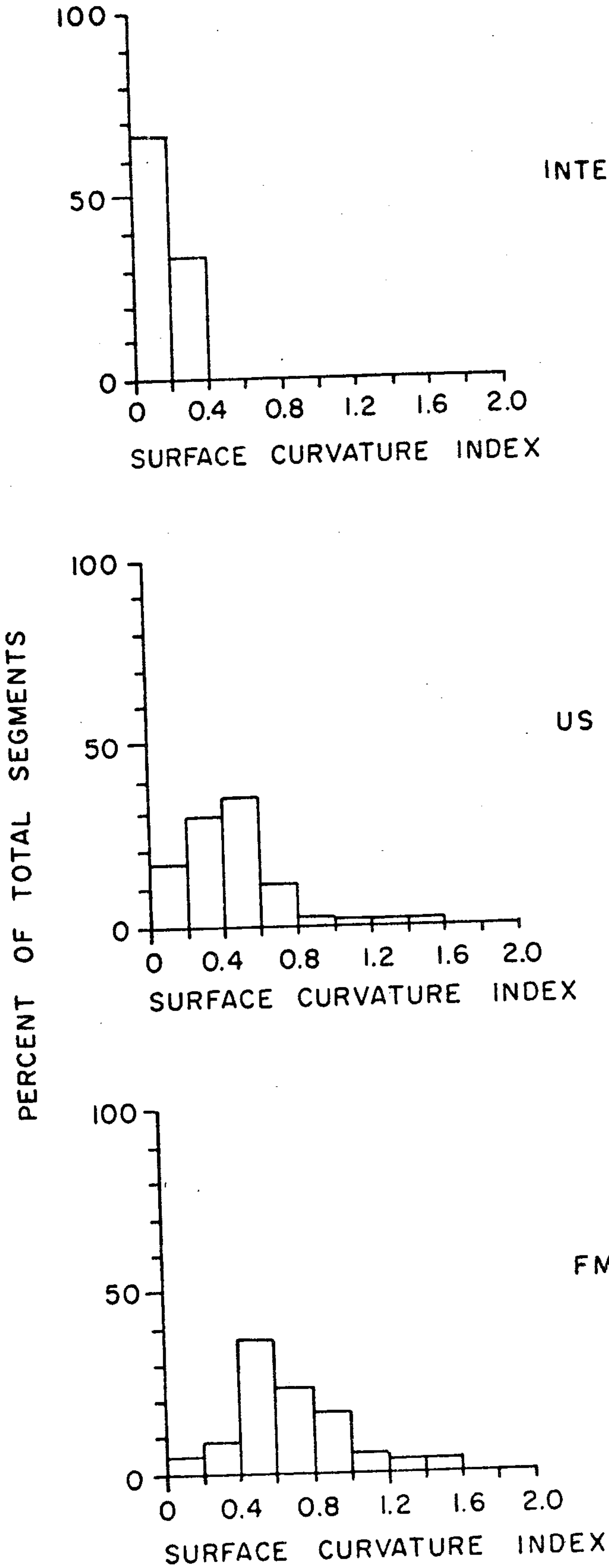

Figure 11. Histograms of Surface Curvature Index Means for Statewide Two-Mile Segments

SIMULATION STUDY TO EVALUATE SAMPLING PROCEDURE

After reviewing the estimates for the three data types, the questions that arise are how "good" are the various estimates based on the current highway segment sample with respect to other (larger and smaller) sample sizes, what is the least costly sample size to achieve adequate estimates, and will some other sampling procedure yield better precision? An approach toward answers to these questions will be presented.

To begin to answer the previously stated questions a simulation study was used to determine the precision of various highway segment sample sizes. This was done since direct experimentation on the highway network was too expensive and direct computation of consistently accurate two-stage sampling errors for various sample sizes was not possible. The simulation study was accomplished for District 21, located in the southernmost part of the state. Extensive data summaries will be shown for this district. This is done not only to perform the simulation study of sampling precision but also to show typical results from a large data collection effort (mass inventory). Such information will be of value in planning the upcoming first yearly statewide mass inventory survey. Appendix B contains additional discussion and presentation of District 21 data. For 1974 and 1975, virtually a complete mass inventory of the district's total mileage for four major kinds of data was collected on all highway types. Table 14 shows the total mileage in the district listed by highway type and county. Since this district has only 33 miles of Interstate highways, this highway type was not considered in the simulation study. The kinds of data used are as follows:

1. Serviceability Index: Obtained every 0.2 mi by use of the

Table 14. District 21 Highway Mileage (12)

COUNTY	HIGHWAY MILEAGE						
	RURAL			URBAN			TOTAL
	IH	US & SH	FM	IH	US & SH	FM	
Brooks	--	64.1	48.3	--	4.2	0.2	116.8
Cameron	--	126.6	279.9	--	68.1	36.8	511.4
Duval	--	173.9	119.3	--	5.2	1.3	299.7
Hidalgo	--	145.4	383.3	--	85.2	50.2	664.1
Jim Hogg	--	51.3	91.8	--	-----	----	143.1
Kenedy	--	46.7	----	--	-----	----	46.7
Starr	--	47.8	169.9	--	2.5	1.6	221.8
Webb	33.1	135.6	126.2	4.8	12.0	0.2	311.9
Willacy	--	47.5	156.5	--	7.0	1.1	212.1
Zapata	--	81.2	33.4	--	-----	----	114.6
District Total	33.1	919.9	1408.5	4.8	184.2	91.5	2642.0

Mays Ride Meter.

2. Pavement Rating Score

3. Skid Number @ 40 mph

4. Surface Curvature Index

Figures 12 through 21 are histograms of the four data types collected in 1975 for both US & SH and FM highways. A similar treatment for 1974 data is shown in Appendix B. The normality of these data distributions was checked using the chi-square test. The null hypothesis (or the question) tested was that the distributions conform to normal distributions. The resulting theoretical normal curve from the chi-square procedure is shown superimposed on each figure. Initially, a level of significance of 0.05 (i.e. probability of 0.05 of rejecting a true null hypothesis) was used. At this level of significance, six out of the ten distributions test to be normal. The remaining four distributions are normal at levels of significance ranging from 0.025 to 0.01. Thus, the four data types test to be normal or near normally distributed.

Of the ten distributions, the four shown for Pavement Rating Score (Figures 18 through 21) are of special interest. Figures 18 and 19 show how the data for District 21 are distributed when the Pavement Rating Score is computed using Mays Ride Meter deduct points. The result is that the Pavement Rating Score is much lower due to deductions for highway roughness. When the Pavement Rating Score is so computed, the resulting distributions are normal at a level of significance of 0.05 for both US & SH and FM highways. Figures 20 and 21 show how the data are distributed when the scores are computed without using Mays Ride Meter deduct points. The resulting distributions are significantly different from Figures 18 and 19. The distribution for FM highways is normally distributed at a

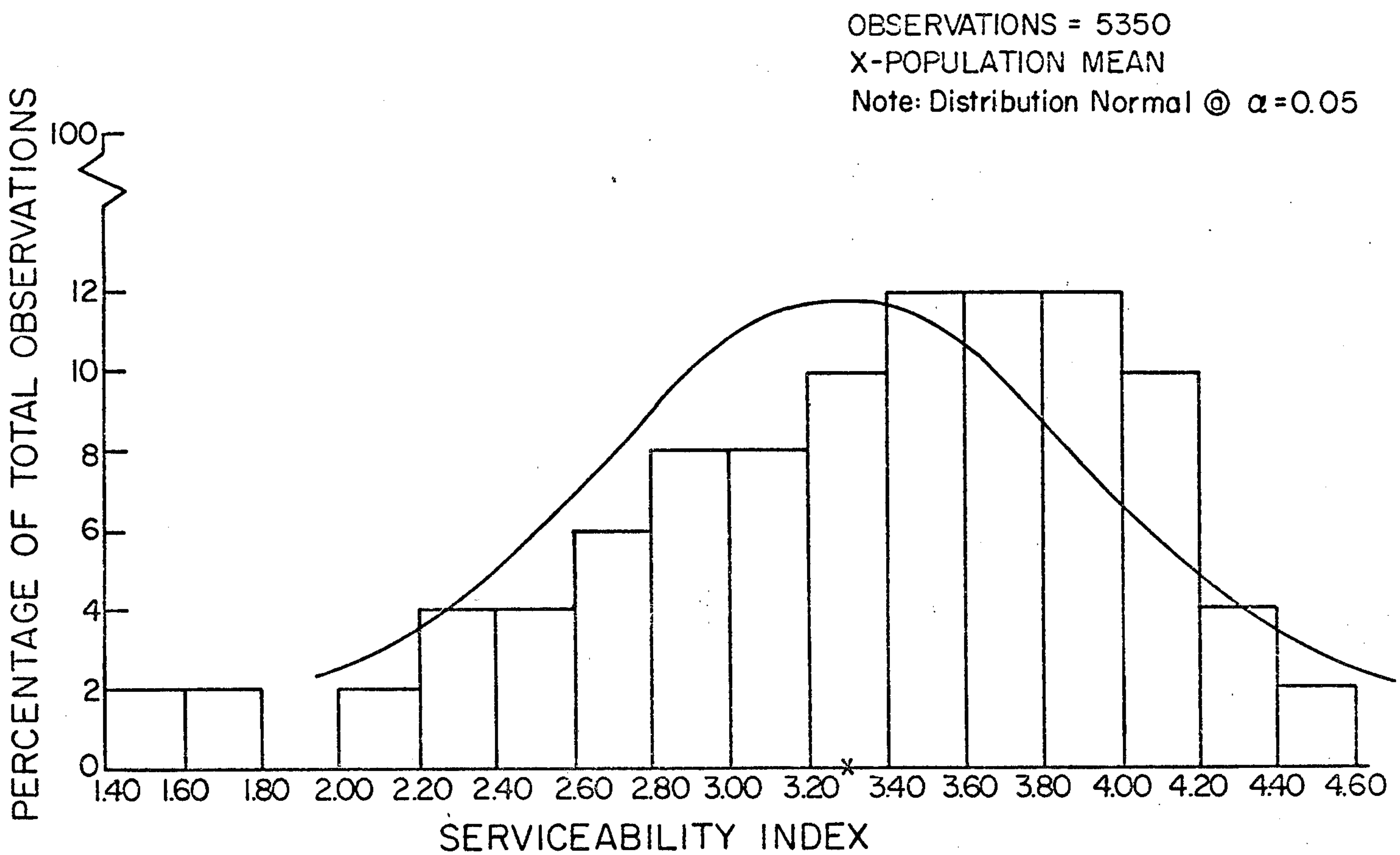

Figure 12. District 21 Serviceability Index Mass Inventory Histogram for US & SH Highways---1975.

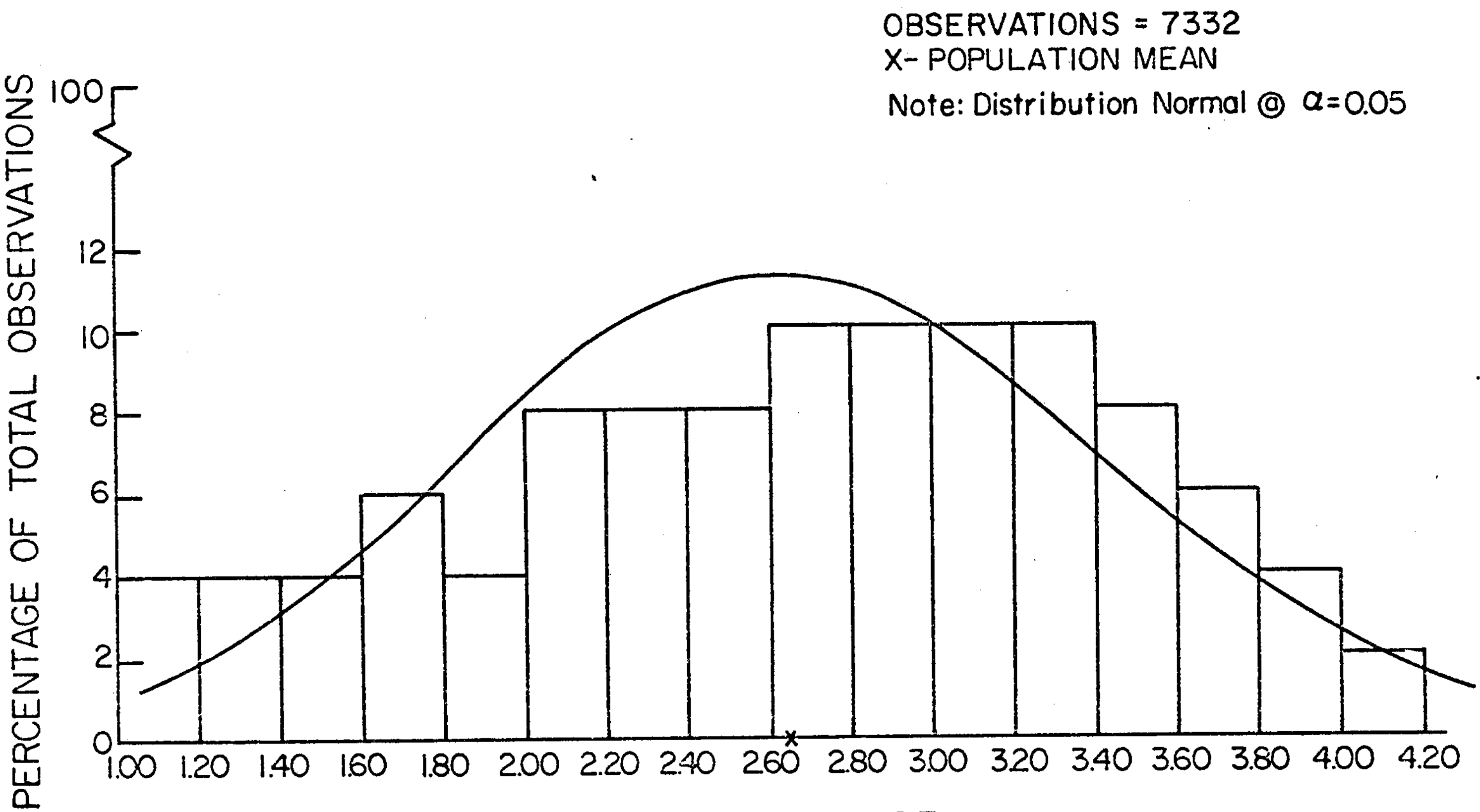

Figure 13. District 21 Serviceability Index Mass Inventory Histogram for FM Highways---1975.

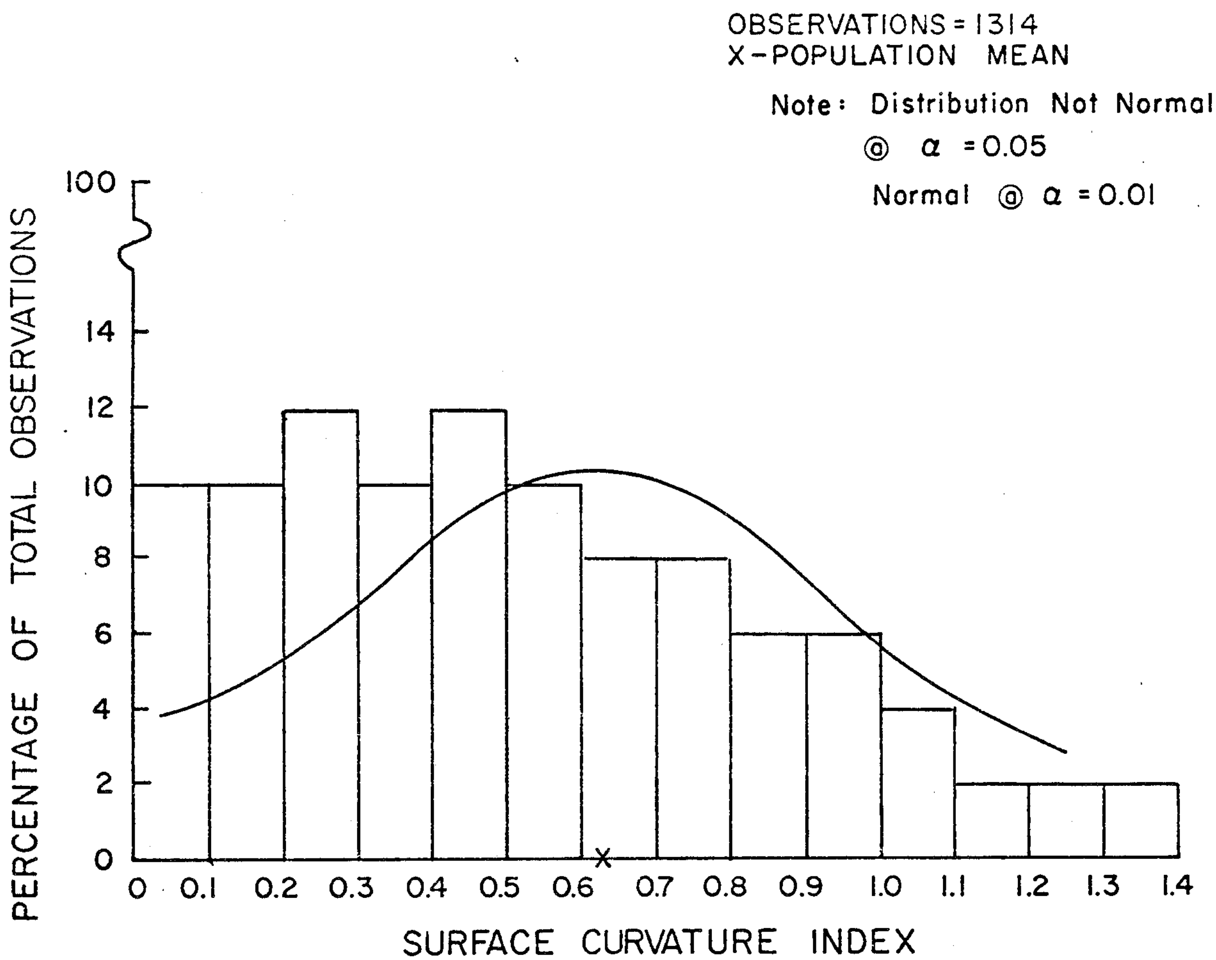

Figure 14. District 21 Surface Curvature Index Mass Inventory Histogram for US & SH Highways---1975.

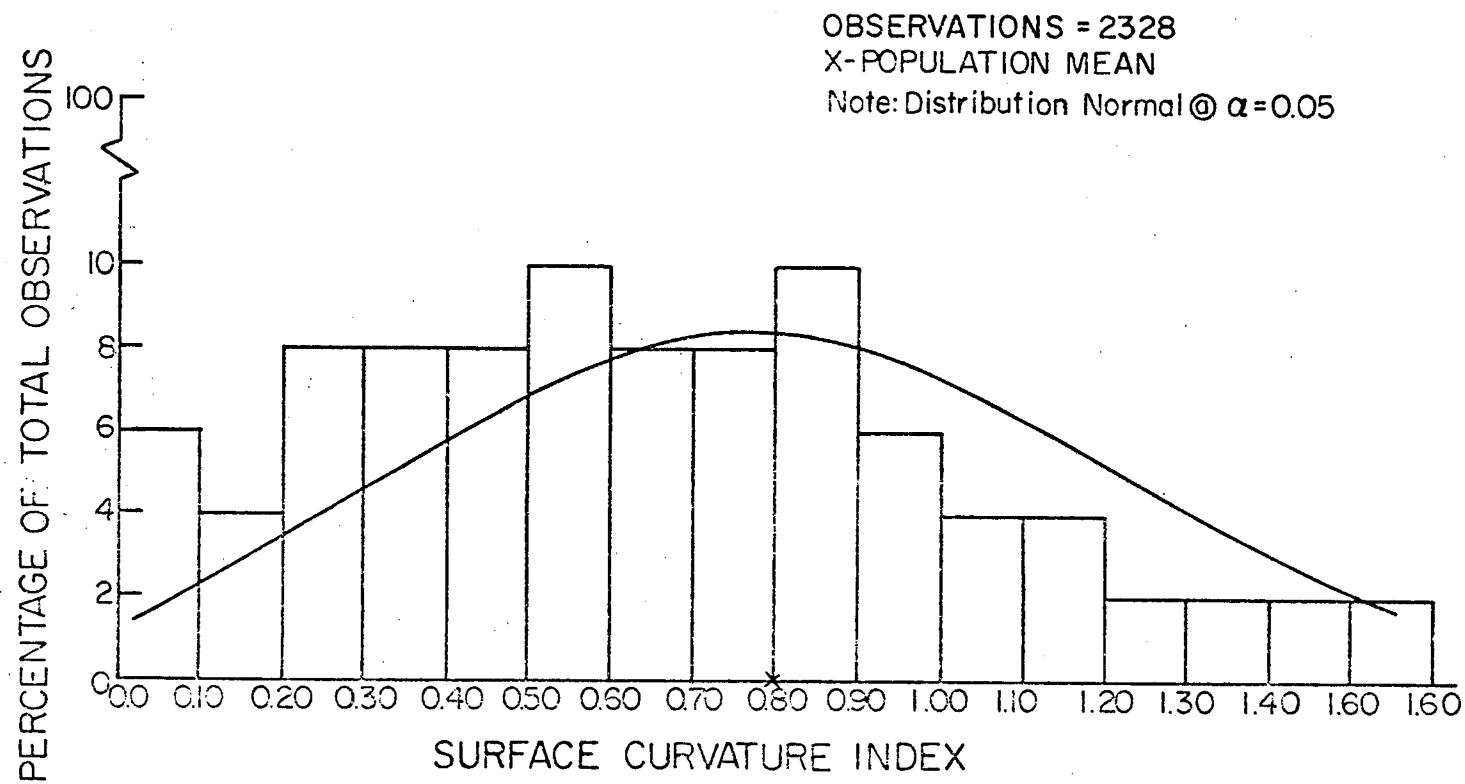

Figure 15. District 21 Surface Curvature Index Mass Inventory Histogram for FM Highways---1975.

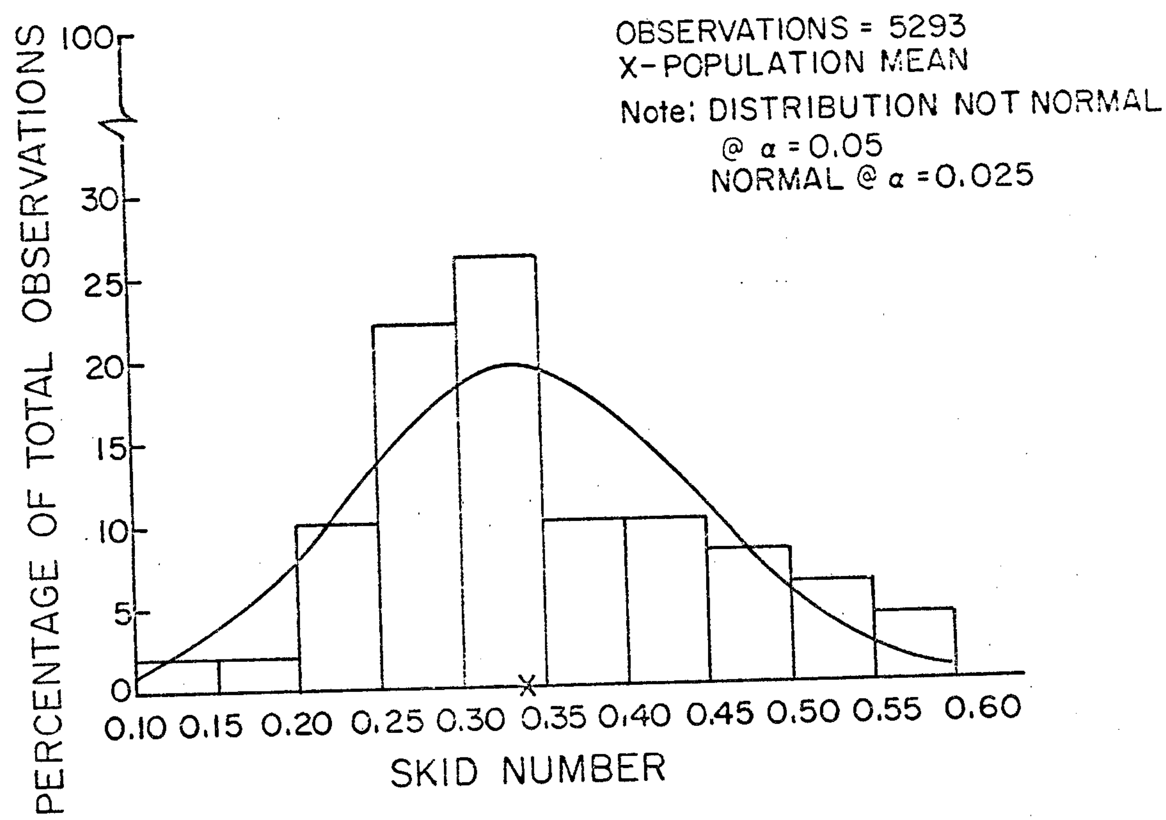

Figure 16. District 21 Skid Number Mass Inventory Histogram for US & SH Highways---1975.

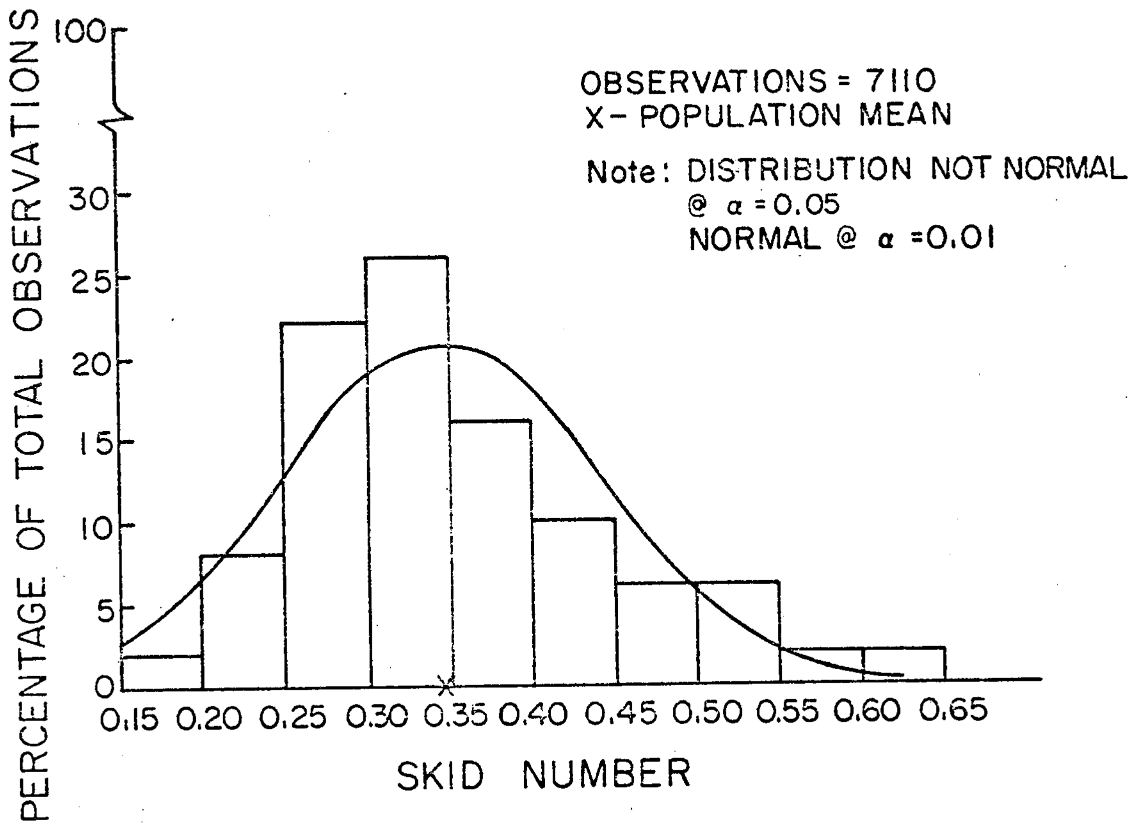

Figure 17. District 21 Skid Number Mass Inventory Histogram for FM Highway---1975.

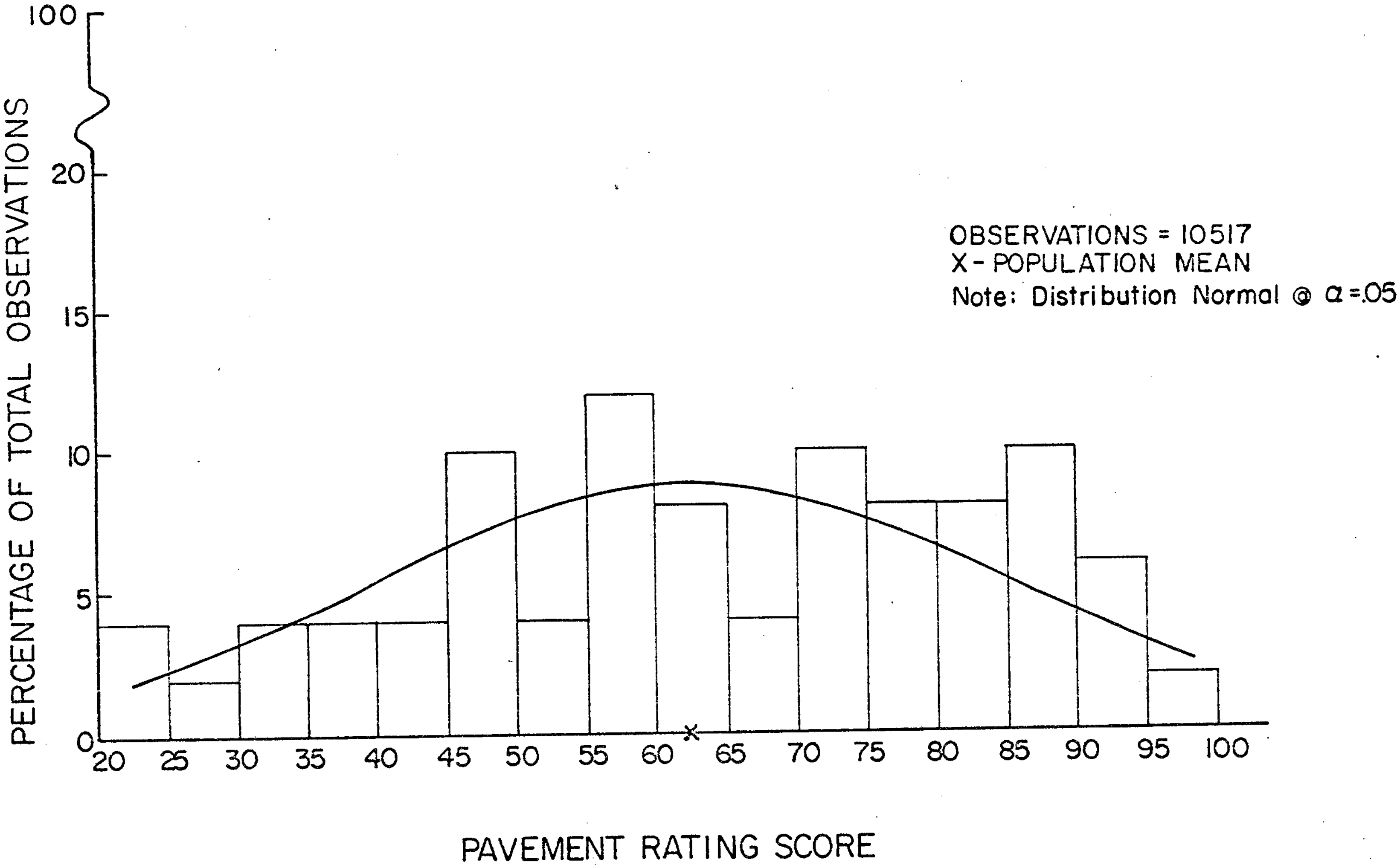

Figure 18. District 21 Pavement Rating Score Mass Inventory Histogram for US & SH Highways---1974.

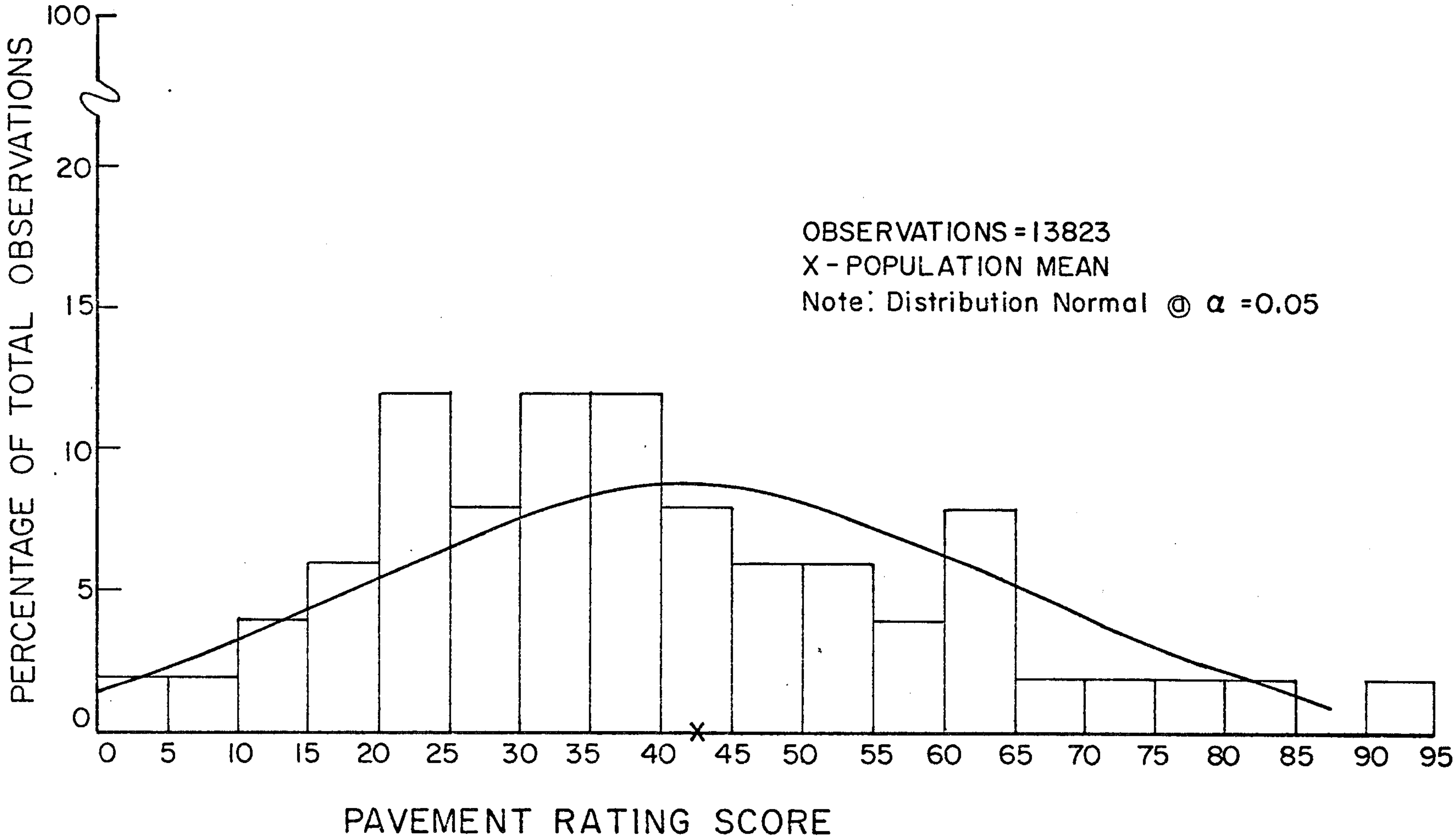

Figure 19. District 21 Pavement Rating Score Mass Inventory Histogram for FM Highways---1974.

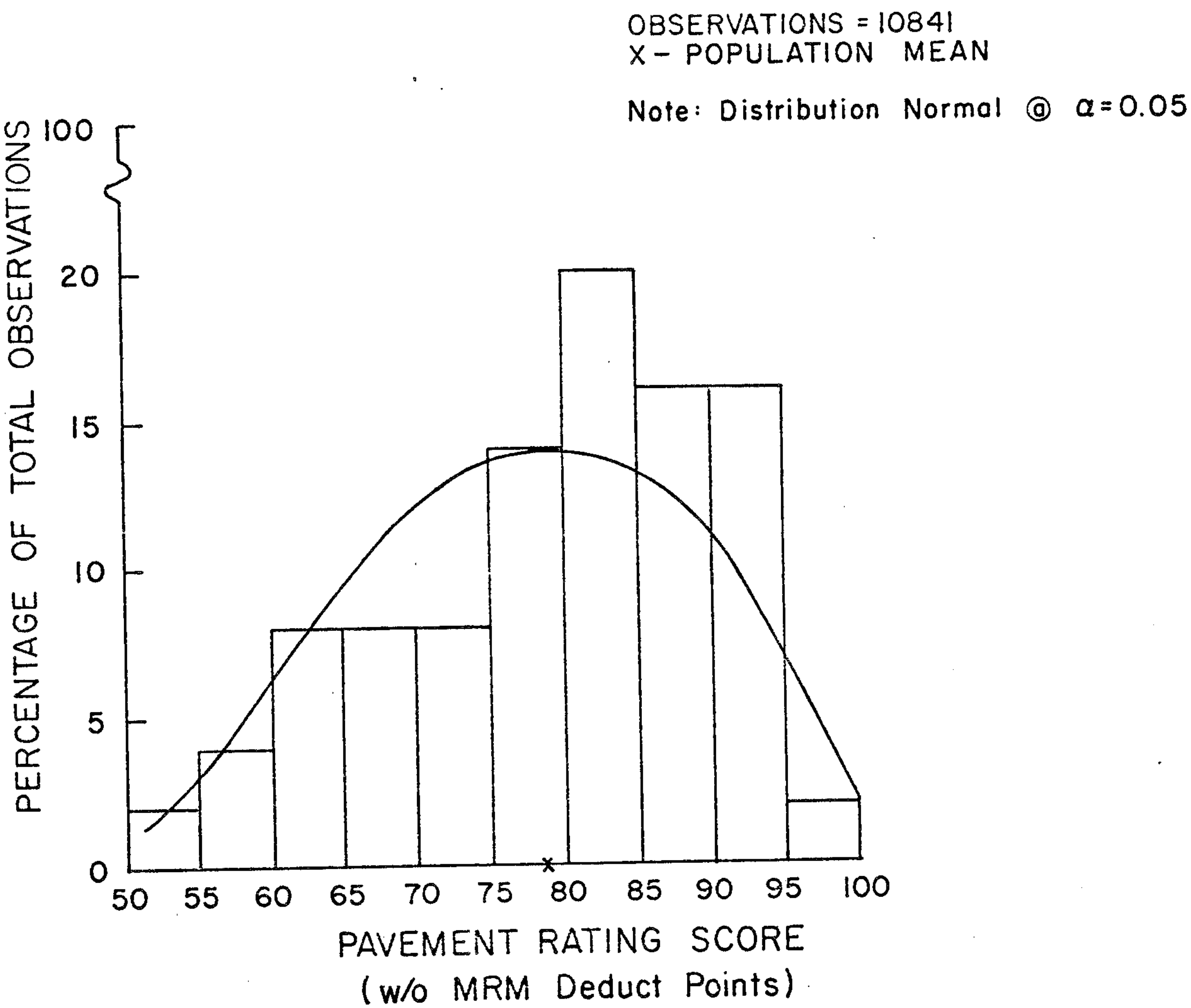

Figure 20. District 21 Pavement Rating Score Mass Inventory Histogram for US & SH Highways---1975.

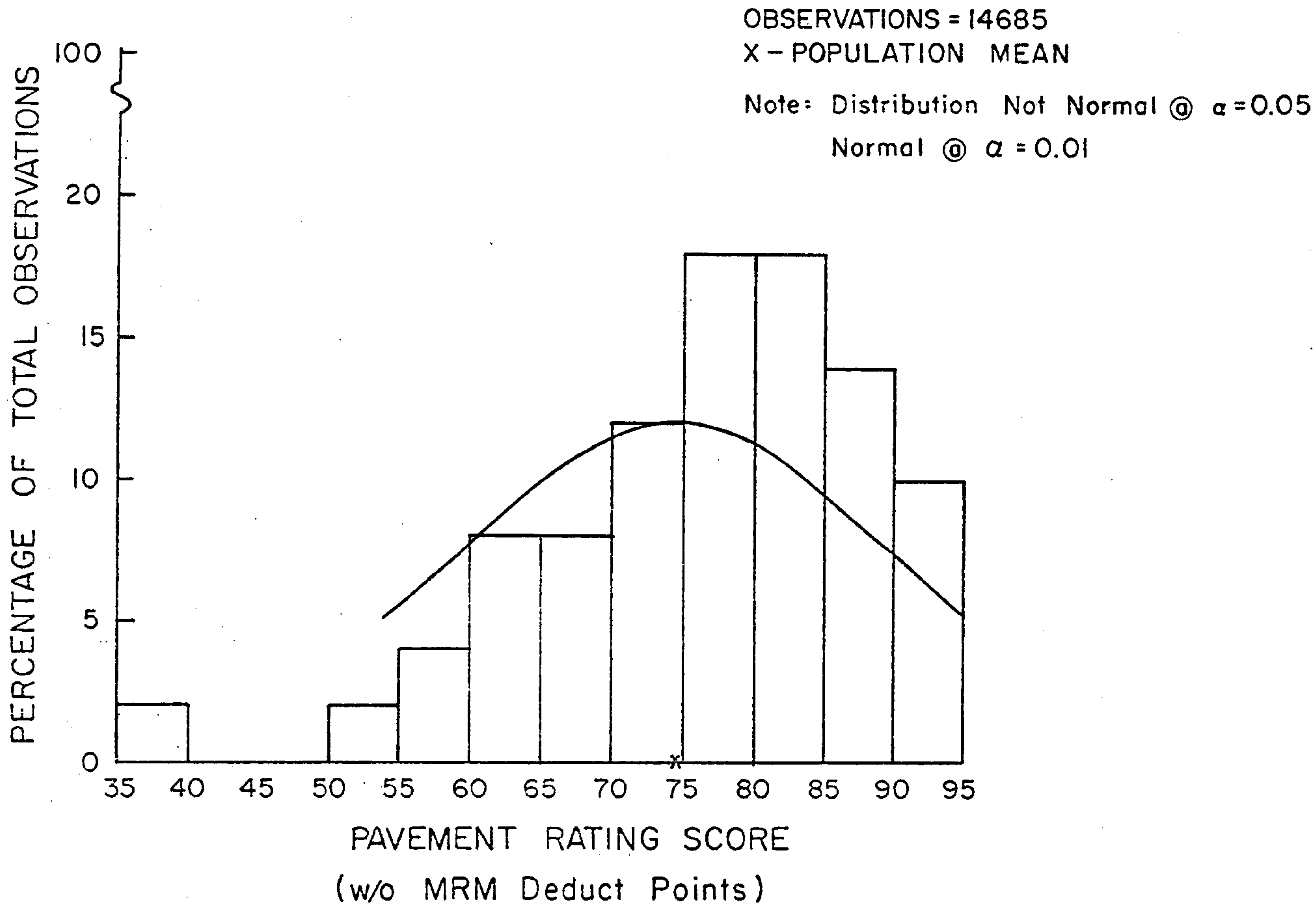

Figure 21. District 21 Pavement Rating Score Mass Inventory Histogram for FM Highways---1975.

level of significance of 0.01 which indicates a near normal condition. Additionally, the distributions without Mays Ride Meter deductions show a much smaller range in the data. Table 15 shows how the Pavement Rating Score means and standard deviations for District 21 vary when computed using the two methods. It is apparent that roughness can completely mask the other distress types used in computing such scores. Thus, the decision was made independently by both District 21 and TTI personnel that only Pavement Rating Score computed without the use of Mays Ride Meter deduct points would be used in subsequent presentations and analysis of such data.

Since a mass inventory was available for both 1974 and 1975 in District 21, a comparison was made of the summary statistics for each year. This information is given in Table 16 and shows the total mileage, mean, and standard deviation for each data type with these values representing the population means and standard deviations. The mileages shown vary between the two years. This primarily occurs for Surface Curvature Index data due to the fact the Dynaflect survey was not completed until 1975 and only partial data were available in 1974. It should also be pointed out that there was some overlap of data between the two years for Serviceability Index and Skid Number data which reduces potential year-to-year differences. This is not true for Pavement Rating Score since independent surveys were conducted during each of the two years.

The differences between the estimated Serviceability Index means shown for District 21 in Table 4 and the population means in Table 16 are of interest. The estimates shown in Table 4 for US & SH and FM highways were obtained from the statewide sample survey for which sampling of highway segments was accomplished in District 21 as well as the other twenty-four districts. The population means shown in Table 16 were ob-

Table 15. Comparison of District 21 Pavement Rating Scores for 1974 With and Without Mays Ride Meter Deduct Points

Highway Type	Pavement Rating Score					
	w/ MRM Deduct Points			w/o MRM Deduct Points		
	Mileage	Mean	Standard Deviation	Mileage	Mean	Standard Deviation
IH	38	54	11	38	83	8
US & SH	1071	62	23	1071	82	13
FM	1438	42	23	1438	78	16

Table 16. District 21 Mass Inventory Statistical Summary

Highway Type	Year	Date Type	Mileage	Mean	Standard Deviation
IH	1974	SI	38	3.3	0.6
		SCI	0	----	----
		SN	33	0.35	0.06
		PRS	38	83	8
	1975	SI	37	3.6	0.5
		SCI	38	0.2	0.1
		SN	39	0.38	0.06
		PRS	37	91	6
US & SH	1974	SI	1094	3.2	0.7
		SCI	373	0.7	0.5
		SN	1013	0.32	0.10
		PRS	1071	82	13
	1975	SI	1070	3.3	0.7
		SCI	701	0.6	0.4
		SN	1123	0.34	0.10
		PRS	1084	78	14
FM	1974	SI	1376	2.6	0.7
		SCI	447	0.8	0.4
		SN	1232	0.34	0.09
		PRS	1438	78	16
	1975	SI	1467	2.6	0.8
		SCI	1176	0.8	0.4
		SN	1537	0.35	0.09
		PRS	1475	75	16

tained from a complete districtwide mass inventory for each highway type. The differences are 0.3 to 0.4 SI units for US & SH highways and 0.2 SI units for FM highways. It is believed these variations between the means are primarily due to differences between the separate Mays Ride Meter units used to conduct the surveys and sampling error. This will be discussed subsequently in more detail.

The same treatment was accomplished for each county in District 21 as was done for the entire district. An example is Zapata County and the summary statistics are shown in Table 17 for both 1974 and 1975. Of special significance in this table is that Pavement Rating Score decreased significantly from 1974 to 1975 - especially for FM highways. As these means decreased, the standard deviations increased for this county. The sources of these year-to-year differences are not known. They could be due to an increase in pavement deterioration, rating error or a combination of the two. A discussion of district and county year-to-year differences is contained in Appendix B along with data summaries for each county in the district.

After the mass inventory data had been organized into a computer accessible form, it was then reorganized into a format similar to that of the statewide random segments. To accomplish this task, a FORTRAN computer program was written which divided all highways in the district into two-mile segments. The program also organized the data contained in each of these two-mile segments into summary form. This summary consisted of the number of data points, means, and standard deviations for each of the data types. This information was computed and stored for future processing. A comparison of the theoretical two mile-segments in District 21 and the actual number generated by the computer program for the available mass inventory of data is shown in Table 18.

Table 17. District 21 Mass Inventory Statistical Summary for Zapata County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	79	3.1	0.5
		SCI	54	0.7	0.3
		SN	76	0.32	0.05
		PRS	77	94	4
	1975	SI	80	3.1	0.6
		SCI	55	0.7	0.3
		SN	83	0.34	0.06
		PRS	80	89	6
FM	1974	SI	24	2.3	0.7
		SCI	20	1.2	0.4
		SN	23	0.39	0.10
		PRS	27	89	8
	1975	SI	33	2.3	0.7
		SCI	28	1.0	0.5
		SN	39	0.38	0.08
		PRS	33	75	25

Table 18. Comparison of Theoretical and Actual Computer Generated Two-Mile Pavement Segments in District 21

County	Number of Two-Mile Highway Segments											
	1974						1975					
	IH		US & SH		FM		IH		US & SH		FM	
	Theor.	Actual	Theor.	Actual	Theor.	Actual	Theor.	Actual	Theor.	Actual	Theor.	Actual
Brooks	--	--	34	35	24	24	--	--	34	34	24	24
Cameron	--	--	97	95	158	149	--	--	97	89	158	163
Duval	--	--	90	94	60	51	--	--	90	102	60	49
Hidalgo	--	--	115	90	217	220	--	--	115	110	217	223
Jim Hogg	--	--	26	26	46	46	--	--	26	26	46	46
Kenedy	--	--	23	23	--	--	--	--	23	23	--	--
Starr	--	--	25	26	86	87	--	--	25	22	86	86
Webb	19	19	74	71	63	50	19	19	74	73	63	64
Willacy	--	--	27	38	79	70	--	--	27	27	79	76
Zapata	--	--	41	38	17	15	--	--	41	41	17	11
District Total	19	19	552	536	750	712	19	19	552	547	750	742

An additional computer program was prepared to access these segments, draw samples, and make estimates of the population mean and standard error for various sample sizes. The computer program essentially performed the same task on all of the two-mile highway segments as was performed manually to select the statewide sample. This selection process was computerized because hundreds of samples were to be selected and statistically summarized to determine the optimum sample size.

To select a given sample size the total highway mileage was multiplied by the sample size percentage desired. This gave the approximate amount of mileage to be sampled. The mileage so obtained was divided by two miles to obtain the number of required highway segments. Next, the program randomly selected a county from the total number of counties in the district. Following this, highway segments were randomly selected within the selected county for both US & SH and FM highways. The number of highway segments chosen for each highway type depended on the county mileage and desired sample size. Additional counties and highway segments were selected until the required sample size for the entire district had been achieved.

To further explain this process the following number of two-mile highway segments were selected for the listed sample sizes for each trial computer iteration.

Sample Size (Based on percentage of District 21 centerline mileage	Number of District 21 Highway Segments Selected (US & SH and FM)
0.5 %	6
1 %	12
2 %	24
3 %	35
5 %	59
10 %	117

The lower and upper bounds for sample sizes were 0.5 and 10 percent, respectively. A sample size of 0.5 percent was felt to represent the smallest reasonable sample size which should be considered. Conversely, a 10 percent sample size was felt to represent a more than adequate estimate of the population parameters.

For both the 1974 and 1975 data, means and standard errors were computed for each of the sample sizes. The overall district mean was computed by weighting the means obtained from each of the sample estimates calculated. The formula used to compute the stratified two-stage sample mean is shown as Equation 1.

$$\hat{\bar{\bar{Y}}} = \frac{\sum_{i=1}^{n} M_i \bar{y}_i}{\sum_{i=1}^{n} M_i} \qquad (1)$$

where:

$\hat{\bar{\bar{Y}}}$ = estimate of district mean for a given sample size, highway type, and data type,

$\bar{y}_i$ = sample mean value for the i^{th} county,

M_i = number of possible two-mile highway segments within the i^{th} county,

n = number of counties selected for a given sample size.

Equation 1 was used to compute a sample mean for each highway and data type being considered. This was repeated for 300 separate sample selection iterations. Each of the 300 district estimates so calculated were used in calculating the overall district mean.

The standard error was computed based on the means obtained by use of Equation 1. The standard error measures the amount by which the mean of a given size sample departs from the overall mean of all samples of that size. The formula used to accomplish this is Equation 2. This formula is similar to that used for calculating the standard deviation of a set of data but it is a different calculation from the standard error computation used for Tables 3 and 5.

$$S.E. = \left[\frac{\sum_{i=1}^{t} (\hat{\bar{\bar{Y}}}_i - \bar{\bar{\bar{Y}}})^2}{t - 1} \right]^{1/2} \qquad (2)$$

where:

$S.E.$ = simulation standard error

$\hat{\bar{\bar{Y}}}_i$ = estimate of district mean for a given sample size, highway type, and data type iteration.

$\bar{\bar{\bar{Y}}}$ = average of all district estimates for a given sample size, highway type, and data type.

t = number of sample selection iterations for a given sample size (300 in all cases).

The standard error computed for the two-stage random sample as shown in Tables 3 and 5 is as follows:

$$\text{SAMPLE S.E.} = \sqrt{v\ (\hat{\bar{\bar{y}}})} = \left[\frac{1 - f_1}{n} \quad \frac{N^2}{M_0^2} \sum_{i=1}^{n} \frac{M_i^2\ (\bar{y}_i - \hat{\bar{\bar{Y}}})^2}{n-1} \right]^{1/2} +$$

$$+ \left[\frac{N}{nM_o^2} \sum_{i=1}^{n} \frac{M_i^2 (1 - f_{2i}) \; s_i^2}{m_i} \right]^{1/2}$$

$$+ \left[\frac{1}{M_o^2} \quad \frac{N}{n} \quad \sum_{i=1}^{n} \quad \frac{M_i}{m_i} \quad \sum_{i,j=1}^{m_i} \quad \frac{s_{ij}^2}{r_{ij}} \right]^{1/2} \qquad (3)$$

where:

$\hat{\bar{\bar{Y}}}$, $\bar{y}_i$, and n are as described previously,

N = total number of counties within a district,

f_1 = $^n/_N$,

M_o = $\sum_{i=1}^{N} M_i$ = number of possible two-mile highway segments within a district,

m_i = number of highway segments selected within the i^{th} county,

f_{2i} = $m_i/_{Mi}$

$$s_i^2 = \sum_{i=1}^{m_i} \frac{(\bar{y}_{ij} - \bar{y}_i)^2}{m_i - 1}$$

$\bar{y}_{ij}$ = mean value of a data type for the j^{th} two-mile highway segment in the i^{th} county,

$s_{ij}^2 = \sum_{j=1}^{r_{ij}} \frac{(y_{ijk} - \bar{y}_{ij})^2}{r_{ij} - 1}$ = square of the standard deviation of a group of data in the j^{th} two-mile highway segment in the i^{th} county,

r_{ij} = number of data points for a given data type in the j^{th} two-mile highway segment in the i^{th} county,

y_{ijk} = value of the k^{th} data point for a given data type in the j^{th} two-mile highway segment in the i^{th} county.

Equation 3 is divided into three parts, as shown, and the first term may be thought of as the variance attributed to the differences between the county and district means. The second term represents the sample variance in each county and the third part represents the variation for each data type within each of the two-mile highway segments.

The overall means and standard errors computed by Equations 1 and 2 are shown in Tables 19 and 20. Table 19 lists the overall means and standard errors for six sample sizes for data obtained primarily during 1975 and Table 20 lists the same kind of data for 1974. The data processed for 1974 were not as extensive as for 1975 due to the incompleteness of Skid Number and Surface Curvature Index data for that year. As should be expected, the data contained in both tables indicate that the standard error decreases as the sample size increases. If sampling of all possible highway segments were repeatedly made (100 percent sample sizes), the standard error would be zero.

It is of interest to compare the above approach of obtaining standard error to that used in simple random sampling. This conceptual sampling scheme would constitute sampling the required highway segments using a completely random pattern throughout a district. The standard error of various sizes of simple random samples can be computed as follows:

$$\text{S.E.} = \sigma_{\bar{y}} = \frac{S}{\sqrt{n}} \sqrt{1 - \frac{n}{N}} \qquad (4)$$

Table 19. District 21 Means and Standard Errors for Six Sample Sizes Using 300 Sample Selection Iterations (1975 Data).

Sample Size	Highway Type	SI		PRS		SCI		SN	
		Mean	S.E	Mean	S.E.	Mean	S.E.	Mean	S.E.
0.5%	US & SH	3.33	0.35	78.6	7.8	0.62	0.20	0.34	0.05
	FM	2.62	0.42	75.8	9.3	0.79	0.21	0.36	0.05
1%	US & SH	3.31	0.28	78.9	5.7	0.61	0.14	0.34	0.04
	FM	2.61	0.27	75.5	5.6	0.80	0.14	0.36	0.04
2%	US & SH	3.32	0.17	78.6	3.8	0.60	0.09	0.34	0.03
	FM	2.62	0.18	75.1	3.9	0.78	0.09	0.35	0.02
3%	US & SH	3.30	0.15	78.2	3.5	0.61	0.08	0.34	0.02
	FM	2.66	0.13	75.0	3.2	0.79	0.07	0.35	0.02
5%	US & SH	3.30	0.11	78.6	2.5	0.61	0.06	0.34	0.02
	FM	2.65	0.11	75.7	2.4	0.79	0.06	0.35	0.02
10%	US & SH	3.31	0.08	78.4	1.7	0.60	0.04	0.34	0.01
	FM	2.64	0.07	75.2	1.6	0.79	0.04	0.35	0.01

Table 20. District 21 Means and Standard Errors for Three Sample Sizes Using 300 Sample Selection Iterations (1974 Data).

Sample Size	Highway Type	SI		PRS	
		Mean	S.E.	Mean	S.E.
0.5%	US & SH	3.19	0.35	82.1	7.6
	FM	2.59	0.39	80.4	9.9
1%	US & SH	3.21	0.27	82.5	5.4
	FM	2.59	0.26	79.9	6.0
3%	US & SH	3.19	0.15	82.9	3.0
	FM	2.61	0.13	78.8	3.2

where:

S.E. $= \sigma_{\bar{y}}$ = standard error of a simple random sample.

S = standard deviation of the population.

n = number of two-mile highway segments sampled for a given sample size.

N = total number of two-mile highway segments in the district.

$\frac{n}{N}$ = sampling fraction.

Using Equation 4 and the population standard deviations in Table 16 for the 1975 data, standard errors for a simple random sampling technique were computed. The values so calculated were compared to those standard errors obtained from the simulation study for the two-stage sampling technique. Table 21 shows a comparison of both standard errors for different sample sizes, highway and data types.

The data contained in Table 21 reveal that the standard errors obtained for the two-stage sampling technique are in most cases lower than those calculated for simple random sampling. Of 48 possible comparisons, the two-stage standard errors are lower in 34 cases, 9 are ties, and 5 are larger. The largest observed difference between standard errors is fifty percent with the simple random sampling standard error being the larger.

The number of sample selection iterations used to compute the means and standard errors shown in Tables 19, 20, and 21 were based on two criteria: cost of running the computer program and standard error stabilization. Figures 22 and 23 show how the standard error for a one percent sample stabilized at approximately 300 iterations. Figure 22 shows this trend for Serviceability Index, Surface Curvature Index, and Skid Number

Table 21. District 21 Standard Errors for Simple Random and Two-Stage Sampling Techniques.

SAMPLE SIZE	HIGHWAY TYPE	STANDARD ERROR							
		SI		PRS		SCI		SN	
		S. RANDOM	TWO-STAGE	S. RANDOM	TWO-STAGE	S. RANDOM	TWO-STAGE	S. RANDOM	TWO-STAGE
0.5 %	US & SH	0.49	0.35	9.9	7.8	0.28	0.20	0.07	0.05
	FM	0.40	0.42	8.0	9.3	0.20	0.21	0.04	0.05
1 %	US & SH	0.31	0.28	6.2	5.7	0.18	0.14	0.04	0.04
	FM	0.30	0.27	6.0	5.6	0.15	0.14	0.03	0.04
2 %	US & SH	0.22	0.17	4.4	3.8	0.13	0.09	0.03	0.03
	FM	0.21	0.18	4.2	3.9	0.11	0.09	0.03	0.03
3 %	US & SH	0.18	0.15	3.7	3.5	0.11	0.08	0.03	0.02
	FM	0.17	0.13	3.4	3.2	0.09	0.07	0.02	0.02
5 %	US & SH	0.14	0.11	2.8	2.5	0.08	0.06	0.02	0.02
	FM	0.13	0.11	2.6	2.4	0.06	0.06	0.02	0.02
10 %	US & SH	0.10	0.08	2.0	1.7	0.06	0.04	0.01	0.01
	FM	0.09	0.07	1.8	1.6	0.05	0.04	0.01	0.01

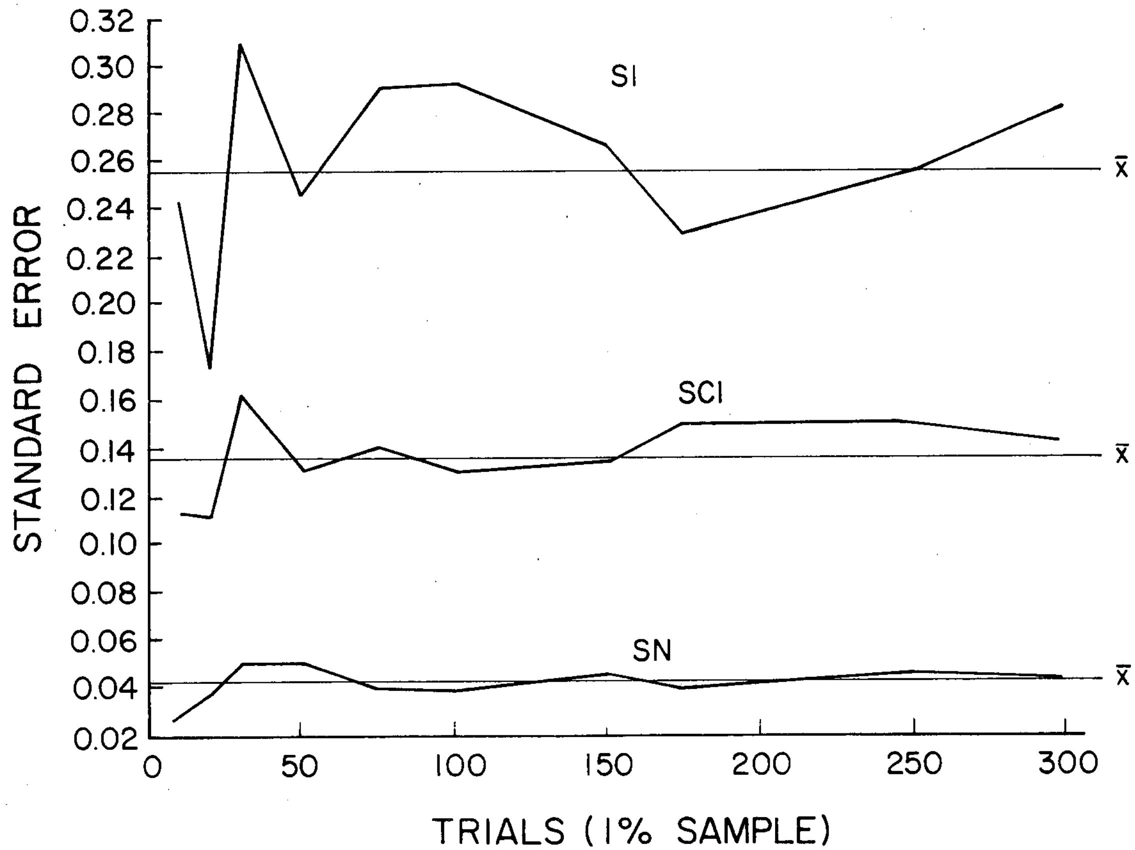

Figure 22. District 21 Sampling Study - Standard Error vs Number of Sample Selection Iterations for SI, SCI, and SN Data

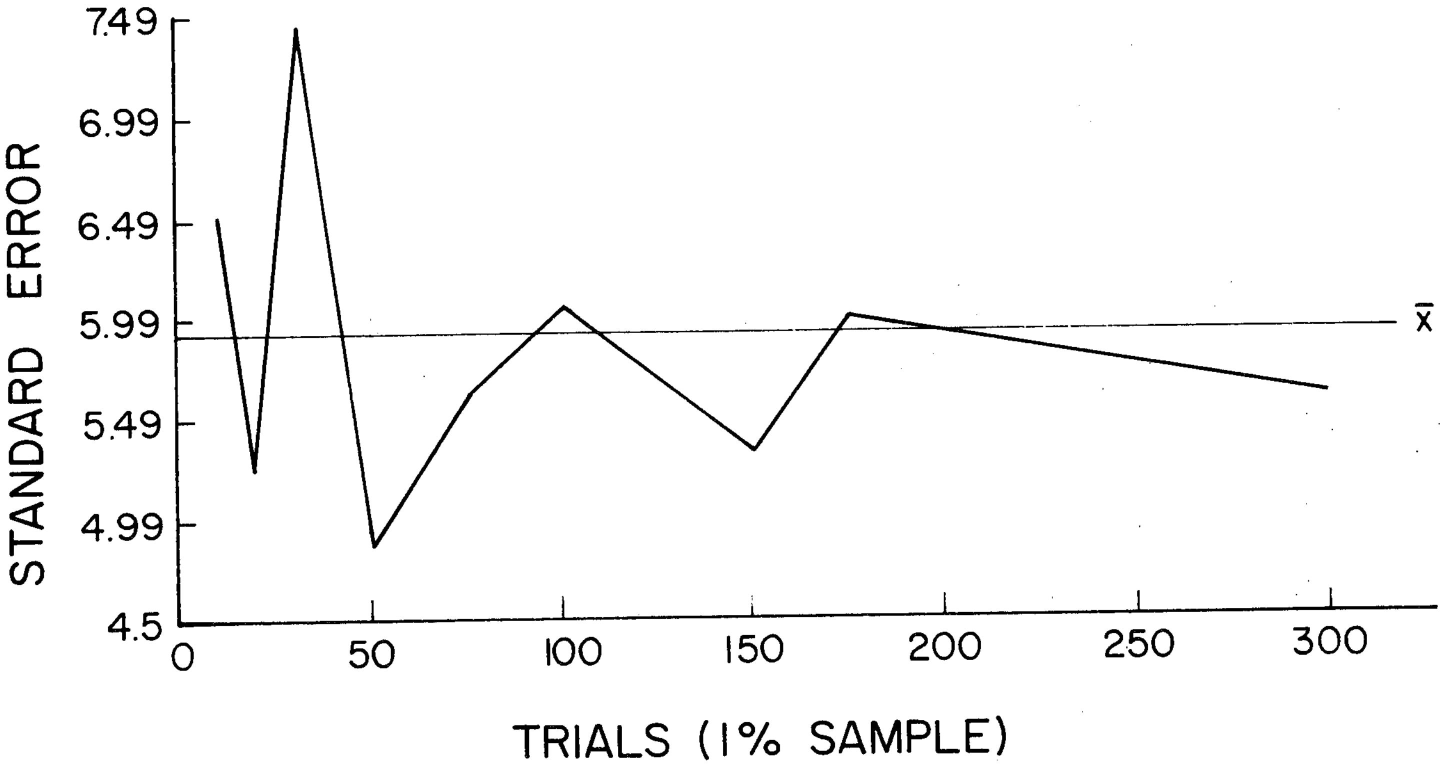

Figure 23. District 21 Sampling Study - Standard Error vs Number of Sample Selection Iterations for PRS Data.

data types and Figures 23 shows the same type of trend for Pavement Rating Score data.

Visual descriptions of how the sampling distributions appeared for the four data types for US & SH and FM highways are shown in Figures 24 through 31. The sample sizes used in these figures are 0.5, 1, and 10 percent. It is of interest to note, as expected, how the data spread decreases with increasing sample size for both data types.

Recalling that the primary goal of this sample size study was to ascertain the optimum sized sample for each highway and data type combination, Figure 32 was produced. Figure 32 is a plot of standard error divided by the mean times 100 plotted against sample size. The ordinate term shall be called the coefficient of sample variation. The coefficient of sample variation term is analogous to a coefficient of variation and allows the standard errors for each data type to be compared. An examination of this figure shows that the variability of a given sample size decreases rapidly at first and then begins to stabilize at about 10 percent. For Serviceability Index, Pavement Rating Score, and Skid Number the coefficient of sample variation at a 0.5 percent sample size ranges from about 10 to 15 percent. At a 10 percent sample size this coefficient ranges from about 3 to 5 percent. The exception is Surface Curvature Index which ranges from about 27 to over 30 percent at a 0.5 percent sample size to less than 10 percent at a 10 percent sample size.

Although the data contained in Figure 32 gives a good indication of the precision gained with increasing sample size, a better gauge was sought to answer the question... "how large is large enough?" To examine this question, utility theory was used.

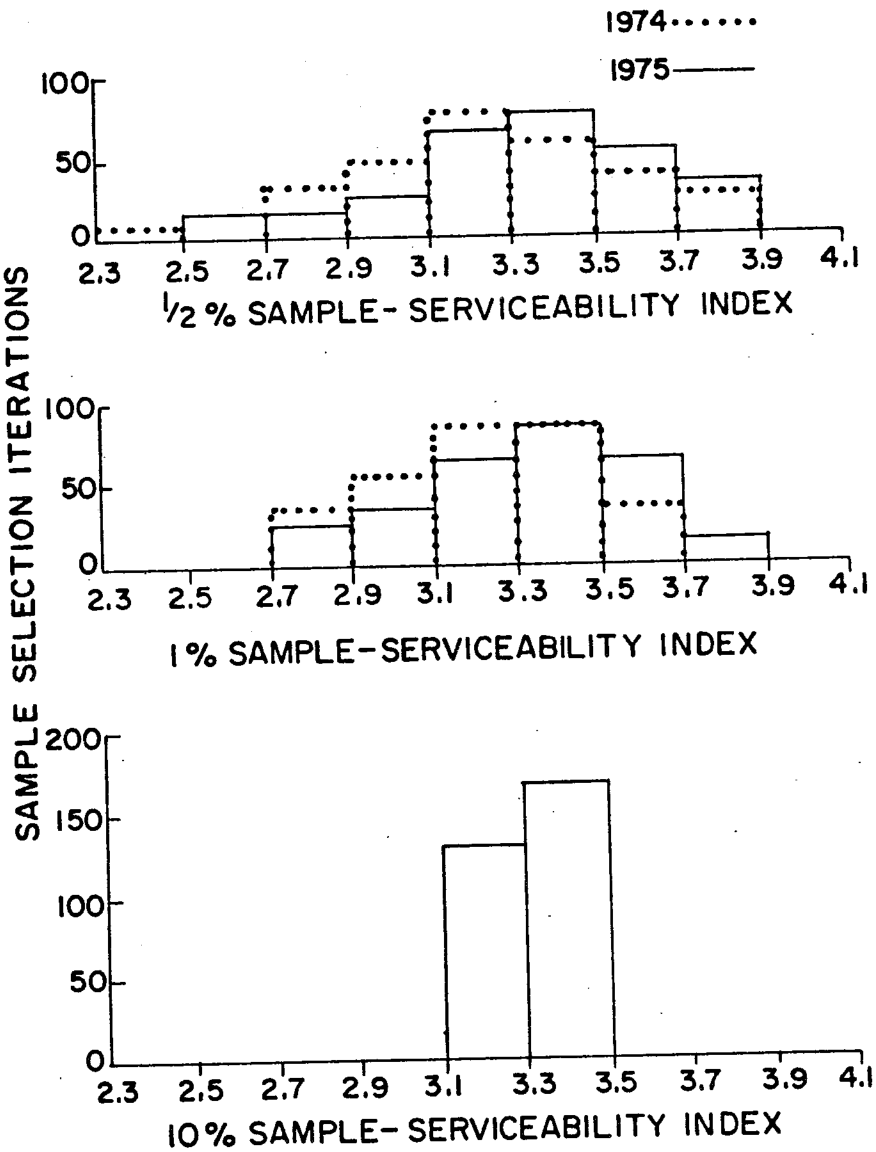

Figure 24. District 21 Sample Mean Histograms for Serviceability Index--US & SH Highways

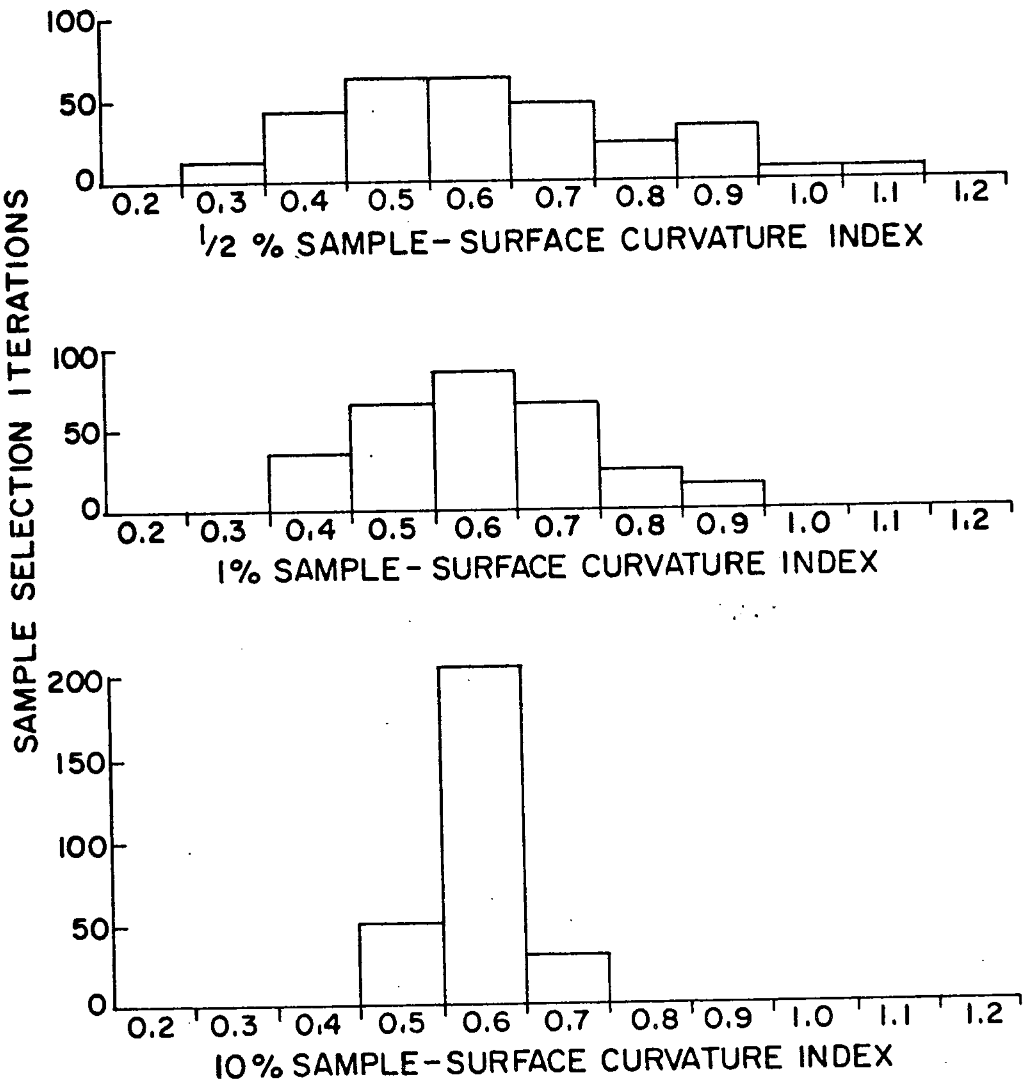

Figure 25. District 21 Sample Mean Histograms for Surface Curvature Index-- US & SH Highways

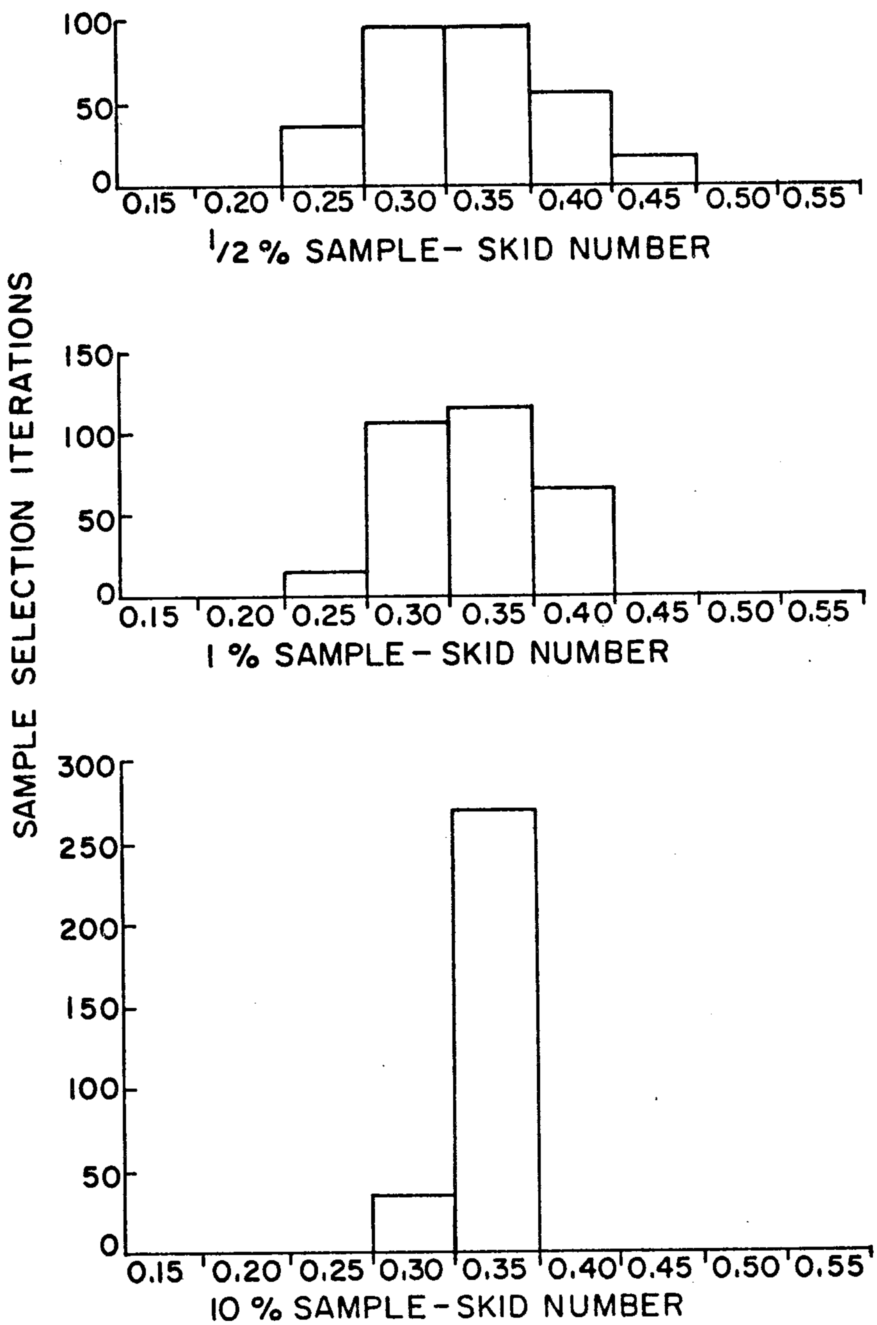

Figure 26. District 21 Sample Mean Histograms for Skid Number--US & SH Highways

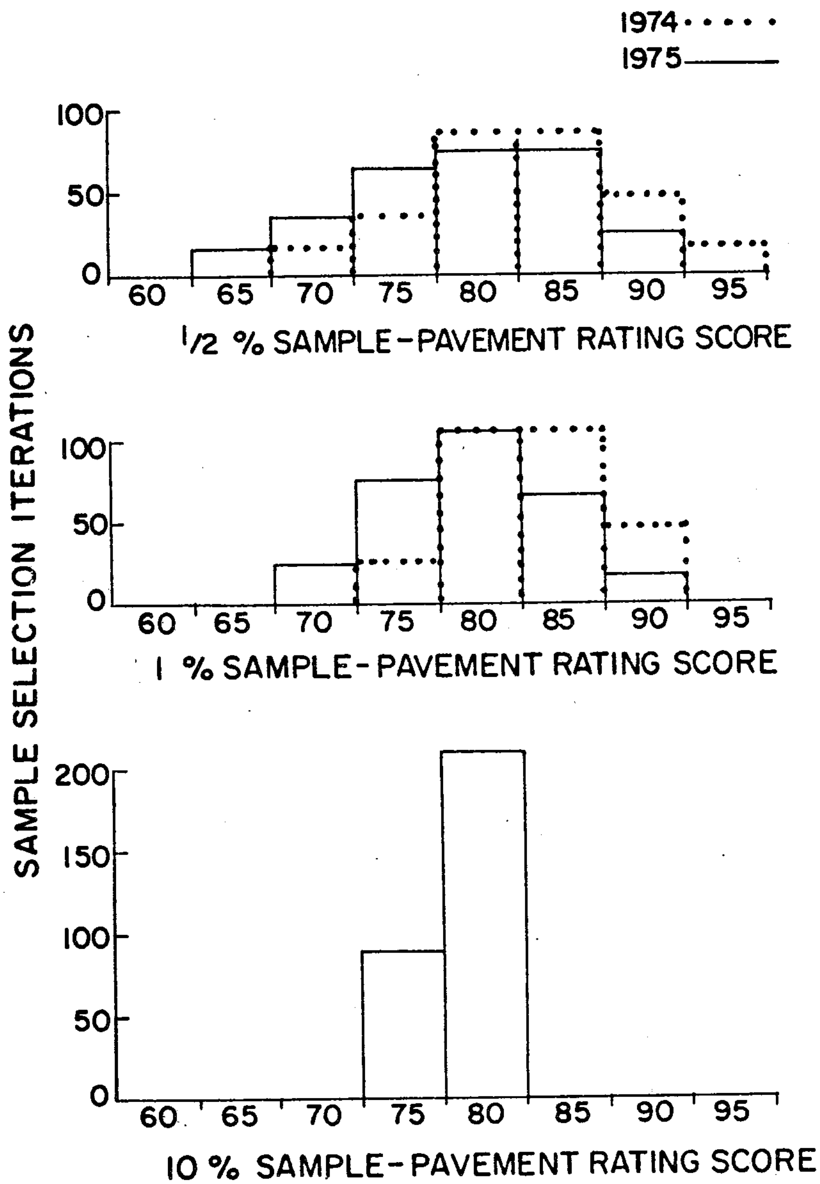

Figure 27. District 21 Sample Mean Histograms for Pavement Rating Score--US & SH Highways

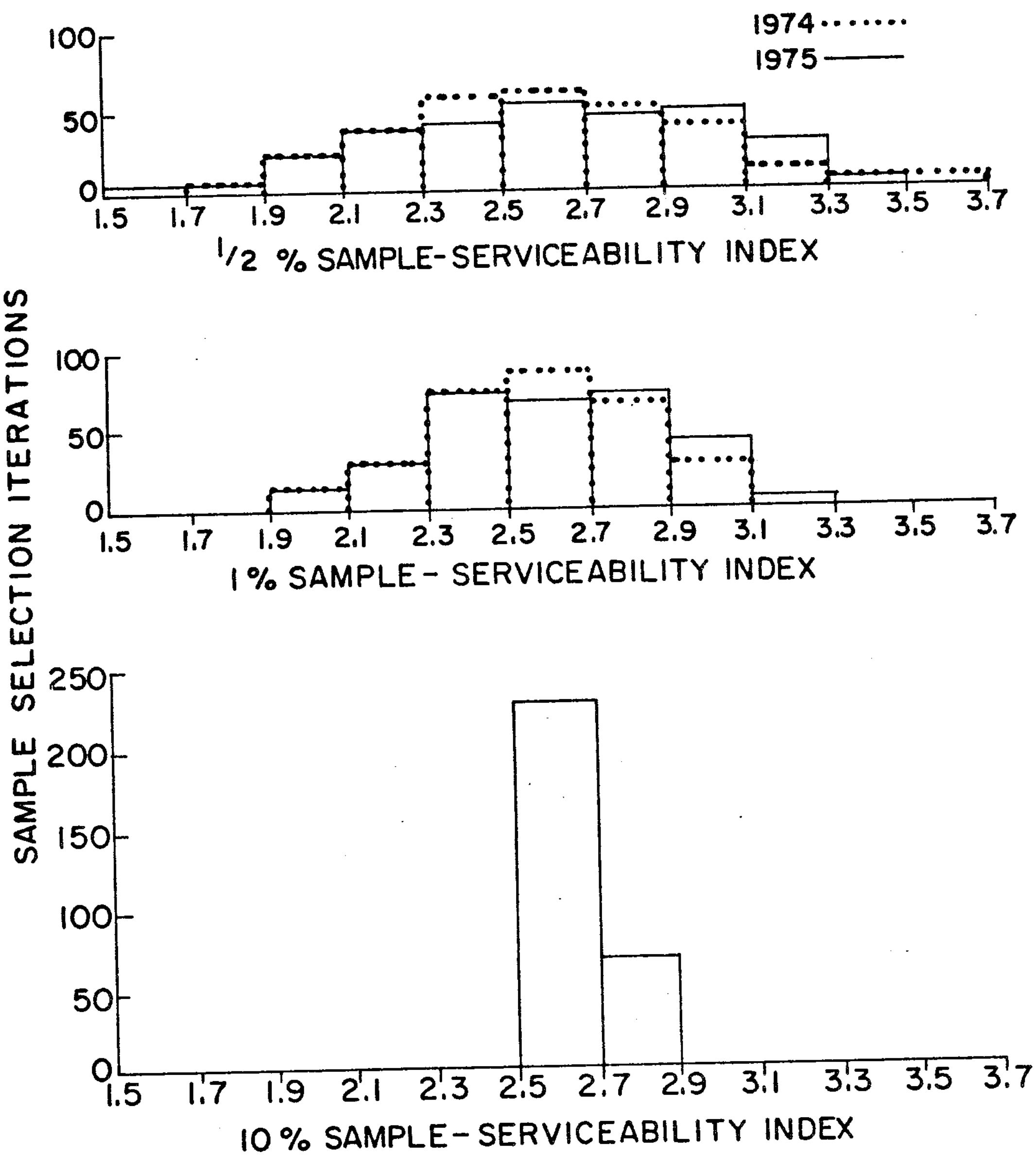

Figure 28. District 21 Sample Mean Histograms for Serviceability Index--FM Highways

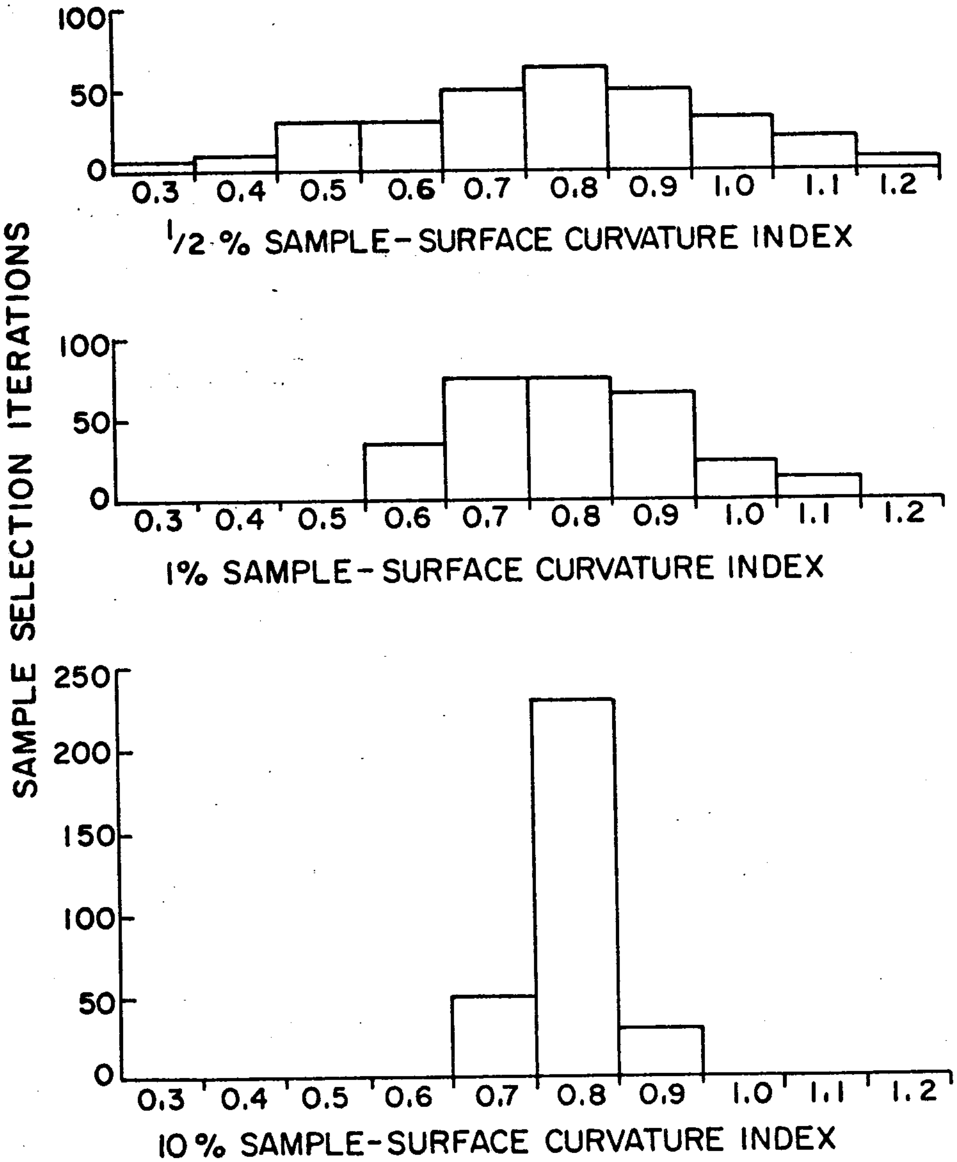

Figure 29. District 21 Sample Mean Histograms for Surface Curvature Index--FM Highways

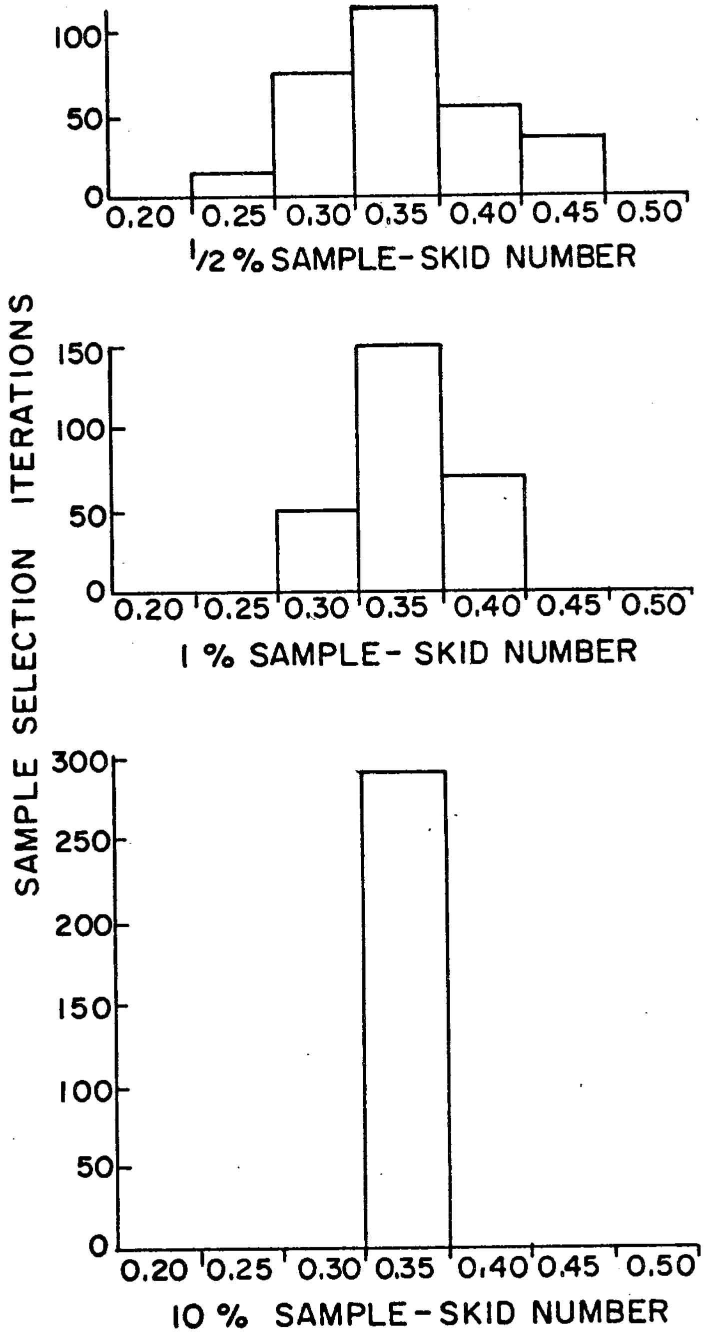

Figure 30. District 21 Sample Mean Histograms for Skid Number--FM Highways

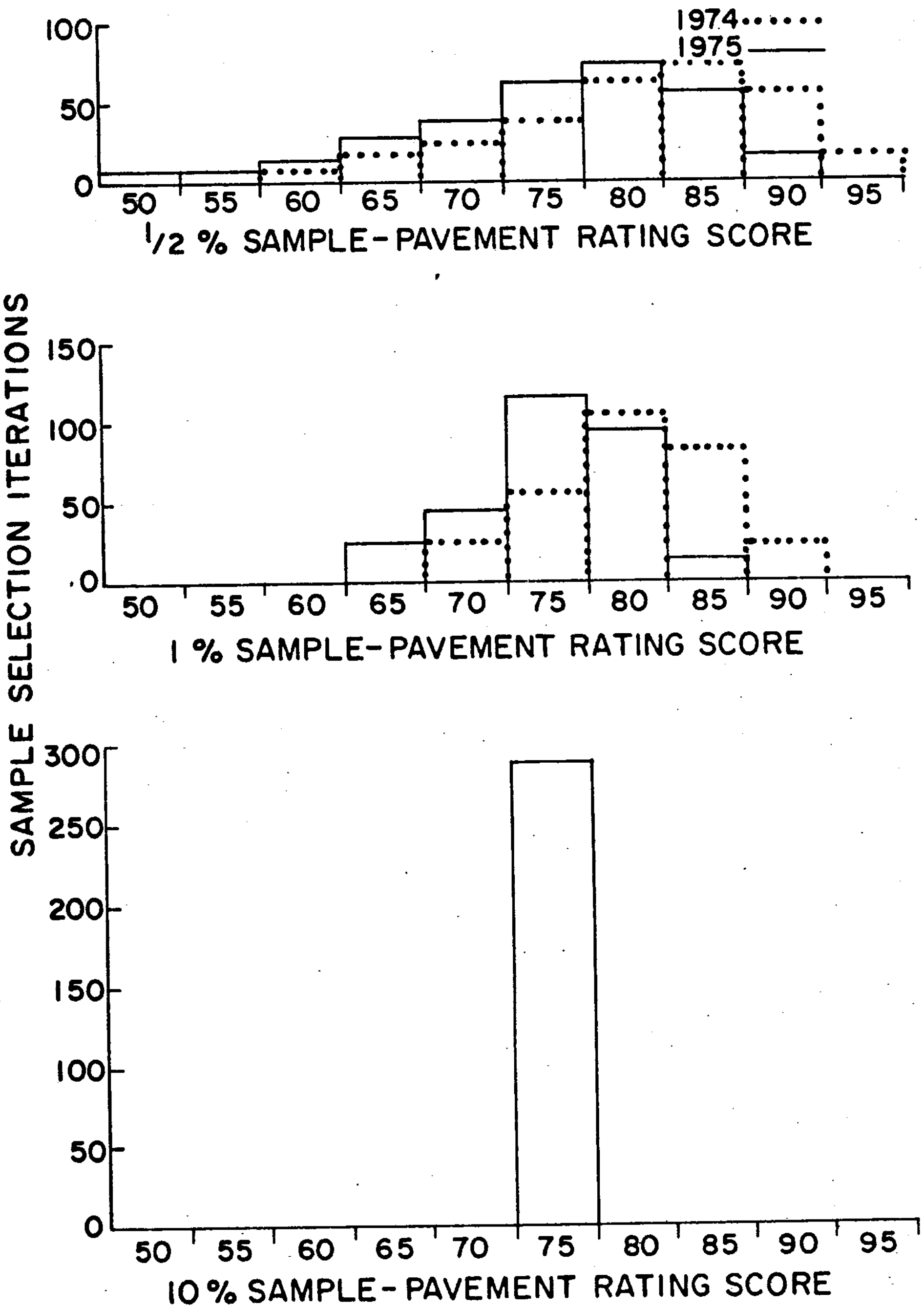

Figure 31. District 21 Sample Mean Histograms for Pavement Rating Score--FM Highways

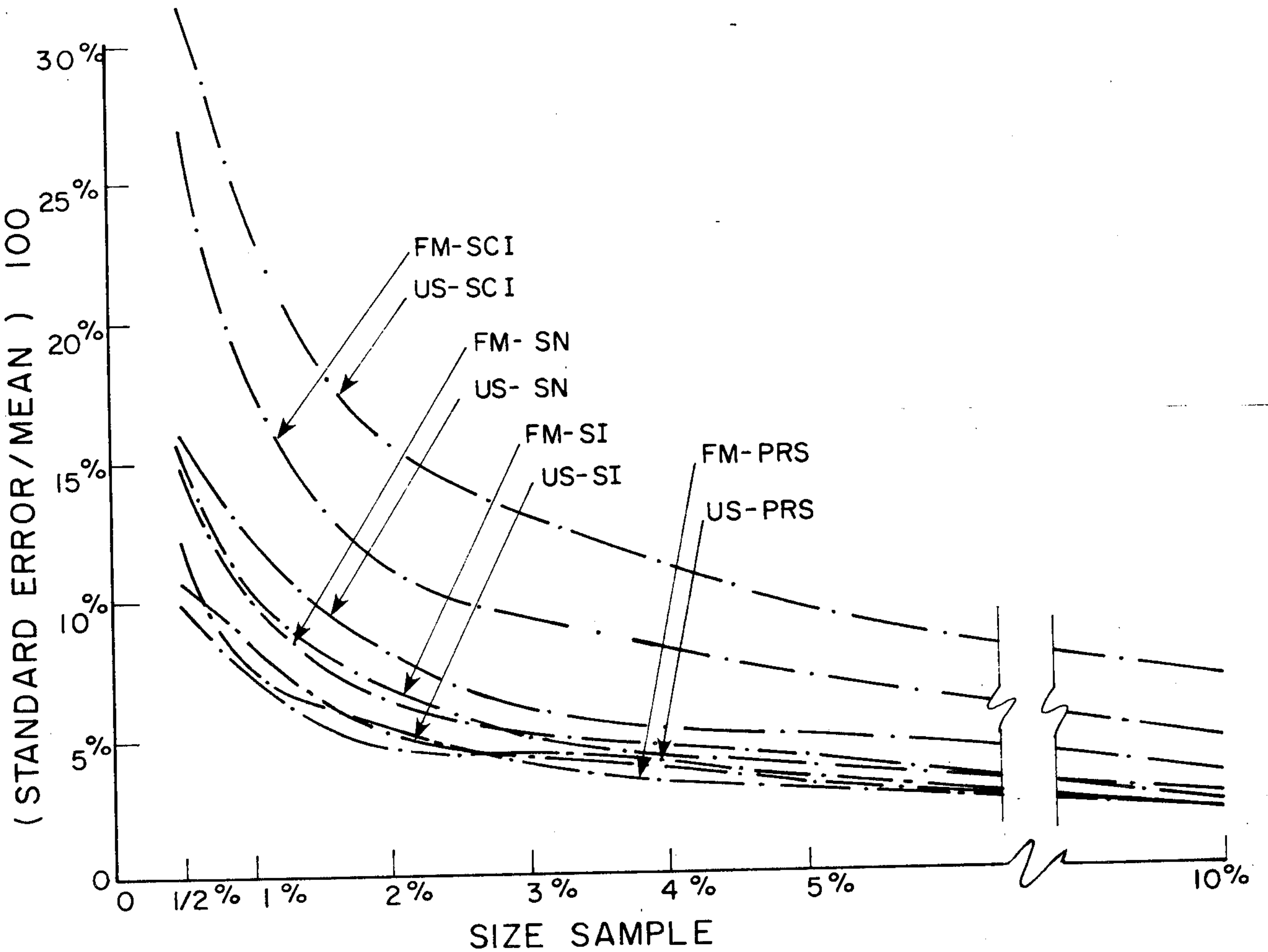

Figure 32. District 21 - Coefficient of Sample Variation vs Sample Size (1975 Data)

Optimum Sample Size

Utility is a measure of preference and is a way of combining dissimilar factors so that optimal solutions can be obtained. Simply stated, utility theory is a way to compare apples with oranges. Numerous references contain discussions on utility but References 13 through 15 primarily were used for this application.

To apply utility methods, two decision criteria were identified to serve as the basis for determining the optimal sample size. These criteria are:

1. Data collection costs
2. Sampling variation

It is desirable to minimize both the sampling costs and variation but the goals of these two criteria conflict. Utility theory provides a way to combine the two to obtain an optimal sample size.

The first step in the optimization process was to develop utility curves for each of the criteria. Utility ranges from 0 (least preferable) to 1 (most preferable) and is plotted as the ordinate for each criterion. The utility curves used in this analysis were subjectively developed by the authors and are shown in Figure 33. These curves are reasonable estimates of the preferability of the different values for each of the two criteria. Other curves could be developed and used to reaccomplish the analysis if desired. The curves as developed are "risk neutral" which means that neither optimistic nor pessimistic chances were made in relating the decision criteria to utility.

The cost ratio used in Figure 33 is the required cost for collecting a given kind of data for a given sample size divided by the required cost for the smallest sample size used for collecting the same type of data (0.5 percent sample for all cases). This allows use of one utility curve

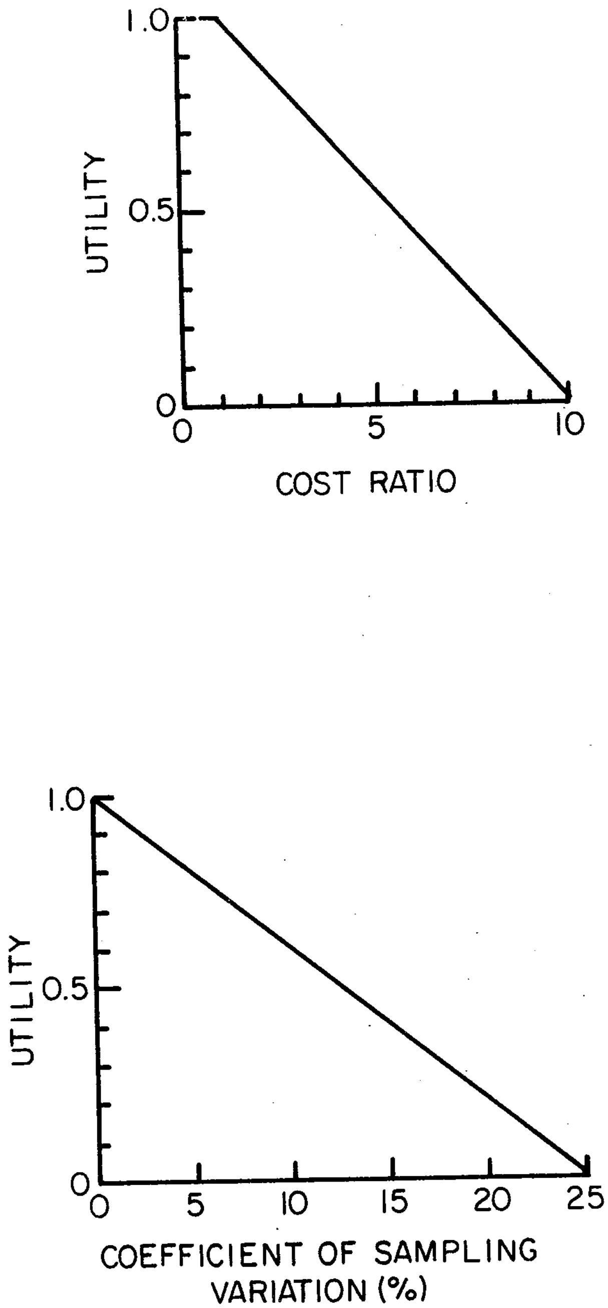

Figure 33. Decision Criteria Utility Curves

for determination of all cost related utilities for the various sample sizes and data types. Table 22 contains the actual costs used in determining the cost ratios. The costs listed in this table do not increase linearly with increasing sample size; instead, as the sample size increases, the number of segments which can be evaluated per unit of time increases due to shorter travel distances.

The coefficient of sampling variation was used as the indicator of sampling variability. Thus, low coefficients of sampling variation are preferable to high values and this is reflected in the utility curve. A coefficient of sampling variation of 25 percent was selected as an upper limit with a resulting utility of zero. Other limiting coefficients were examined ranging from 12.5 to 50 percent and only slight changes in the optimal sample size were noted.

To determine the optimal sample size, the two decision criteria were combined by use of the following additive model:

$$SU = W_1U_1 + W_2U_s \qquad (5)$$

where

SU = sampling utility--a term which represents the sum of the weighted decision criteria utilities

U_1 = utility determined by use of the cost ratio associated with each sample size and data type combination

U_2 = utility determined by use of the coefficient of sampling variation associated with each sample size and data type combination

Table 22. Estimated Costs for Various Sample Sizes*

Sample Size (%)	Data Type	Cost Per District ($)
0.5	SI	155
	SCI	420
	SN	280
	PRS	155
1.0	SI	185
	SCI	780
	SN	335
	PRS	190
2.0	SI	215
	SCI	1500
	SN	385
	PRS	290
3.0	SI	260
	SCI	2225
	SN	445
	PRS	370
5.0	SI	350
	SCI	3085
	SN	590
	PRS	555
10.0	SI	675
	SCI	5325
	SN	1175
	PRS	1000

* Estimates of January 1977

W_1, W_2 = utility weighting factors with requirement that

$$\sum_{i=1}^{2} W_i = 1$$

This relationship was used to determine the maximum sampling utility associated with each combination of highway and data type. The utility weights were used to demonstrate how changing emphasis on the two decision criteria affects the optimal sample size. If the cost decision criterion was used without consideration of the sampling variation, the optimum sample size would be zero. Conversely, if the sampling variation criterion was used without regard for costs, an infinite sample size would be required. The actual utility weights used were 0.75, 0.50, and 0.25.

The calculated sampling utilities determined by using Equation 5 are shown in Figures 34 and 35 and are plotted as a function of sample size. Figure 34 was developed for Serviceability Index and Pavement Rating Score data types and Figure 35 for Surface Curvature Index and Skid Number. Both figures show the maximum sampling utility where the optimal sample size occurs for each highway type.

The optimal sample sizes shown in the above figures are summarized in Table 23 which is a listing of the optimal sampling utility and sample size for the various combinations of highway types, data types, and utility weights. These results indicate that optimal sample sizes range from 0.5 to 3.0 percent if data collection cost is weighted three times as heavily as sampling variation. The optimal sample size for this case averaged over the two highway types and the four data types is 1.5 percent. The optimum ranges between 2.0 to 3.0 percent when the decision criteria are weighted equally with an average of 2.3 percent. The optimal sample size ranges between 3.0 to 10.0 percent when the sampling variation

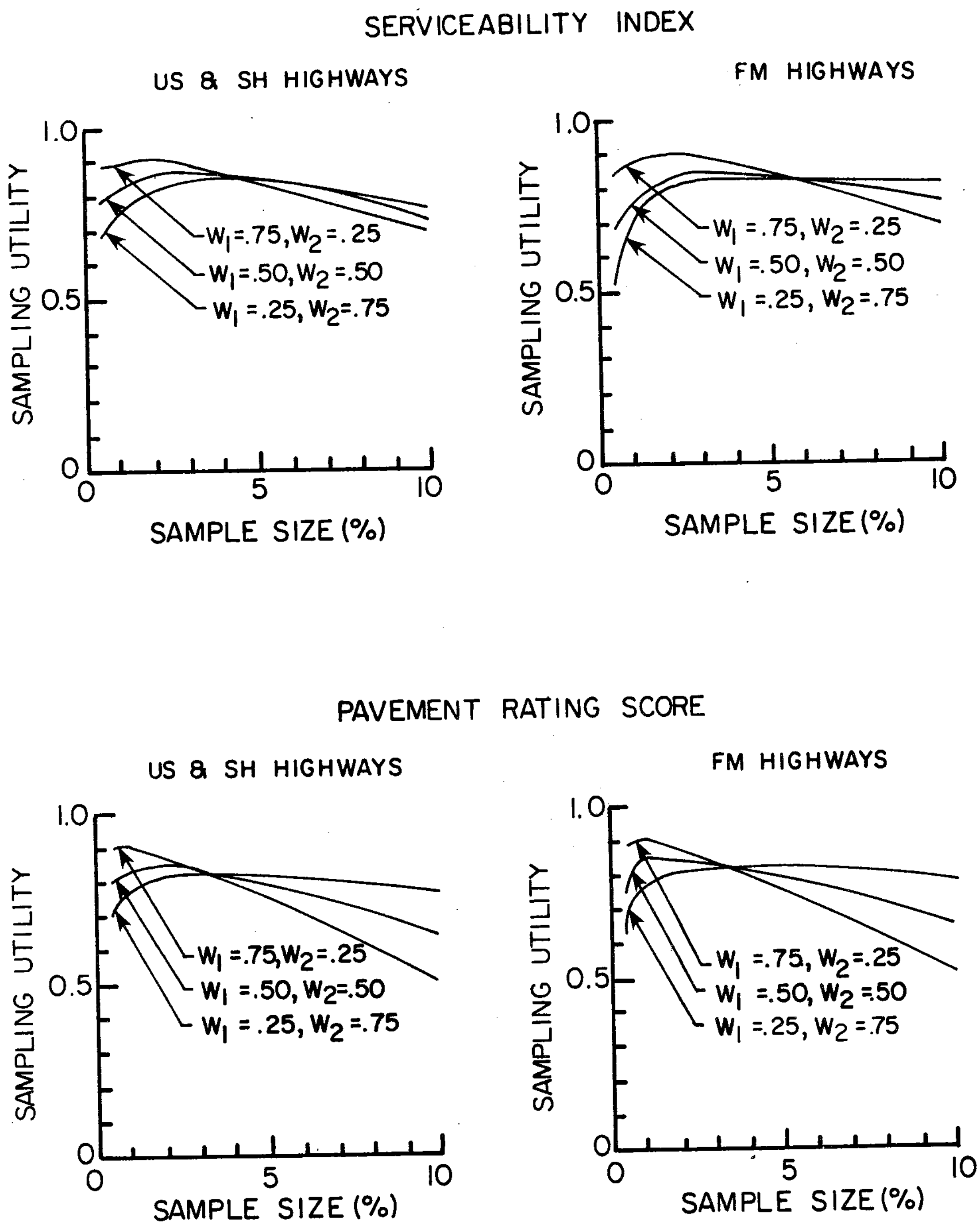

Figure 34. Utility Determination of Optimum Sample Size for Serviceability Index and Pavement Rating Score Data Types

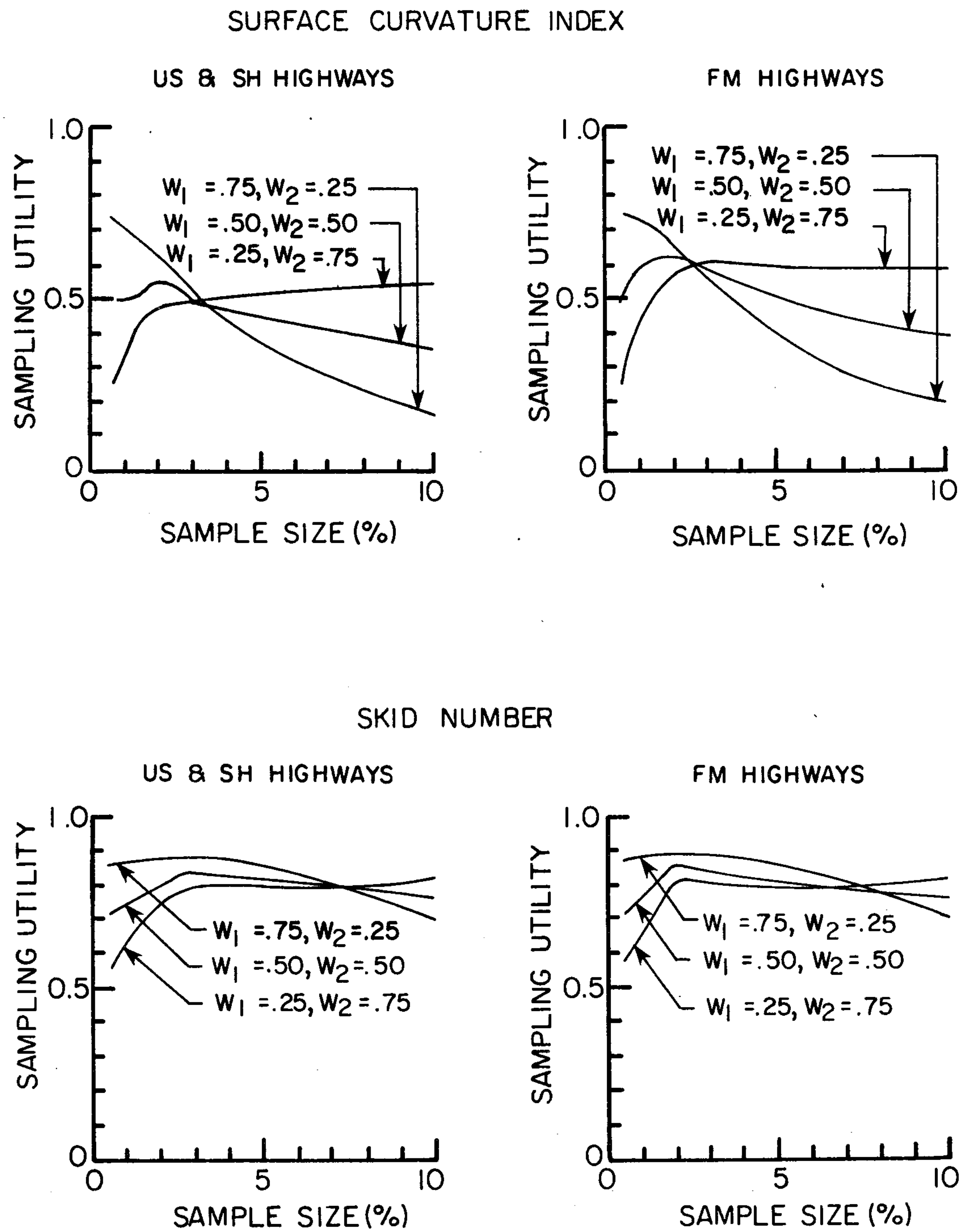

Figure 35. Utility Determination of Optimum Sample Size for Surface Curvature Index and Skid Number Data Types

Table 23. Optimal Sample Size Determination

Highway Type	Data Type	Utility Weights		Optimum Sampling Utility	Optimum Sampling Size
		W_1	W_2		
US & SH	SI	0.75	0.25	0.91	2.0
		0.50	0.50	0.87	2.0
		0.25	0.75	0.85	**5.0**
	SCI	0.75	0.25	0.75	0.5
		0.50	0.50	0.56	2.0
		0.25	0.75	0.55	10.0
	SN	0.75	0.25	0.89	3.0
		0.50	0.50	0.85	3.0
		0.25	0.75	0.82	10.0
	PRS	0.75	0.25	0.91	1.0
		0.50	0.50	0.85	2.0
		0.25	0.25	0.83	5.0
FM	SI	0.75	0.25	0.89	2.0
		0.50	0.50	0.86	3.0
		0.25	0.75	0.84	5.0
	SCI	0.75	0.25	0.75	0.5
		0.50	0.50	0.62	2.0
		0.25	0.75	0.61	3.0
	SN	0.75	0.25	0.90	2.0
		0.50	0.50	0.86	2.0
		0.25	0.75	0.82	10.0
	PRS	0.75	0.25	0.91	1.0
		0.50	0.50	0.84	2.0
		0.25	0.75	0.83	5.0

decision criterion is weighted three times as heavily as the cost criterion with an overall average of 6.6 percent. Thus, depending on the importance placed on each of the decision criteria, the average optimal sample size ranges from 1.5 to 6.6 percent.

Finally, a comparison between the two-stage random sample means obtained for the highway segments originally selected in District 21 as part of the statewide sample, the district population means, and simulation standard errors is appropriate. The 1974 sample and population means are used in this comparison since the sample survey in District 21 was unfortunately not accomplished during 1975. Only the Serviceability Index, Surface Curvature Index, and Pavement Rating Score data types for each highway type are considered with this information shown in Table 24.

The sample sizes shown in Table 24 are for the original two-stage samples. For US & SH highways the actual sample size was 0.9 percent and for FM highways 0.6 percent. This consisted of four two-mile US & SH segments and four FM segments. The population means and the simulation standard errors are compared to the original sample means. It can be seen that all means except one compare favorably.

The population means $\pm$ one standard error are also shown in Table 24 for the actual sample sizes used. Approximately 68 percent of all possible sample means for the given sample sizes should fall within these ranges. For US & SH highways, this range of Serviceability Index is 0.6 units for the 0.9 percent sample, less than 0.4 units for a two percent sample (not shown in table) and less than 0.2 units for a ten percent sample (not shown in table). Using a different highway and data type, Pavement Rating Score ranges for FM highways are 18 units for a 0.6 percent sample, 12 units for a one percent sample (not shown in table), less than 8 units for a two

Table 24. Comparison of District 21 Two-Stage Random Sample and Population Means.

Original Sample Size	Highway Type	Data Type	Original Sample Mean	Population Mean	Population Mean + 1 S.E.	Population Mean - 1 S.E.
0.9%	US & SH	SI	3.6	3.2	3.5	2.9
		SCI	0.5	0.6	0.8	0.4
		PRS	85	82	88	76
0.6%	FM	SI	2.8	2.6	3.0	2.2
		SCI	0.8	0.8	1.0	0.6
		PRS	76	78	87	69

percent sample and slightly more than 3 units for a ten percent sample (not shown in table). This again demonstrates how the range of the standard error decreases with increasing sample size.

SUMMARY AND CONCLUSIONS

Three methods were initially discussed which can be used by management to obtain performance information on a highway network. Of the three, statistical sampling surveys were examined in depth and a mass inventory conducted in District 21 was discussed (also refer to Appendices). A stratified two-stage random sample was used to obtain a limited amount of performance data throughout the state. Using two-mile highway segments, approximately one percent of the total statewide centerline mileage was sampled. Construction, traffic, climate, roughness, visually determined condition, deflection, rut depth, and skid are the kinds of information obtained for each of the sampled highway segments.

District and statewide means for Serviceability Index, Pavement Rating Score, and Surface Curvature Index data types were presented for the period of 1973 through 1976. This information was based on the statewide sample survey of highway segments. It was observed that the statewide Serviceability Index means for 1976 were about 4.0 for IH highways, 3.5 for US & SH, and 2.8 for FM. Pavement Rating Score means for the same year ranged from a high of 79 for IH highways to 74 for both US & SH and FM. Both data types have decreased from 1973 to 1976. The two principal sources of variation in the mean data estimates were determined and examined. These two sources are sampling error and year-to-year variation. With the year-to-year data errors encountered, it is not clear if the observed decreases between 1973 and 1976 are true indications of a correct trend. This problem will be examined upon availability of the 1977 survey data. Four specific recommendations were made to reduce the year-to-year variation for Pavement Rating Score data. Two of the more significant recommendations were that prior year rating information should be available during subsequent evaluations and raters should always stop at the same locations within a highway segment each year.

To examine the sample survey method and size currently used in Texas, simulation techniques were used on a complete set (mass inventory) of data available from District 21. The precision (as measured by standard error) of the two-stage sampling method was shown to be superior to simple random sampling. Additionally, by combining the results of the Distrcit 21 simulation study with utility theory, the optimal sample size was found to be a function of the amount of weighting placed on the decision criteria of cost and sampling variability. The results indicate that on the average the optimum sample lies between 1.5 to 6.6 percent of the centerline mileage depending on the ranges of weighting used. The optimum sample is 1.5 percent if cost is weighted three times as heavily as sampling variability and 2.3 percent if both criteria are weighted equally. Thus, the optimum sample size is, in general, larger than originally selected for statewide survey. Although, the estimates provided by the portion of the original statewide sample in District 21 are generally in reasonable agreement with the population means obtained for that district.

The most reliable information provided by the currently used sample sizes are the statewide data estimates and the next most reliable are the district estimates. With current instrument, personnel and sampling errors, small district year-to-year data variations are difficult to detect although reductions in all three error sources can be made.

New needs may require a sample survey conforming to a selected precision. Thus, a determination of the most cost effective sample size may not be necessary. If such a requirement should arise, the information contained in this report should allow the proper selection of the required sample size to be made.

A sample survey will not answer all of the important questions about the performance of the Texas highway network but can provide a significant amount of valuable, relatively inexpensive information.

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APPENDICES

APPENDIX A. Pavement Segment Location Information

The pertinent location information for each pavement segment studied is shown in Table A-1. Each individual location item was chosen so that field crews could adequately locate each segment and allow access to all appropriate SDHPT records and automated data files.

The following abbreviations are used:

1. SIDNO: Section identification number. Used to uniquely identify each pavement segment. The last digit is a check number used in the computer to verify that the section is properly identified.
2. DATE: The date the pavement segment was entered into the file or a revision to the location was made.
3. DIS: District number.
4. CO: County number.
5. CNTL-SEC: Control-Section number.
6. MILE-POINTS: Milepoints of the beginning and ending of each pavement segment.
7. LN: Lane designation according to format described in TTI Research Report 151-2, "Roadway Maintenance Evaluation User's Manual."
8. COUNTY-NAME: Self-explanatory.
9. HIGHWAY: Highway designation.
10. MILE-POST DESCRIPTION: Mileposts or other explanatory location information define the physical boundaries of the beginning and ending of each pavement segment.

SIDNO's 13 through 2497 define the randomly selected pavement segments. Segments for all twenty-five SDHPT districts are contained in this grouping. SIDNO's 2502 through 3370 represent nonrandomly selected segments which have been used in a special study of black base constructed pavements. SIDNO's 3252 through 3278 are exceptions and were selected because these pavements were recycled and thus of interest. The 1977 highway segment survey also included additional IH highway segments which are not shown in this listing. These additional segments will be reported in a subsequent report.

Table A-1. Listing of Pavement Segment Locations

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN|COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
13	75/06	01:092	0045-04	22.000-24.000	R|GRAYSON	US 82	:FROM POST 22 TO POST 24
26	75/06	01:092	2798-03	10.720-12.720	R|GRAYSON	FM 2729	:FROM POST 4 TO POST 6
39	76/11	01:117	0009-13	27.800-29.800	R|HUNT	IH 30	:POST 107 TO H-H CO.LINE
42	76/11	01:117	0173-06	00.026-01.850	R|HUNT	SH 34	:FROM CASH TO POST 30
55	75/06	01:117	1495-01	02.000-03.980	L|HUNT	FM 1566	:FROM POST 4 TO POST 2
68	76/02	01:117	2732-01	00.000-02.010	R|HUNT	FM 2736	:FROM POST 0 TO POST 2
71	75/06	01:139	0136-08	05.620-07.560	R|LAMAR	US 271	:FROM POST 6 TO POST 8
84	76/11	01:139	0730-03	14.790-16.440	R|LAMAR	FM 905	:FROM POST 14 TO FM 1497
97	75/06	01:139	0688-02	14.000-16.000	L|LAMAR	FM 79	:FROM POST 16 TO POST 14
102	75/06	01:190	0203-03	06.140-08.140	R|RAINS	US 69	:FROM POST 6 TO POST 8
115	76/11	01:190	2606-01	02.000-04.000	R|RAINS	FM 779	:FROM POST 2 TO POST 4
128	75/06	02:073	0258-01	08.000-10.000	R|ERATH	SH 6	:FROM POST 8 TO POST 10
131	75/06	02:073	1990-01	04.000-06.000	R|ERATH	FM 2157	:FROM POST 4 TO POST 6
144	75/06	02:120	0249-07	41.100-43.100	L|JACK	US 281	:FROM POST 38 TO POST 36
157	76/02	02:120	0391-07	04.000-06.000	L|JACK	FM 206	:FROM POST 6 TO POST 4
160	75/06	02:127	0259-04	02.790-04.790	R|JOHNSON	US 67	:FROM POST 28 TO POST 30
173	75/06	02:127	1181-02	02.000-04.000	R|JOHNSON	FM 917	:FROM POST 2 TO POST 4
186	76/11	02:220	0080-07	00.000-00.000	R|TARRANT	US 377	:FROM POST 0 TO POST 2
199	77/ 4	02:220	2208-01	00.000-00.000	L|TARRANT	SP 303	:PK SPRGS BLVD TO 2 MI.W
204	76/04	02:220	1603-03	02.000-04.000	R|TARRANT	FM 1709	:FROM POST 2 TO POST 4

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
217	76/02	02:127	0014-04	04.680-06.680	R	JOHNSON	IH 35W	:FROM POST 19 TO POST 21
220	76/02	03:039	0282-02	03.940-06.330	L	CLAY	SH 79	:FROM POST 6 TO POST 4
233	75/06	03:039	1350-01	09.960-11.940	R	CLAY	FM 1197	:FROM POST 10 TO POST 12
246	75/06	03:169	0239-02	16.950-18.950	L	MONTAGUE	SH 59	:FROM POST 22 TO POST 20
259	76/11	03:169	0845-01	04.010-05.970	R	MONTAGUE	FM 455	:FROM POST 6 TO POST 8
262	75/06	03:224	0404-01	33.840-35.830	L	THROCKMORTON	US 183	:FROM POST 36 TO POST 34
275	76/02	03:224	2645-01	06.000-07.750	R	THROCKMORTON	FM 2651	:FROM POST 2 TO US 380
288	75/06	03:244	0147-01	04.170-05.570	L	WILBARGER	US 183	:FROM POST29.4 TO POST 28
291	75/06	03:244	0702-01	09.940-11.930	R	WILBARGER	FM 91	:FROM POST 10 TO POST11.8
306	76/02	04:033	0275-04	00.174-01.180	L	CARSON	IH 40	:FROM POST 105 TO POST 104
319	75/10	04:033	0169-05	07.100-08.860	L	CARSON	US 60	:FROM WHITE DEER CL TO POST 26
322	75/06	04:033	1884-01	09.700-11.630	L	CARSON	FM 1342	:FROM POST 12 TO POST 10
335	75/06	04:104	0041-01	05.070-07.010	L	HARTLEY	US 87	:FROM POST 6 TO POST 4
348	75/06	04:104	1622-02	02.040-04.000	R	HARTLEY	FM 998	:FROM POST 2 TO POST 4
351	76/02	04:118	0557-02	06.023-07.870	L	HUTCHINSON	SH 152	:FROM POST 8 TO POST 6
364	76/10	04:118	1515-03	01.488-03.328	L	HUTCHINSON	FM 1598	:FROM POST 2 TO POST 0
377	75/06	04:148	0582-01	11.980-13.890	R	LIPSCOMB	SH 305	:FROM POST 2 TO POST 4
380	75/06	04:148	1337-02	26.700-28.550	R	LIPSCOMB	FM 1265	:FROM POST 28 TO POST 30
393	76/02	04:180	0090-03	05.430-07.430	R	OLDHAM	IH 40	:FROM POST 20 TO POST 22
408	75/06	04:180	0226-02	04.930-06.930	L	OLDHAM	US 385	:FROM POST 6 TO POST 4

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN|COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
411	76/02	04:180	0461-13	08.950-10.575	L|OLDHAM	FM 290	:O-DS CO.LINE TO POST 4
424	75/06	04:104	0238-02	14.640-16.580	R|HARTLEY	US 54	:FROM POST 34 TO POST 36
437	76/02	05:096	0067-06	24.230-26.230	R|HALE	US 87	:FROM POST 24 TO POST 26
440	75/06	05:096	0439-04	06.000-08.000	R|HALE	SH 194	:FROM POST 6 TO POST 8
453	75/06	05:096	1041-01	35.360-37.360	R|HALE	FM 400	:FROM POST 26 TO POST 28
466	75/06	05:096	2332-02	00.000-02.000	L|HALE	FM 1612	:FROM POST 2 TO POST 0
479	75/06	05:111	0227-05	08.000-10.000	R|HOCKLEY	US 385	:FROM POST 8 TO POST 10
482	75/06	05:111	2904-01	04.000-06.000	L|HOCKLEY	FM 1490	:FROM POST 6 TO POST 4
495	75/06	05:111	2182-02	24.460-26.460	L|HOCKLEY	FM 1585	:FROM POST 30 TO POST 28
500	76/04	05:152	0067-07	02.024-04.024	R|LUBBOCK	US 87	:FROM POST 2 TO POST 4
513	75/06	05:152	0052-07	02.000-04.000	R|LUBBOCK	US 84	:FROM POST 2 TO POST 4
526	75/06	05:152	1632-02	18.990-20.990	R|LUBBOCK	FM 1729	:FROM POST 18 TO POST 20
539	75/06	05:185	0302-01	18.000-20.000	L|PARMER	SH 86	:FROM POST 20 TO POST 18
542	75/06	05:185	2185-01	02.000-04.000	L|PARMER	FM 2013	:FROM POST 4 TO POST 2
555	75/06	05:219	0067-03	24.040-26.040	R|SWISHER	US 87	:FROM POST 24 TO POST 26
568	75/06	05:219	0302-04	10.000-12.000	R|SWISHER	SH 86	:FROM POST 10 TO POST 12
571	76/04	05:219	1635-01	06.330-08.330	L|SWISHER	FM 1424	:FROM POST 12 TO POST 10
584	75/06	05:251	0461-05	02.000-03.990	L|YOAKUM	SH 214	:FROM POST 4 TO POST 2
597	75/06	05:251	0987-04	02.000-04.000	L|YOAKUM	FM 1780	:FROM POST 4 TO POST 2
602	75/06	06:069	0004-07	25.990-27.990	L|ECTOR	IH 20	:FROM POST 110 TO POST 108

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN|COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
615	75/06	06:069	0229-01	06.700-08.770	L|ECTOR	US 385	:FROM POST 26 TO POST 24
628	75/06	06:069	1127-04	12.080-14.160	L|ECTOR	FM 866	:FROM POST 4 TO POST 2
631	76/02	06:151	0479-02	00.000-02.000	L|LOVING	SH 302	:FROM POST 2 TO POST 0
644	76/11	06:151	0479-03	15.627-17.627	R|LOVING	FM 1211	:FROM POST 16 TO POST 18
657	75/06	06:186	0441-07	22.540-23.550	L|PECOS	IH 10	:FROM POST 251 TO POST 250
660	75/06	06:186	0292-06	21.670-23.670	L|PECOS	SH 18	:FROM POST 24 TO POST 22
673	76/11	06:186	0076-01	18.800-20.790	R|PECOS	US 385	:POST 54 TO POST 56
686	75/06	06:186	2262-04	03.470-05.400	L|PECOS	FM 1776	:FROM POST 34 TO POST 32
699	75/06	06:186	1639-02	09.050-11.050	L|PECOS	FM 1450	:FROM POST 10 TO POST 8
704	75/06	06:186	2905-01	02.000-03.980	R|PECOS	FM 2886	:FROM POST 2 TO POST 4
717	76/10	06:231	0076-07	04.571-06.571	R|UPTON	US 67	:FROM POST 30 TO POST 28
720	75/06	06:231	2906-02	12.000-14.000	R|UPTON	FM 1492	:FROM POST 12 TO POST 14
733	75/06	07:048	0035-03	14.000-16.000	R|CONCHO	US 83	:FROM POST 14 TO POST 16
746	75/06	07:048	2278-01	02.000-04.000	L|CONCHO	FM 2402	:FROM POST 4 TO POST 2
759	75/06	07:119	0077-02	05.120-07.120	L|IRION	US 67	:FROM POST 38 TO POST 36
762	75/06	07:119	1648-04	12.020-13.990	L|IRION	SH 163	:FROM POST 14 TO POST 12
775	75/06	07:164	0035-06	08.760-10.760	L|MENARD	US 83	:FROM POST 26 TO POST 24
788	75/06	07:164	2008-01	11.890-13.890	L|MENARD	FM 2092	:FROM POST 6 TO POST 4
791	75/10	07:200	0158-01	13.220-15.220	L|RUNNELS	US 67	:FROM POST 30 TO POST 28
806	75/06	07:200	0826-03	07.000-09.000	R|RUNNELS	FM 2133	:FROM POST 6 TO POST 8

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
819	75/06	07:200	0828-02	02.000-04.000	R	RUNNELS	FM 2111	:FROM POST 2 TO POST 4
822	76/02	08:017	0295-03	28.499-30.586	L	BORDEN	US 180	:FROM POST 30 TO POST 28
835	75/06	08:017	0682-02	12.010-13.970	R	BORDEN	FM 612	:FROM POST 2 TO POST 4
848	75/10	08:030	0007-01	17.670-19.670	R	CALLAHAN	IH 20	:FROM POST 311 TO POST 313
851	75/06	08:030	0437-03	14.710-16.710	L	CALLAHAN	US 283	:FROM POST 16 TO POST 14
864	75/06	08:030	0974-01	02.820-04.820	R	CALLAHAN	FM 604	:FROM POST 12 TO POST 14
877	75/06	08:077	0296-03	11.720-13.670	R	FISHER	US 180	:FROM POST 28 TO POST 30
880	75/06	08:077	1526-04	02.000-03.920	R	FISHER	FM 1606	:FROM POST 2 TO POST 4
893	75/06	08:168	0005-08	12.180-14.170	R	MITCHELL	IH 20	:FROM POST 208 TO POST 210
908	75/06	08:168	0454-03	21.700-23.630	R	MITCHELL	SH 208	:FROM POST 22 TO POST 24
911	75/06	08:168	2472-01	01.990-03.980	L	MITCHELL	FM 1899	:FROM POST 4 TO POST 2
924	75/06	09:014	0015-06	11.150-13.150	L	BELL	IH 35	:FROM POST 291 TO POST 289
937	75/06	09:014	0185-01	36.050-38.030	L	BELL	US 190	:FROM POST 38 TO POST 36
940	75/06	09:014	0752-03	10.000-12.010	R	BELL	FM 935	:FROM POST 0 TO POST 2
953	75/06	09:014	0836-02	05.970-07.960	R	BELL	FM 440	:FROM POST 6 TO POST 8
966	75/06	09:018	0258-07	38.000-40.000	R	BOSQUE	SH 6	:FROM POST 38 TO POST 40
979	75/10	09:018	1054-02	12.580-14.590	R	BOSQUE	FM 219	:FROM POST 10 TO POST 12
982	75/06	09:074	1077-01	00.010-01.980	R	FALLS	FM 434	:FROM POST 0 TO POST 2
995	75/10	09:110	0014-07	05.571-07.599	L	HILL	IH 35	:FROM POST 363 TO POST 361
1001	75/06	09:110	0162-02	07.970-09.960	L	HILL	SH 31	:FROM POST 10 TO POST 8

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
1014	75/06	09:110	0888-02	05.970-07.980	L	HILL	FM 309	:FROM POST 8 TO POST 6
1027	75/06	09:110	1374-02	03.350-05.340	L	HILL	FM 1243	:FROM POST 10 TO POST 8
1030	75/06	09:074	0382-02	15.960-17.600	R	FALLS	SH 7	:FROM POST 16 TO POST17.6
1043	75/06	10:093	0096-04	06.000-08.000	R	GREGG	US 80	:FROM POST 6 TO POST 8
1056	75/06	10:093	1932-01	00.000-02.000	L	GREGG	FM 2011	:FROM POST 2 TO POST 0
1069	75/06	10:212	0492-05	11.760-13.760	R	SMITH	FM 346	:FROM POST 16 TO POST 18
1072	75/06	10:212	1934-02	00.000-02.850	L	SMITH	FM 2015	:FROM POST 6 TO POST 4
1085	75/06	10:234	0505-01	02.000-04.000	R	VAN ZANDT	SH 110	:FROM POST 2 TO POST 4
1098	75/06	10:234	1172-01	00.020-02.000	R	VAN ZANDT	FM 1256	:FROM POST 0 TO POST 2
1103	75/06	10:234	2477-01	12.000-14.000	L	VAN ZANDT	FM 1395	:FROM POST 4 TO POST 2
1116	75/06	10:250	0401-03	13.260-15.260	L	WOOD	SH 154	:FROM POST 30 TO POST 28
1129	75/06	10:250	0657-01	00.290-02.290	L	WOOD	FM 515	:FROM POST 16 TO POST 14
1132	75/06	10:250	1390-03	04.000-06.000	R	WOOD	FM 1254	:FROM POST 4 TO POST 6
1145	75/06	11:114	0109-04	14.000-16.000	L	HOUSTON	US 287	:FROM POST 16 TO POST 14
1158	75/06	11:114	1677-01	04.000-06.000	R	HOUSTON	FM 1733	:FROM POST 4 TO POST 6
1161	75/06	11:114	1676-02	10.050-12.050	R	HOUSTON	FM 1280	:FROM POST 14 TO POST 16
1174	75/06	11:174	0175-07	09.990-12.000	R	NACOGDOCHES	US 59	:FROM POST 10 TO POST 12
1187	75/06	11:174	0594-04	17.210-19.210	L	NACOGDOCHES	FM 225	:FROM POST 18 TO POST 16
1190	75/06	11:202	0064-05	06.000-08.000	L	SABINE	US 96	:FROM POST 8 TO POST 6
1205	75/06	11:202	0896-01	02.000-04.000	L	SABINE	FM 330	:FROM POST 4 TO POST 2

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
1218	75/06	11:228	0319-02	02.940-04.950	L	TRINITY	SH 94	:FROM POST 24 TO POST 22
1221	75/06	11:228	0930-01	06.000-08.000	R	TRINITY	FM 355	:FROM POST 6 TO POST 8
1234	75/06	12:020	0178-03	25.830-27.810	L	BRAZORIA	SH 35	:FROM POST 28 TO POST 26
1247	75/06	12:020	1003-01	07.810-09.770	R	BRAZORIA	FM 523	:FROM POST 8 TO POST 10
1250	75/11	12:102	0500-03	00.100-02.100	L	HARRIS	IH 45	:FROM POST 26 TO POST 24
1263	75/06	12:085	0192-04	01.980-03.890	R	GALVESTON	SH 6	:FROM POST 2 TO POST 4
1276	76/02	12:085	0978-02	12.040-14.630	L	GALVESTON	FM 517	:FROM POST 14 TO POST 12
1289	75/06	12:170	0110-04	06.270-08.270	L	MONTGOMERY	IH 45	:FROM POST 81 TO POST 79
1292	75/06	12:170	0338-03	11.110-11.790	R	MONTGOMERY	SH 105	:FROM POST11.3 TO POST 12
1307	75/06	12:170	1062-03	21.780-23.780	R	MONTGOMERY	FM 1485	:FROM POST 12 TO POST 14
1310	75/06	12:170	0720-02	25.700-27.670	R	MONTGOMERY	FM 149	:FROM POST 26 TO POST 28
1323	76/02	12:237	0050-05	12.460-14.720	R	WALLER	US 290	:FROM POST 12 TO POST 14
1336	75/06	12:237	0543-01	11.970-13.970	R	WALLER	FM 359	:FROM POST 12 TO POST 14
1349	75/06	13:062	0270-01	09.010-11.010	L	DEWITT	SH 72	:FROM POST 22 TO POST 20
1352	75/06	13:062	1113-02	08.000-10.000	L	DEWITT	FM 1447	:FROM POST 10 TO POST 8
1365	75/06	13:076	0211-06	07.000-09.000	R	FAYETTE	US 77	:FROM POST 6 TO POST 8
1378	75/06	13:076	2096-01	02.010-04.010	L	FAYETTE	FM 2237	:FROM POST 4 TO POST 2
1381	75/06	13:076	0211-09	08.110-10.110	L	FAYETTE	FM 155	:FROM POST 10 TO POST 8
1394	76/05	13:090	0025-05	04.000-06.000	L	GONZALES	US 90A	:FROM POST 6 TO POST 4
1409	76/02	13:090	1007-02	05.000-07.000	L	GONZALES	FM 532	:FROM POST 6 TO POST 4

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
1412	75/06	13:241	0089-06	15.330-17.330	L	WHARTON	US 59	:FROM POST 32 TO POST 30
1425	75/06	13:241	0420-10	00.000-02.000	R	WHARTON	FM 1300	:FROM POST 0 TO POST 2
1438	76/05	13:241	1412-03	14.870-15.870	L	WHARTON	FM 1301	:W-M CO.LINE TO 1 MI. N.
1441	75/06	14:011	0471-05	06.000-08.000	R	BASTROP	SH 21	:FROM POST 6 TO POST 8
1454	75/06	14:011	1533-01	03.990-05.990	R	BASTROP	FM 1704	:FROM POST 4 TO POST 6
1467	76/02	14:016	0253-01	22.000-23.970	R	BLANCO	US 281	:FROM POST 22 TO POST 24
1470	75/06	14:016	1056-05	06.000-08.000	L	BLANCO	FM 1323	:FROM POST 8 TO POST 6
1483	75/06	14:106	0113-07	02.000-04.000	L	HAYS	US 290	:FROM POST 4 TO POST 2
1496	75/06	14:106	0683-03	10.000-12.000	R	HAYS	FM 12	:FROM POST 10 TO POST 12
1501	76/02	14:150	0700-04	06.190-08.200	R	LLANO	SH 71	:FROM POST 30 TO POST 32
1514	75/06	14:150	0396-09	12.000-13.990	L	LLANO	FM 152	:FROM POST 14 TO POST 12
1527	75/06	15:007	0517-01	27.920-29.920	R	ATASCOSA	SH 16	:FROM POST 28 TO POST 30
1530	75/11	15:007	2018-01	00.000-01.990	L	ATASCOSA	FM 2146	:FROM POST 2 TO FM 476
1543	76/02	15:015	0025-02	33.130-35.130	R	BEXAR	IH 10	:FROM POST 588 TO 590
1556	75/06	15:015	0024-07	04.430-06.430	R	BEXAR	US 90	:FROM FM 1604 TO WEST 2MI
1569	75/06	15:046	1728-02	05.160-07.150	L	COMAL	FM 306	:FROM POST 14 TO POST 12
1572	76/02	15:095	0535-02	21.750-23.750	R	GUADALUPE	IH 10	:FROM POST 616 TO POST 618
1585	75/10	15:095	0366-03	10.179-12.139	R	GUADALUPE	SH 123	:FROM POST 24 TO POST 26
1598	75/06	15:095	2021-02	01.980-03.970	L	GUADALUPE	FM 1044	:FROM POST 4 TO POST 2
1603	76/02	15:142	0017-08	06.308-08.308	R	LASALLE	IH 35	:FROM POST 73 TO POST 75

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
1616	75/06	15:142	0483-01	09.960-11.950	R	LASALLE	SH 97	:FROM POST 10 TO POST 12
1629	75/06	15:142	0652-05	38.420-40.410	R	LASALLE	FM 468	:FROM POST 32 TO POST 34
1632	75/06	16:004	0180-05	03.730-05.730	L	ARANSAS	SH 35	:FROM POST 26 TO POST 24
1645	75/06	16:004	0507-04	02.020-04.010	R	ARANSAS	FM 881	:FROM POST 2 TO POST 4
1658	75/06	16:149	0483-04	05.990-07.980	L	LIVE OAK	SH 72	:FROM POST 8 TO POST 6
1661	75/06	16:149	1206-01	12.010-14.000	L	LIVE OAK	FM 1358	:FROM POST 14 TO POST 12
1674	76/02	16:149	0254-01	17.250-19.310	R	LIVE OAK	US 281	:FROM POST 28 TO POST 30
1687	76/02	16:178	0074-06	03.480-05.014	L	NUECES	IH 37	:FROM SPUR 72-SE 1.5 MI
1690	75/06	16:178	0102-02	04.020-06.020	L	NUECES	US 77	:FROM POST 14 TO POST 12
1705	75/06	16:178	0086-20	04.020-06.050	R	NUECES	FM 665	:FROM POST 4 TO POST 6
1718	75/06	16:196	0447-04	03.990-06.000	L	REFUGIO	SH 202	:FROM POST 6 TO POST 4
1721	75/06	16:196	0447-05	02.040-04.030	R	REFUGIO	FM 774	:FROM POST 2 TO POST 4
1734	75/06	17:026	0116-03	19.840-21.820	R	BURLESON	SH 21	:FROM POST 20 TO POST 22
1747	75/10	17:026	0648-03	03.800-05.800	L	BURLESON	FM 60	:FROM POST 24 TO POST 22
1750	76/05	17:154	0117-04	08.030-10.010	R	MADISON	US 190+SH 21	:FROM P.8 TO P.10
1763	76/02	17:154	1401-01	01.230-03.210	R	MADISON	FM 1372	:FROM POST 6 TO POST 8
1776	75/06	17:198	0205-02	06.000-08.000	R	ROBERTSON	US 79	:FROM POST 6 TO POST 8
1789	75/06	17:198	2400-01	25.080-27.080	L	ROBERTSON	FM 979	:FROM POST 24 TO POST 22
1792	77/ 4	17:236	0213-01	07.200-09.192	L	WALKER	US 190	:FROM POST 28 TO POST 26
1807	75/06	17:236	0578-03	13.990-15.940	L	WALKER	FM 1374	:FROM POST 16 TO POST 14

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
1810	75/06	18:043	1014-01	00.000-02.100	L	COLLIN	FM 547	:FROM POST 2 TO POST 0
1823	75/11	18:043	2351-01	04.100-06.130	R	COLLIN	FM 2478	:FROM POST 4 TO POST 6
1836	76/02	18:061	0081-06	08.670-10.670	R	DENTON	US 377	:FROM FM 428 SO. TO SW 2 MI
1849	75/06	18:061	0718-01	19.800-21.800	L	DENTON	FM 156	:1 MI N TO 3 MI N OF SH114
1852	75/06	18:061	1567-02	01.290-03.270	L	DENTON	FM 423	:FROM POST 8 TO POST 6
1865	75/06	18:071	0172-08	25.670-27.720	R	ELLIS	US 287	:FROM POST 26 TO POST 28
1878	75/06	18:071	1048-02	03.840-05.840	R	ELLIS	FM 660	:FROM POST 4 TO POST 6
1881	75/06	18:071	1451-02	20.980-23.030	R	ELLIS	FM 55	:FROM POST 12 TO POST 14
1894	76/02	18:199	0009-12	07.320-09.320	R	ROCKWALL	IH 30	:FROM POST 18 TO POST 20
1909	75/06	18:199	0009-04	01.600-03.100	R	ROCKWALL	SH 66	:FROM RHBRG TO E 1.5 MI
1912	76/11	18:199	1016-04	05.891-07.891	L	ROCKWALL	FM 548	:1.2 MI.SW POST 10 TO P.10
1925	75/06	19:032	0248-02	00.000-02.000	R	CAMP	US 271	:FROM POST 0 TO POST 2
1938	75/06	19:032	1019-01	03.990-05.990	R	CAMP	FM 556	:FROM POST 4 TO POST 6
1941	75/06	19:172	0010-08	07.930-09.920	L	MORRIS	US 67	:FROM POST 10 TO POST 8
1954	75/06	19:172	0750-01	12.740-14.740	L	MORRIS	FM 144	:FROM POST 8 TO POST 6
1967	76/02	19:183	0247-02	00.000-01.070	R	PANOLA	US 79	:FROM FM 31 TO POST 10
1970	75/06	19:183	1894-01	02.020-04.010	L	PANOLA	FM 1971	:FROM POST 4 TO POST 2
1983	75/06	19:230	0392-02	05.960-07.990	R	UPSHUR	US 259	:FROM POST 6 TO POST 8
1996	75/06	19:230	0964-02	10.000-12.000	R	UPSHUR	FM 2088	:FROM POST 10 TO POST 12
2002	76/02	20:036	0508-02	09.188-10.880	L	CHAMBERS	IH 10	:FROM POST 808 TO POST 806

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
2015	76/02	20:036	0389-02	00.000-00.800	L	CHAMBERS	SH 146	:FROM M.B. CL TO LIBERTY CO.LN
2028	75/06	20:036	1022-01	09.960-11.950	R	CHAMBERS	FM 562	:FROM POST 10 TO POST 12
2031	75/06	20:101	0200-12	00.000-02.000	L	HARDIN	FM 418	:FROM POST 2 TO POST 0
2044	75/11	20:124	0508-04	07.504-09.508	R	JEFFERSON	SH 73	:FROM POST 6 TO POST 8
2057	76/02	20:124	0932-02	12.000-14.000	L	JEFFERSON	FM 365	:FROM POST 14 TO POST 12
2060	76/02	20:229	0213-07	00.459-02.459	R	TYLER	US 190	:FROM FM 1746 TO 2 MI EAST
2073	75/11	20:229	1828-01	04.221-06.230	R	TYLER	FM 1943	:FROM POST 12 TO POST 14
2086	75/06	21:066	0327-02	05.950-07.960	R	KENEDY	US 77	:FROM POST 6 TO POST 8
2099	75/06	21:067	0542-03	06.500-08.500	R	DUVAL	US 59	:FROM POST 26 TO POST 28
2104	75/06	21:067	1083-02	04.000-06.000	R	DUVAL	FM 716	:FROM POST 4 TO POST 6
2117	76/02	21:109	0255-07	24.012-26.012	R	HIDALGO	US 281	:FROM POST 24 TO POST 26
2120	75/10	21:109	0863-01	22.486-24.481	R	HIDALGO	FM 493	:FROM POST 26 TO POST 28
2133	75/06	21:253	0038-04	36.000-38.000	L	ZAPATA	US 83	:FROM POST 38 TO POST 36
2146	75/06	21:253	2530-01	10.000-12.000	L	ZAPATA	FM 2687	:FROM POST 12 TO POST 10
2159	75/06	22:064	0037-06	17.720-19.770	R	DIMMIT	US 83	:FROM POST 18 TO POST 20
2162	75/06	22:064	0301-04	02.010-04.020	R	DIMMIT	FM 186	:FROM POST 2 TO POST 4
2175	75/06	22:070	0235-02	03.430-05.390	L	EDWARDS	SH 55	:FROM POST 48 TO POST 46
2188	75/06	22:070	0375-05	03.930-05.870	R	EDWARDS	FM 674	:FROM POST 4 TO POST 6
2191	75/06	22:159	0300-01	36.100-38.100	R	MAVERICK	US 277	:FROM POST 36 TO POST 38
2206	75/06	22:159	1229-01	09.940-11.950	R	MAVERICK	FM 1021	:FROM POST 10 TO POST 12

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN|COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
2219	75/06	22:254	0276-03	04.040-06.030	L|ZAVALA	US 57	:FROM POST 6 TO POST 4
2222	75/11	22:254	1279-01	02.000-04.000	R|ZAVALA	FM 1025	:FROM POST 2 TO POST 4
2235	76/02	23:047	0289-01	02.806-04.806	L|COMANCHE	SH 16	:FROM POST 32 TO POST 30
2248	75/06	23:047	2107-02	04.000-06.000	R|COMANCHE	FM 679	:FROM POST 4 TO POST 6
2251	76/10	23:068	0314-05	12.625-14.417	L|EASTLAND	IH 20	:FROM POST 362 TO POST 360
2264	75/06	23:068	2638-01	02.000-03.990	R|EASTLAND	SH 206	:FROM POST 2 TO POST 4
2277	75/06	23:068	1697-02	05.840-07.890	R|EASTLAND	FM 2214	:FROM POST 6 TO POST 8
2280	75/06	23:160	1102-01	06.000-08.000	R|MCCULLOCH	SH 71	:FROM POST 6 TO POST 8
2293	75/06	23:160	1306-01	00.000-01.990	R|MCCULLOCH	FM 1028	:FROM POST 0 TO POST 2
2308	75/06	23:206	0289-04	01.960-03.920	L|SAN SABA	SH 16	:FROM POST 4 TO POST 2
2311	75/06	23:206	2729-01	06.000-08.000	R|SAN SABA	FM 2732	:FROM POST 6 TO POST 8
2324	76/04	24:072	2121-04	46.875-48.895	L|EL PASO	IH 10	:FROM POST 48 TO POST 46
2337	75/06	24:055	0233-05	46.630-48.600	L|CULBERSON	SH 54	:FROM POST 50 TO POST 48
2340	76/02	24:055	1158-01	08.000-10.000	R|CULBERSON	FM 2185	:FROM POST 8 TO POST 10
2353	76/02	24:072	0374-02	24.882-26.882	L|EL PASO	US 180	:FROM POST 18 TO POST 16
2366	75/06	24:072	2552-01	02.000-03.990	R|EL PASO	LP 375	:FROM POST 2 TO POST 4
2379	75/06	24:123	0104-04	34.000-36.000	R|JEFF DAVIS	SH 17	:FROM POST 34 TO POST 36
2382	76/02	24:123	0871-01	02.900-04.900	L|JEFF DAVIS	FM 505	:FROM 4 MI W 166 TO 6 MI.W 166
2395	75/06	24:189	0020-08	06.320-08.330	R|PRESIDIO	US 90	:FROM POST 34 TO POST 36
2400	76/02	24:189	1283-02	03.100-05.100	R|PRESIDIO	FM 2810	:FROM POST 4 TO POST 6

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
2413	75/06	25:023	0541-01	12.390-14.420	L	BRISCOE	SH 256	:FROM POST 14 TO POST 12
2426	75/10	25:023	0740-03	16.402-18.442	L	BRISCOE	FM 1065	:FROM POST 2 TO POST 0
2439	75/06	25:038	0381-03	01.990-03.940	L	CHILDRESS	SH 256	:FROM POST 4 TO POST 2
2442	75/06	25:038	1346-02	03.170-05.180	L	CHILDRESS	FM 1438	:FROM POST 4 TO POST 2
2455	76/02	04:091	0275-07	02.465-04.465	R	GRAY	IH 40	:FROM POST 122 TO POST 124
2468	75/10	25:065	0042-08	07.770-09.880	L	DONLEY	US 287	:FROM HALL CO.LINE TO POST 34
2471	75/06	25:065	2252-01	00.000-02.010	R	DONLEY	FM 2362	:FROM POST 0 TO POST 2
2484	75/06	25:138	0098-04	02.000-04.040	R	KNOX	SH 283	:FROM POST 2 TO POST 4
2497	76/02	25:138	0538-05	00.000-02.020	L	KNOX	FM 1756	:FROM POST 2 TO POST 0
2502	76/10	05:054	0131-03	13.000-15.000	L	CROSBY	US 82	:POST 14 TO POST 12
2515	75/06	05:078	0145-07	04.000-06.000	R	FLOYD	US 62+US70	:POST 22 TO 24
2528	75/06	05:096	0145-05	03.860-05.860	R	HALE	US 70	:POST 26 TO POST 28
2531	75/06	05:035	0226-06	08.000-10.000	R	CASTRO	US 385	:FROM POST 8 TO POST 10
2544	75/06	05:111	0052-06	04.000-06.000	R	HOCKLEY	US 84	:POST 4 TO POST 6
2557	76/10	:	-	00.000-00.000				
2560	75/06	05:152	0052-07	12.000-14.000	L	LUBBOCK	US 84	:FROM POST 14 TO POST 12
2573	75/06	05:152	0783-02	15.110-18.100	L	LUBBOCK	LP 289	:FROM FM2255 TO US62
2586	75/06	05:152	0783-01	05.530-08.660	L	LUBBOCK	LP 289	:FROM US87 TO SPUR 331
2599	75/06	05:152	0068-01	05.350-07.350	L	LUBBOCK	US 87	:FROM POST 26 TO POST 24
2604	75/06	05:152	0783-01	10.220-13.840	L	LUBBOCK	LP 289	:FROM SPUR 327 TO UNIV AVE

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
2617	75/06	05:152	0783-01	01.600-04.610	L	LUBBOCK	LP 289	:FROM FM835 TO FM40
2620	75/06	05:152	0131-01	19.590-21.590	L	LUBBOCK	US 62+82	:FROM POST 24 TO POST 22
2633	75/06	05:152	0068-01	00.750-01.800	R	LUBBOCK	US 87	:FROM 46TH ST TO TRAF CIRCLE
2646	75/06	05:086	0053-05	20.000-22.000	R	GARZA	US 84	:FROM POST 20 TO POST 22
2659	75/06	05:086	0053-05	28.000-30.000	R	GARZA	US 84	:FROM POST 28 TO POST 30
2662	75/06	05:153	0068-02	13.000-14.200	R	LYNN	US 87	:FROM POST 13 TO POST 14.2
2675	75/06	05:096	0067-05	10.000-12.000	R	HALE	US 87	:FROM POST 10 TO POST 12
2688	75/06	05:054	0131-05	23.990-25.990	R	CROSBY	US 82	:FROM POST 24 TO POST 26
2691	75/06	05:086	0053-04	00.000-02.000	R	GARZA	US 84	:FROM POST 0 TO POST 2
2706	75/06	05:009	0052-03	04.870-06.870	R	BAILEY	US 84	:FROM POST 16 TO POST 18
2719	75/06	05:009	0052-03	04.870-06.870	L	BAILEY	US 84	:FROM POST 18 TO POST 16
2722	75/06	05:009	0052-02	04.000-06.000	R	BAILEY	US 70+US84	: POST 4 TO POST 6
2735	76/02	05:009	0052-02	04.000-06.000	L	BAILEY	US 70+US84	:FROM POST 6 TO POST 4
2748	75/06	05:140	0052-05	20.000-22.000	R	LAMB	US 84	:FROM POST 20 TO POST 22
2751	75/06	05:140	0052-04	12.000-14.000	R	LAMB	US 84	:FROM POST 12 TO POST 14
2764	75/06	05:140	0052-04	12.000-14.000	L	LAMB	US 84	:FROM POST 14 TO POST 12
2777	76/10	05:152	0053-01	36.400-38.400	R	LUBBOCK	US 84	:FROM POST 36 TO POST 38
2780	76/06	:	-	. - .			DELETED	:WAS DUPICATE OF TEST-SECT 513
2793	75/06	05:152	0052-07	02.000-04.000	L	LUBBOCK	US 84	:FROM POST 4 TO POST 2
2808	75/06	05:185	0052-01	04.000-06.000	R	PARMER	US 70+US84	:POST 4 TO POST 6

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
2811	75/06	05:185	0052-01	04.000-06.000	L	PARMER	US 70+US84	:POST 6 TO POST 4
2824	76/10	25:138	0098-05	11.530-13.650	L	KNOX	SH 283	:FROM POST 20 TO POST 18
2837	75/06	25:135	0032-06	02.230-04.230	L	KING	US 83	:FROM POST 20 TO POST 18
2840	75/06	25:063	0132-02	03.910-05.990	R	DICKENS	US 82	:FROM POST 26 TO POST 28
2853	76/10	25:063	0131-06	08.000-10.000	L	DICKENS	US 82	:FROM POST 10 TO POST 8
2866	75/06	25:100	0043-02	11.000-13.000	R	HARDEMAN	US 287	:FROM POST 12 TO POST 14
2879	75/10	25:100	0043-04	20.000-22.030	L	HARDEMAN	US 287	:FROM POST 22 TO POST 20
2882	75/06	25:038	0043-01	06.440-08.440	L	CHILDRESS	US 287	:FROM POST 22 TO POST 20
2895	75/06	25:038	0381-01	03.000-05.000	L	CHILDRESS	US 62	:FROM POST 4 TO POST 2
2900	76/10	:	-	00.000-00.000				
2913	75/06	25:065	0042-07	20.640-22.730	R	DONLEY	US 287	:FROM POST 20 TO POST 22
2926	75/10	25:065	0042-08	03.540-05.670	L	DONLEY	US 287	:FROM POST 32 TO POST 30
2939	75/06	25:097	0042-09	08.160-10.200	R	HALL	US 287	:FROM POST 8 TO POST 10
2942	75/10	25:038	0042-12	09.900-11.903	R	CHILDRESS	US 287	:FROM POST 10 TO POST 12
2955	75/06	25:038	0042-12	01.920-03.910	R	CHILDRESS	US 287	:FROM POST 2 TO POST 4
2968	76/02	25:097	0042-09	02.760-04.180	R	HALL	US 287	:FROM MEMPHIS CL TO POST 4
2971	75/06	25:138	0133-03	00.410-02.400	L	KNOX	US 82	:FROM POST 14 TO POST 12
2984	75/06	25:135	0133-01	13.750-15.730	L	KING	US 82	: FROM POST 16 TO POST 14
2997	75/06	25:135	0132-03	00.000-01.950	R	KING	US 82	:FROM POST 0 TO POST 2
3003	75/06	25:135	0032-05	05.910-07.870	L	KING	US 83	:FROM POST 8 TO POST 6

Table A-1. Continued

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SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
3016	75/06	25:135	0032-05	09.800-11.790	L	KING	US 83	:FROM POST 12 TO POST 10
3029	76/10	25:063	0131-06	08.000-10.000	R	DICKENS	US 82	:FROM POST 8 TO POST 10
3032	75/06	25:173	0105-05	09.030-11.050	R	MOTLEY	SH 70	:FROM POST 32 TO POST 34
3045	75/06	25:173	0105-04	19.380-21.290	L	MOTLEY	SH 70	:FROM POST 22 TO POST 20
3058	75/06	25:173	0105-04	01.990-03.870	L	MOTLEY	SH 70	:FROM POST 4 TO POST 2
3061	75/06	25:173	0146-01	16.440-18.510	L	MOTLEY	US 62+US70	:POST 18 TO POST 16
3074	75/06	25:173	0145-08	10.200-12.270	R	MOTLEY	US 62+US70	:FROM POST 10 TO POST 12
3087	75/06	25:051	0032-03	13.730-14.750	R	COTTLE	US 62+US83	:FROM FM3256 TO FM2998
3090	75/06	25:051	0032-02	03.600-06.060	R	COTTLE	US 62+US83	:FROM POST 4 TO FM1440
3105	75/06	25:079	0146-04	08.190-10.190	L	FOARD	US 70	:FROM POST 10 TO POST 8
3118	75/10	25:097	0105-03	12.900-14.900	L	HALL	SH 70	:FROM POST 14 TO POST 12
3121	75/06	25:023	0303-03	18.090-20.090	R	BRISCOE	SH 86	:FROM POST 18 TO POST 20
3134	75/06	25:023	0303-04	23.900-25.920	L	BRISCOE	SH 86	:FROM POST 26 TO POST 24
3147	75/06	25:065	0042-06	08.180-10.230	L	DONLEY	US 287	:FROM POST 10 TO POST 8
3150	75/06	25:065	0310-01	22.350-24.400	L	DONLEY	SH 70	:FROM POST 14 TO POST 12
3163	75/06	25:065	0310-01	18.240-20.280	L	DONLEY	SH 70	:FROM POST 10 TO POST 8
3176	76/10	17:166	0204-08	10.890-12.720	L	MILAM	US 79	:FROM POST 12 TO POST 10
3189	76/04	17:166	0204-05	00.000-01.880	L	MILAM	US 79	:FROM P.34 TO ROCKY CREEK
3192	75/06	17:166	0210-01	02.120-04.050	L	MILAM	US 77	:FROM POST 20 TO POST 18
3207	75/06	17:166	0186-01	03.660-05.660	L	MILAM	SH 36	:FROM POST 16 TO POST 14

Table A-1. Continued

4/1/1977

SIDNO	DATE	DIS:CO.	CNTL-SEC	MILE-POINTS	LN	COUNTY-NAME	HIGHWAY	:MILE-POST DESCRIPTION
3210	76/02	17:026	0186-02	01.000-02.000	R	BURLESON	SH 36	:FROM POST 1 TO POST 2
3223	75/11	17:026	0186-03	08.380-10.410	L	BURLESON	SH 36	:FROM POST 20 TO POST 18
3236	75/06	17:239	0114-09	00.000-02.000	R	WASHINGTON	US 290	:FROM POST 0 TO POST 2
3249	76/04	17:239	0114-09	21.064-23.064	R	WASHINGTON	US 290	:FROM POST 12 TO POST 14
3252	76/10	17:021	2851-01	07.676-08.116	L	BRAZOS	FM 2818	:FROM FM2513 TO FM 1688
3265	76/02	17:094	0315-04	38.830-39.495	R	GRIMES	SH 105	:0.7 MI NE TO NAVASOTA R.BR
3278	76/02	08:221	0407-06	03.367-03.667	R	TAYLOR	US 277	:2.3 MI. SW OF US 83
3281	76/02	13:062	0269-06	09.967-11.987	R	DEWITT	US 77A	:FROM POST 10 TO POST 12
3294	76/02	13:062	0143-08	07.919-09.879	R	DEWITT	US 87	:FROM POST 8 TO POST 10
3309	76/02	13:062	0143-09	25.754-27.154	R	DEWITT	US 87	:FROM POST 26 TO 1.4 MI.SO.
3312	76/02	13:235	0432-02	06.608-07.601	R	VICTORIA	FM 404	:FROM ODEM ST. TO MARSHALL ST
3325	76/02	15:095	0535-01	17.750-19.750	L	GUADALUPE	IH 10	:FROM POST 614 TO POST 612
3338	76/02	15:095	0535-02	26.710-28.710	L	GUADALUPE	IH 10	:FROM POST 623 TO POST 621
3341	76/02	15:142	0017-08	13.261-15.261	R	LASALLE	IH 35	:FROM POST 80 TO POST 82
3354	76/02	15:163	0017-05	07.725-09.725	R	MEDINA	IH 35	:FROM POST 126 TO POST 128
3367	76/02	15:163	0017-05	00.660-02.660	R	MEDINA	IH 35	:FROM POST 119 TO POST 121
3370	76/02	15:083	0017-06	32.400-34.400	R	FRIO	IH 35	:FROM POST 115 TO POST 117

APPENDIX B. STATISTICAL SUMMARIES AND DISCUSSION OF DISTRICT 21 MASS INVENTORY OF DATA

Introduction

This appendix contains tables and figures which statistically summarize much of the mass inventory of data collected in District 21. Presentation and subsequent discussion of these data can be useful in the planning of future, similar data collection efforts.

District 21 was the first SDHPT district to undertake the effort of collecting and organizing a mass inventory of performance related pavement data. The first inventory (survey) was conducted primarily in 1974 although some data collection began as early as 1972. Subsequently, additional inventories were obtained. TTI worked closely with the personnel in District 21 in all phases of the data collection and organization. To assist with this work, TTI developed computer programs which processed and displayed summaries of the collected information in Study 151. Background information on the computer programs which were developed can be found in References B-1 and B-2.

It is important to note that the data collection effort in District 21 was at least partially experimental because from its inception, improvements and refinements were expected once the results of the inventories were reviewed. The objective of the following discussion is to review a few possible weaknesses and resulting improvements that can be made in the inventory procedure.

It is also important to note briefly the state-of-the-art at the time of the District 21 inventory. For example, the Mays Ride Meter was used to obtain Serviceability Index data on virtually all pavements in this district. Although the Mays Ride Meter was not new at the time, its use by the SDHPT and TTI was. Little experience was available on conducting such a large survey. Additionally, the visual rating procedure which produces Pavement, Shoulder, Roadside, Drainage, and Traffic Services Rating Scores was only developed use in Texas during the 1973-1974 time frame. The Surface Curvature Index which is obtained by use of the Dynaflect deflection device was initially developed during the 1960's. But never had such a large amount of this kind of data been obtained in the state of Texas. Fortunately, the skid data collection system was originally intended to cover large mileages of highways with the result being this specific data collection effort was relatively straightforward.

This appendix contains three unique data groupings which will be discussed separately. The first data grouping is a districtwide presentation of all data observed in District 21 in 1974 and 1975. The second data grouping is a collection of the mean values of the different data types obtained from two-mile highway segments. The third and last data grouping is composed of all data points obtained for Shoulder, Roadside, Drainage, and Traffic Services Rating Scores. Contained in each grouping will be tables consisting of the mean, standard deviation, and mileage evaluated for each highway type, year, and data type. Also in each grouping are figures containing histograms for various highway, year, and data types.

<u>Data Grouping of All Serviceability Index, Surface Curvature Index, Skid Number, and Pavement Rating Score</u>

Table B-1, Figures 12 through 21 (in the main body of this report), and Figures B-1 through B-8 contain summaries of all Serviceability Index, Surface Curvature Index, Skid Number, and Pavement Rating Score data obtained. Tables B-2 through B-11 contain similar data for each of the ten counties in the district. The tabular presentations are made for IH, US & SH, and FM highways for both 1974 and 1975. The figures (histograms) do not include the IH highway type becuase the total number of data points were relatively small.

The number of data points shown on each figure represents the total number of points used to generate the histograms. One Serviceability Index data point was obtained ever 0.2 mile, a standard Mays Ride Meter distance. The distance interval for skid data ranged from approximately 0.1 to 0.5 mile. A preselected interval was not used in obtaining a Pavement Rating Scores. Instead, the raters collecting visual condition information stopped to make observations of pavement distress and adjacent roadside conditions wherever the following changes were observed (B-1):

1. County line,
2. Control and section limits,
3. Limits of past or present construction projects,
4. Limits of seal or overlay projects,
5. Changes in roadway geometrics,
6. At maintenance section boundaries,
7. At certain roadway intersections where a single roadway is designated as more than one route, and
8. Significant changes in the pavement, shoulder, roadside or traffic services.

The number of data points shown on each figure for Pavement Rating Score are much larger than the number of actual observations made by the raters.

This anomaly is due to the procedure used to summarize the data for the uneven lengths of highway segments encountered. The population mean is denoted on each figure by an "X" on the abscissa.

The chi-square test was used to check the normality of the data distributions shown in Figures B-1 through B-8 in a treatment similar to those in Fiqures 12 through 21 in the main body of this report. This is important to know if statistical inferences (decisions) are used which require an assumption of data normality. The null hypothesis (the statement) tested was that the distribution conforms to a normal distribution. The levels of significance used ranged between 0.05 and 0.01. A level of significance of 0.05 indicates that 5 out of every 100 distributions tested for normality will be incorrectly classified as being nonnormal. Similarly, a level of significance of 0.01 indicates than only one out of every 100 distributions tested will be incorrectly identified. Thus, the chi-square test is unusual in that it becomes increasing more difficult to detect a nonnormal distribution as the level of significance decreases.

Serviceability Index data for US & SH and FM highways, Surface Curvature Index and Skid Number data for FM highways tests to be normal at the 0.05 level of significance. Three of the remaining four plots (Skid Number data for US & SH highways and Pavement Rating Score data for US & SH and FM highways) test to be normal at a level of significance of 0.01. This indicates that these data are only approximately normally distributed but are adequate for use in making inferences which require an assumption of normality. Surface Curvature Index data for US & SH highways does not test to be normally distributed even at a level of significance of 0.005.

The information contained in Tables B-1 through B-11. Figures B-1 through B-8 and Figures 12 through 21 can be compared directly to observe any year-to-year differences between the highway and data types. Referring to Table B-1 (districtwide summary), the comparisons between 1974 and 1975 data types are similar in eight out of twelve possible comparisons. The four exceptions are Serviceability Index data for IH highways and Pavement Rating Score for IH, US & SH, and FM highways.

In 1974 the observed Serviceability Index mean for 38 miles of IH highway was 3.3 and in 1975 it was 3.6. Since roads do not have a tendency to become smoother with time, the observed difference of 0.3 SI units is assumed to be due to differences between the Mays Ride Meter units or the calibration of the units.

The visual condition surveys which produced the 1974 and 1975 Pavement Rating Scores were obtained independently with no known data overlap between the two years. The Pavement Rating Score for 1975 for IH highways is 8 points higher than 1974, 4 points lower for US & SH highways, and 3 points lower for FM highways.

The data trends observed in Table B-1 are also found in Tables B-2 through B-11 for the individual counties. Of 76 possible data comparisons between the two years, eighteen are considered to be different and fifteen of these are the Pavement Rating Score. The Serviceability Index data accounted for two more of the observed differences and Skid Number the remaining one. In all fifteen of the Pavement Rating Score differences, all scores decreased from 1974 to 1975 with the average decrease being approximately seven Pavement Rating Score points. At least three alteratives exist which can explain these year-to-year districtwide and county differences. One alternative is that the actual, observed surface distress manifestations did change from 1974 and 1975. The second alterative is that rater evaluation error (not being able to consistently evaluate a given segment of highway from one year to another) accounts for these differences. A third alternative is that the noted differences are a result of the two tendencies to work together, i.e., the roads deterioated somewhat and the raters, with one year's experience behind them, became more discriminating. There is no way at present to determine the extent of change in the pavement condition and the degree of error in the rater evaluation; but it is reasonable to assume that the third alternative is the most likely. The obvious reasons for a change in rater evaluation are that the visual condition evaluation procedure was still relatively new and the District 21 SDHPT personnel were the first to conduct a districtwide survey. Additionally and possibly more importantly, the evaluation procedure does <u>not</u> call for evaluation locations (stops) to be made at the same place along the roadway each year. This fact alone could easily account for the observed differences and should be considered in future surveys.

Table B-1. District 21 Mass Inventory Statistical Summary

Highway Type	Year	Date Type	Mileage	Mean	Standard Deviation
IH	1974	SI	38	3.3	0.6
		SCI	0	----	----
		SN	33	0.35	0.06
		PRS	38	83	8
	1975	SI	37	3.6	0.5
		SCI	38	0.2	0.1
		SN	39	0.38	0.06
		PRS	37	91	6
US & SH	1974	SI	1094	3.2	0.7
		SCI	373	0.7	0.5
		SN	1013	0.32	0.10
		PRS	1071	82	13
	1975	SI	1070	3.3	0.7
		SCI	701	0.6	0.4
		SN	1123	0.34	0.10
		PRS	1084	78	14
FM	1974	SI	1376	2.6	0.7
		SCI	447	0.8	0.4
		SN	1232	0.34	0.09
		PRS	1438	78	16
	1975	SI	1467	2.6	0.8
		SCI	1176	0.8	0.4
		SN	1537	0.35	0.09
		PRS	1475	75	16

Table B-2. District 21 Mass Inventory Statistical Summary for Brooks County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	67	3.2	0.5
		SCI	34	0.9	0.3
		SN	64	0.39	0.09
		PRS	69	77	14
	1975	SI	68	3.1	0.6
		SCI	48	0.8	0.3
		SN	73	0.36	0.08
		PRS	68	71	15
FM	1974	SI	46	2.7	0.6
		SCI	22	0.7	0.4
		SN	43	0.41	0.10
		PRS	49	85	6
	1975	SI	49	2.7	0.7
		SCI	44	0.7	0.3
		SN	56	0.36	0.08
		PRS	48	77	7

Table B-3. District 21 Mass Inventory Statistical Summary for Cameron County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	208	3.3	0.7
		SCI	34	0.6	0.5
		SN	176	0.30	0.07
		PRS	193	75	14
	1975	SI	167	3.4	0.8
		SCI	66	0.5	0.4
		SN	198	0.30	0.07
		PRS	179	74	20
FM	1974	SI	297	2.6	0.7
		SCI	70	0.8	0.5
		SN	286	0.32	0.08
		PRS	317	70	17
	1975	SI	324	2.7	0.8
		SCI	213	0.8	0.5
		SN	310	0.3	0.07
		PRS	323	71	17

Table B-4. District 21 Mass Inventory Statistical Summary for Duval County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	193	3.2	0.7
		SCI	69	0.9	0.5
		SN	180	0.31	0.08
		PRS	186	84	10
	1975	SI	211	3.1	0.8
		SCI	168	0.8	0.4
		SN	197	0.38	0.12
		PRS	202	81	11
FM	1974	SI	98	2.5	0.6
		SCI	10	1.1	0.3
		SN	91	0.39	0.12
		PRS	101	86	11
	1975	SI	96	2.6	0.6
		SCI	78	0.6	0.3
		SN	104	0.40	0.13
		PRS	97	81	12

Table B-5. District 21 Mass Inventory Statistical Summary for Hidalgo County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	216	3.1	0.7
		SCI	31	0.5	0.4
		SN	199	0.29	0.08
		PRS	178	79	15
	1975	SI	204	3.4	0.8
		SCI	112	0.5	0.3
		SN	227	0.29	0.06
		PRS	217	78	13
FM	1974	SI	399	2.8	0.7
		SCI	126	0.7	0.4
		SN	371	0.31	0.06
		PRS	433	72	17
	1975	SI	420	2.8	0.8
		SCI	348	0.8	0.4
		SN	445	0.30	0.06
		PRS	431	72	18

Table B-6. District 21 Mass Inventory Statistical Summary for Jim Hogg County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	49	3.4	0.5
		SCI	37	0.6	0.3
		SN	41	0.40	0.12
		PRS	52	89	6
	1975	SI	51	3.4	0.5
		SCI	41	0.6	0.3
		SN	54	0.39	0.12
		PRS	52	85	8
FM	1974	SI	91	2.1	0.7
		SCI	40	0.9	0.3
		SN	62	0.37	0.09
		PRS	95	85	9
	1975	SI	92	2.2	0.7
		SCI	76	0.7	0.3
		SN	95	0.45	0.11
		PRS	92	75	13

Table B-7. District 21 Mass Inventory Statistical Summary for Kenedy County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	47	3.5	0.4
		SCI	0	----	----
		SN	43	0.46	0.06
		PRS	47	92	2
	1975	SI	45	3.6	0.3
		SCI	45	0.5	0.2
		SN	46	0.42	0.06
		PRS	47	82	6
FM	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----

Table B-8. District 21 Mass Inventory Statistical Summary for Starr County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	48	3.4	0.5
		SCI	47	0.6	0.7
		SN	42	0.35	0.05
		PRS	50	86	8
	1975	SI	49	3.4	0.6
		SCI	47	0.6	0.8
		SN	50	0.26	0.08
		PRS	43	78	12
FM	1974	SI	168	2.2	0.7
		SCI	66	0.8	0.3
		SN	137	0.37	0.07
		PRS	175	86	7
	1975	SI	171	2.3	0.9
		SCI	140	0.7	0.3
		SN	175	0.36	0.07
		PRS	172	81	8

Table B-9. District 21 Mass Inventory Statistical Summary for Webb County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	38	3.3	0.6
		SCI	0	----	----
		SN	33	0.35	0.06
		PRS	38	83	8
	1975	SI	37	3.6	0.5
		SCI	38	0.2	0.1
		SN	39	0.38	0.06
		PRS	37	91	6
US & SH	1974	SI	129	3.0	0.5
		SCI	52	0.6	0.4
		SN	129	0.37	0.13
		PRS	141	85	9
	1975	SI	141	3.1	0.5
		SCI	106	0.5	0.4
		SN	148	0.40	0.12
		PRS	143	76	12
FM	1974	SI	122	2.6	0.7
		SCI	61	0.9	0.5
		SN	106	0.47	0.13
		PRS	99	90	9
	1975	SI	126	2.8	0.6
		SCI	109	0.6	0.3
		SN	134	0.44	0.10
		PRS	125	80	12

Table B-10. District 21 Mass Inventory Statistical Summary for Willacy County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	56	3.2	0.7
		SCI	14	0.9	0.3
		SN	62	0.30	0.06
		PRS	77	79	11
	1975	SI	53	3.7	0.5
		SCI	14	0.7	0.3
		SN	48	0.29	0.03
		PRS	54	76	9
FM	1974	SI	130	2.8	0.5
		SCI	34	1.0	0.5
		SN	113	0.32	0.08
		PRS	142	84	9
	1975	SI	156	2.9	0.6
		SCI	140	1.0	0.5
		SN	178	0.33	0.08
		PRS	154	76	11

Table B-11. District 21 Mass Inventory Statistical Summary for Zapata County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
	1975	SI	0	----	----
		SCI	0	----	----
		SN	0	----	----
		PRS	0	----	----
US & SH	1974	SI	79	3.1	0.5
		SCI	54	0.7	0.3
		SN	76	0.32	0.05
		PRS	77	94	4
	1975	SI	80	3.1	0.6
		SCI	55	0.7	0.3
		SN	83	0.34	0.06
		PRS	80	89	6
FM	1974	SI	24	2.3	0.7
		SCI	20	1.2	0.4
		SN	23	0.39	0.10
		PRS	27	89	8
	1975	SI	33	2.3	0.7
		SCI	28	1.0	0.5
		SN	39	0.38	0.08
		PRS	33	75	25

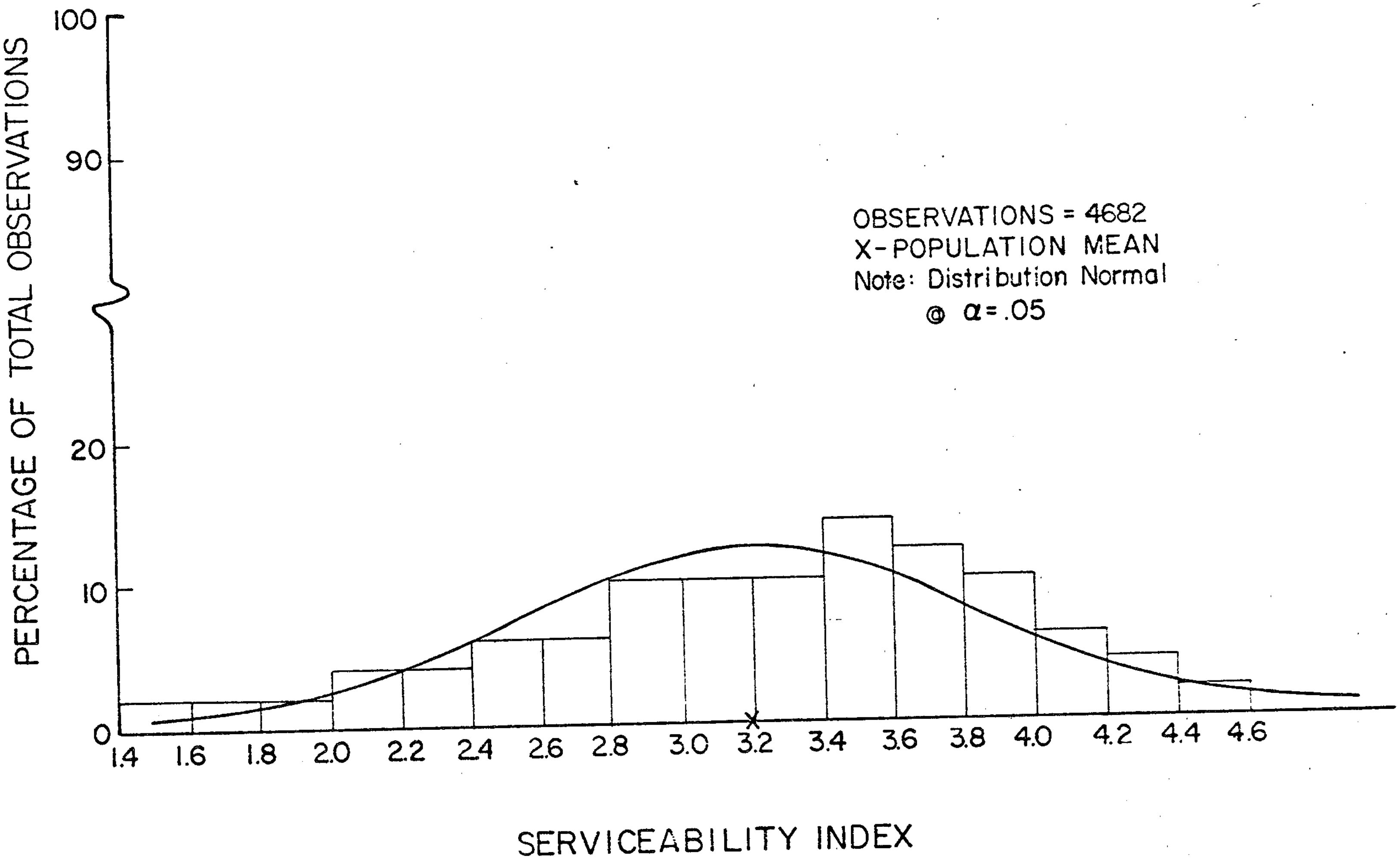


Figure B-1. District 21 Serviceability Index Mass Inventory Histogram for US & SH Highways --- 1974.

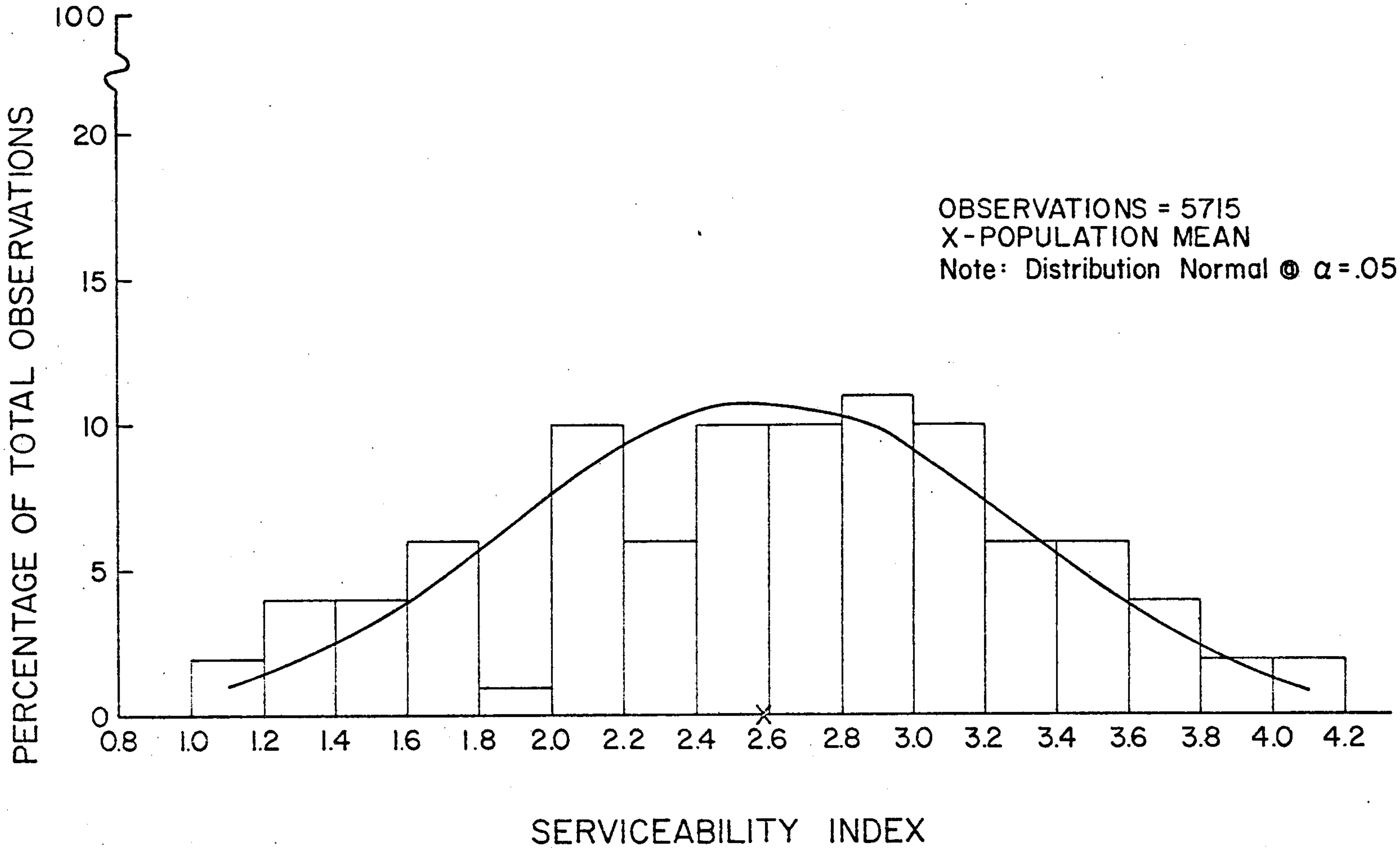


Figure B-2. District 21 Serviceability Index Mass Inventory Histogram for FM Highways --- 1974.

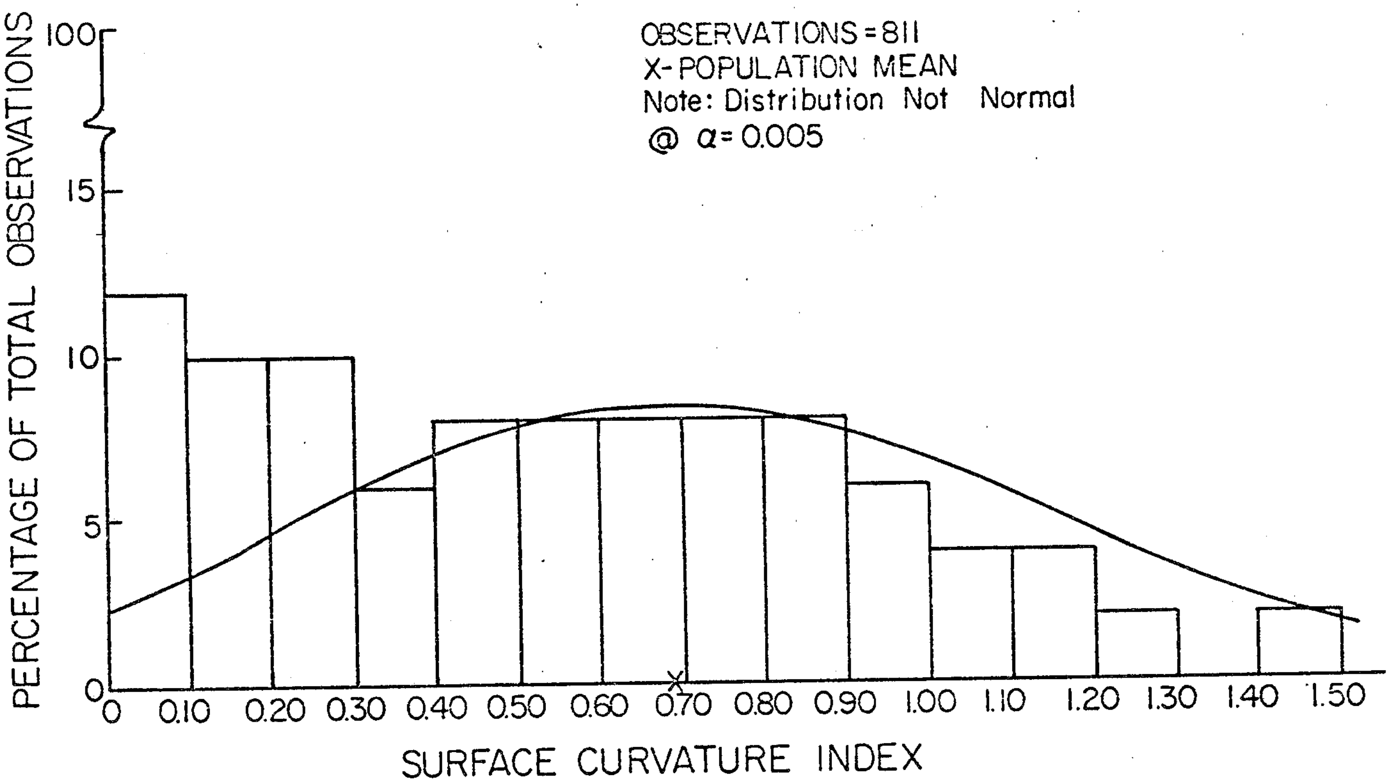


Figure B-3. District 21 Surface Curvature Index Mass Inventory Histogram for US & SH Highways --- 1974.

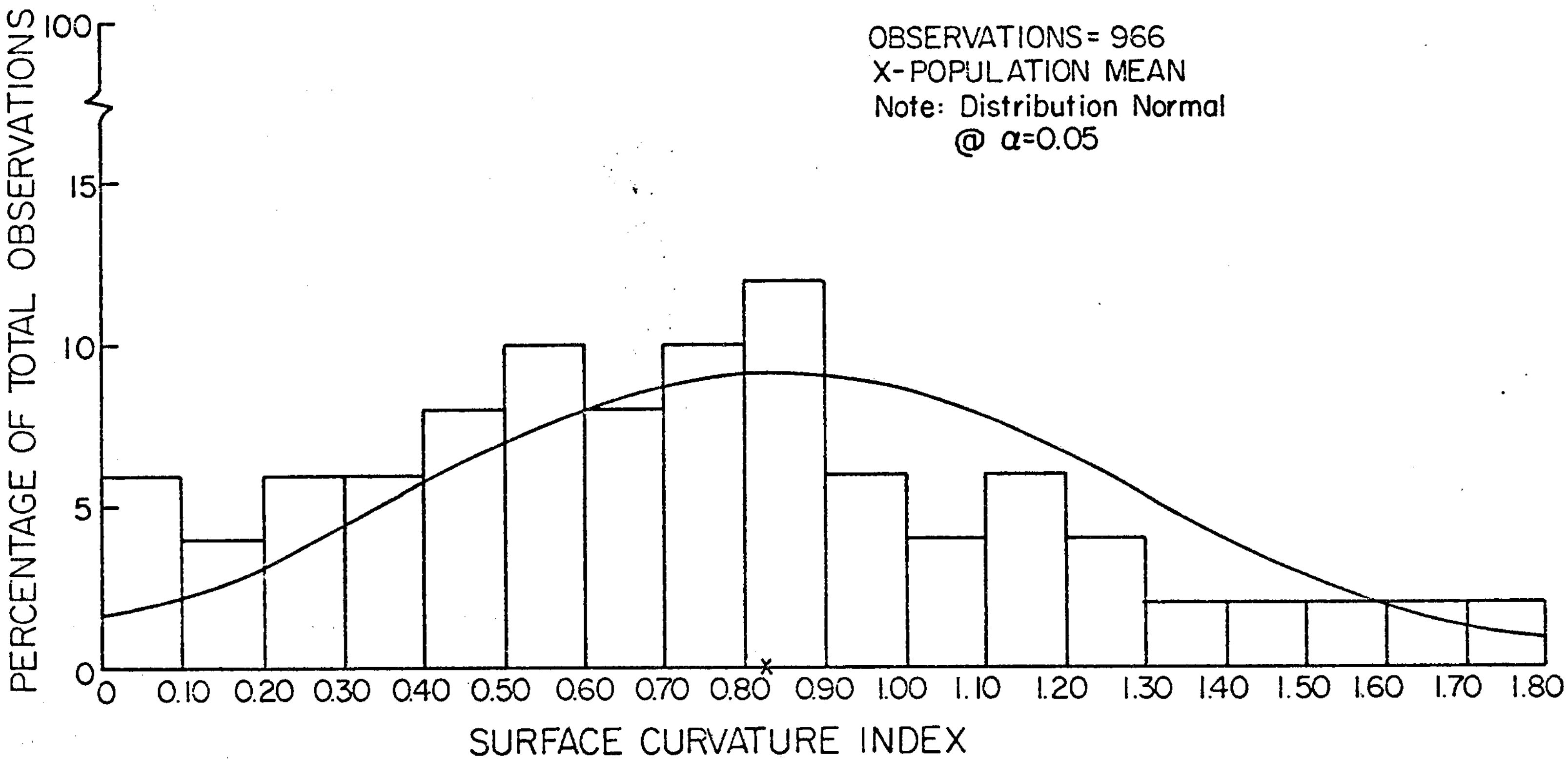


Figure B-4. District 21 Surface Curvature Index Mass Inventory Histogram for FM Highways --- 1974.

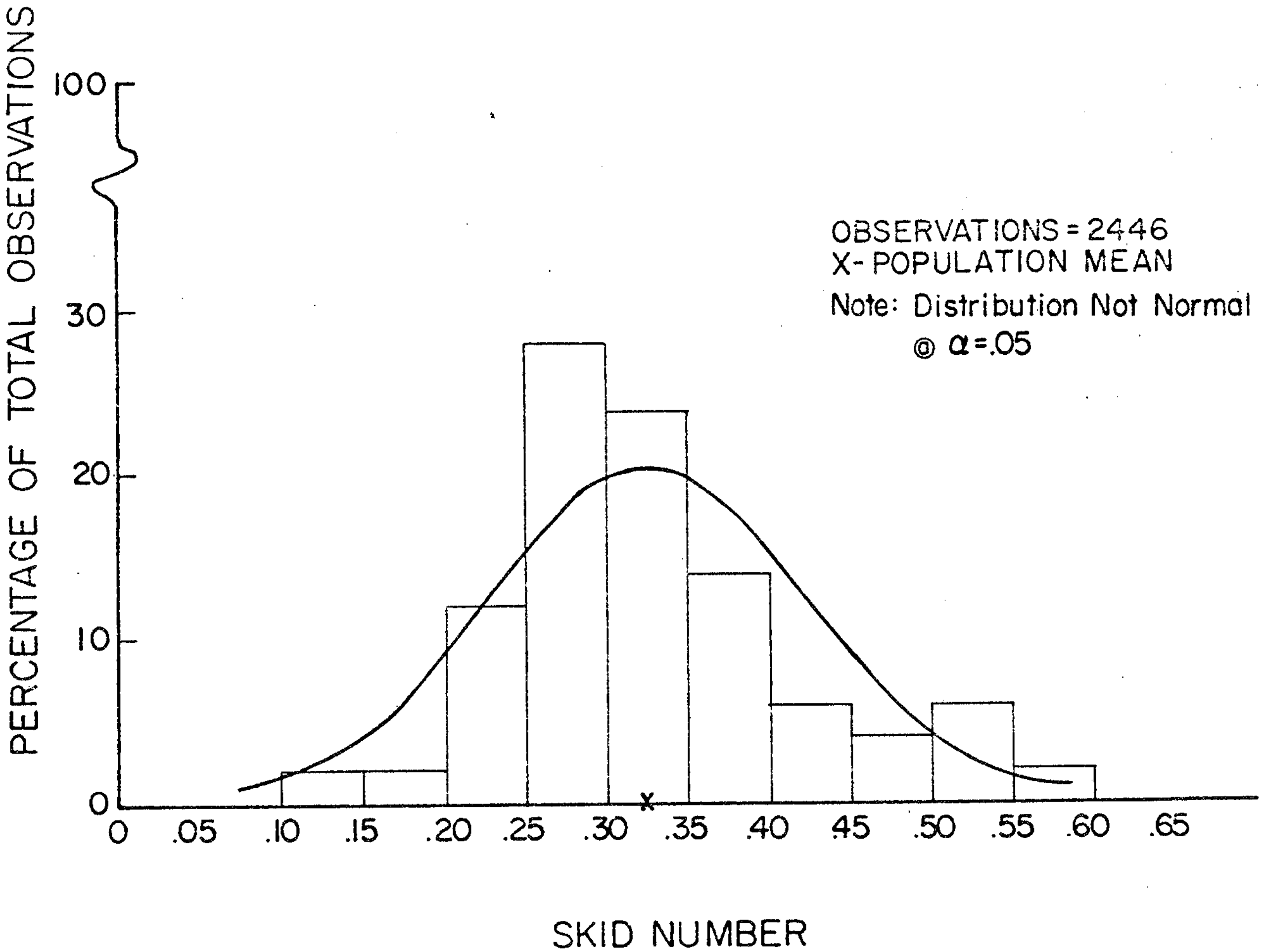


Figure B-5. District 21 Skid Number Mass Inventory Histogram for US & SH Highways --- 1974.

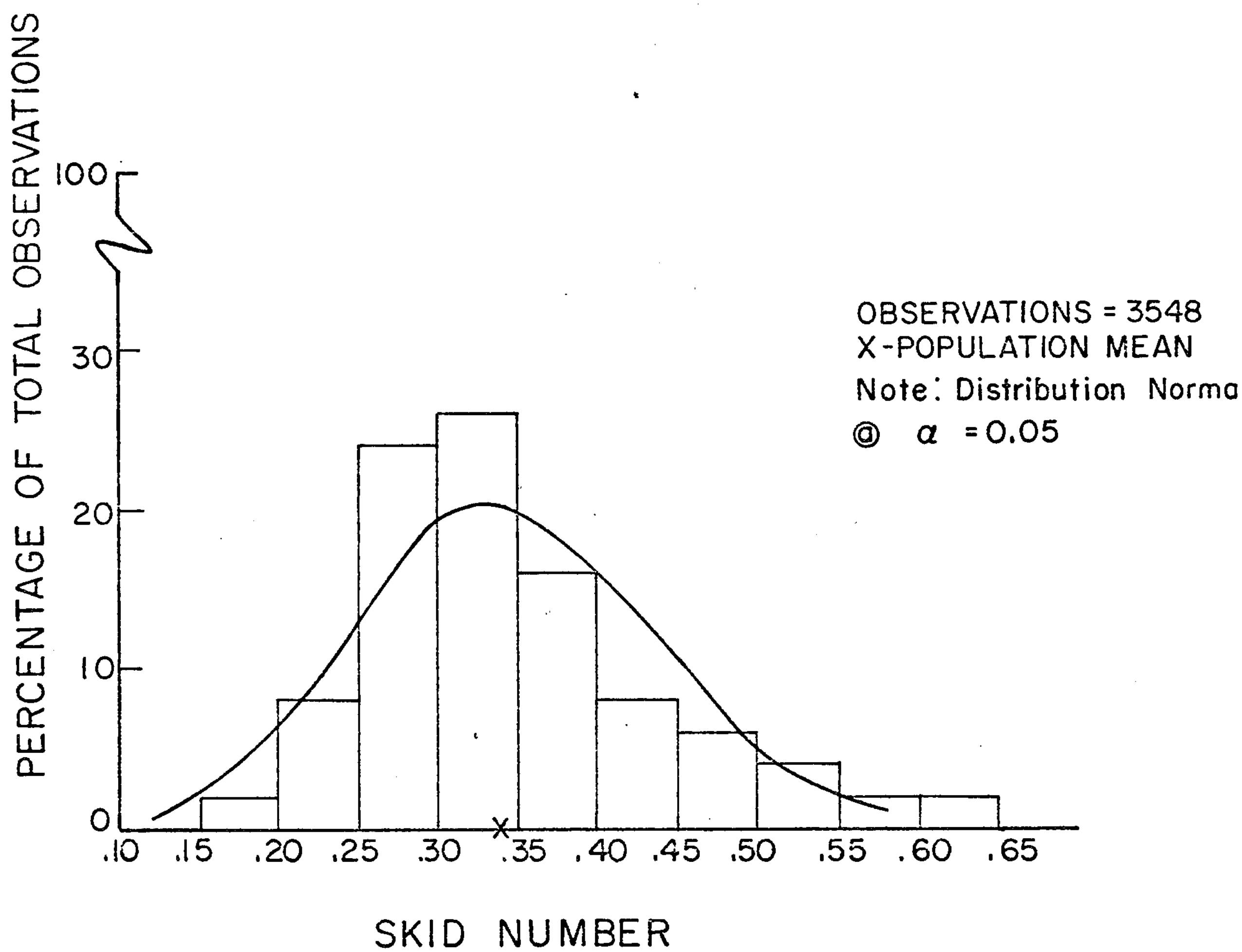


Figure B-6. District 21 Skid Number Mass Inventory Histogram for FM Highways---1974.

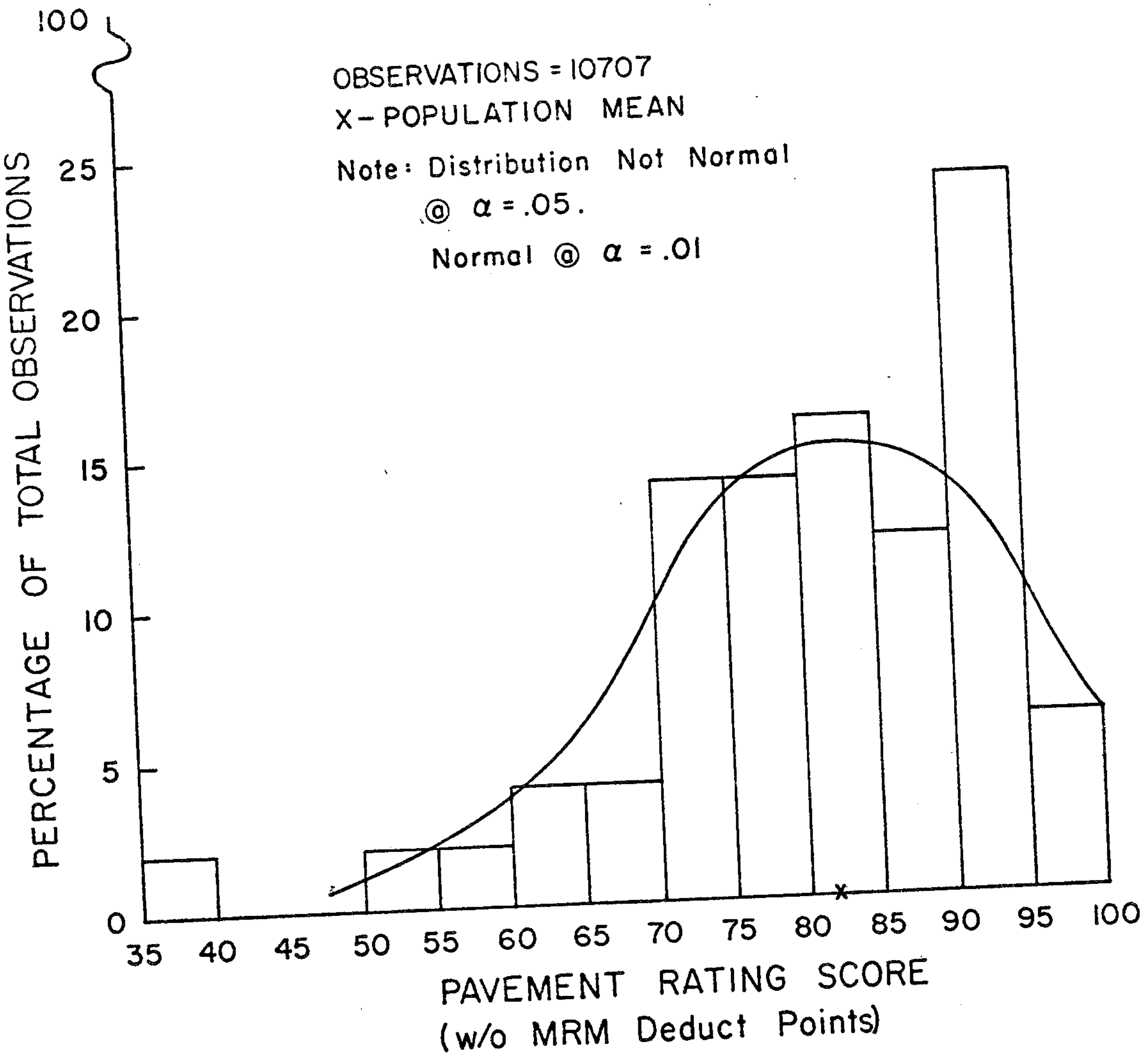


Figure B-7. District 21 Pavement Rating Score Mass Inventory Histogram for US & SH Highways---1974.

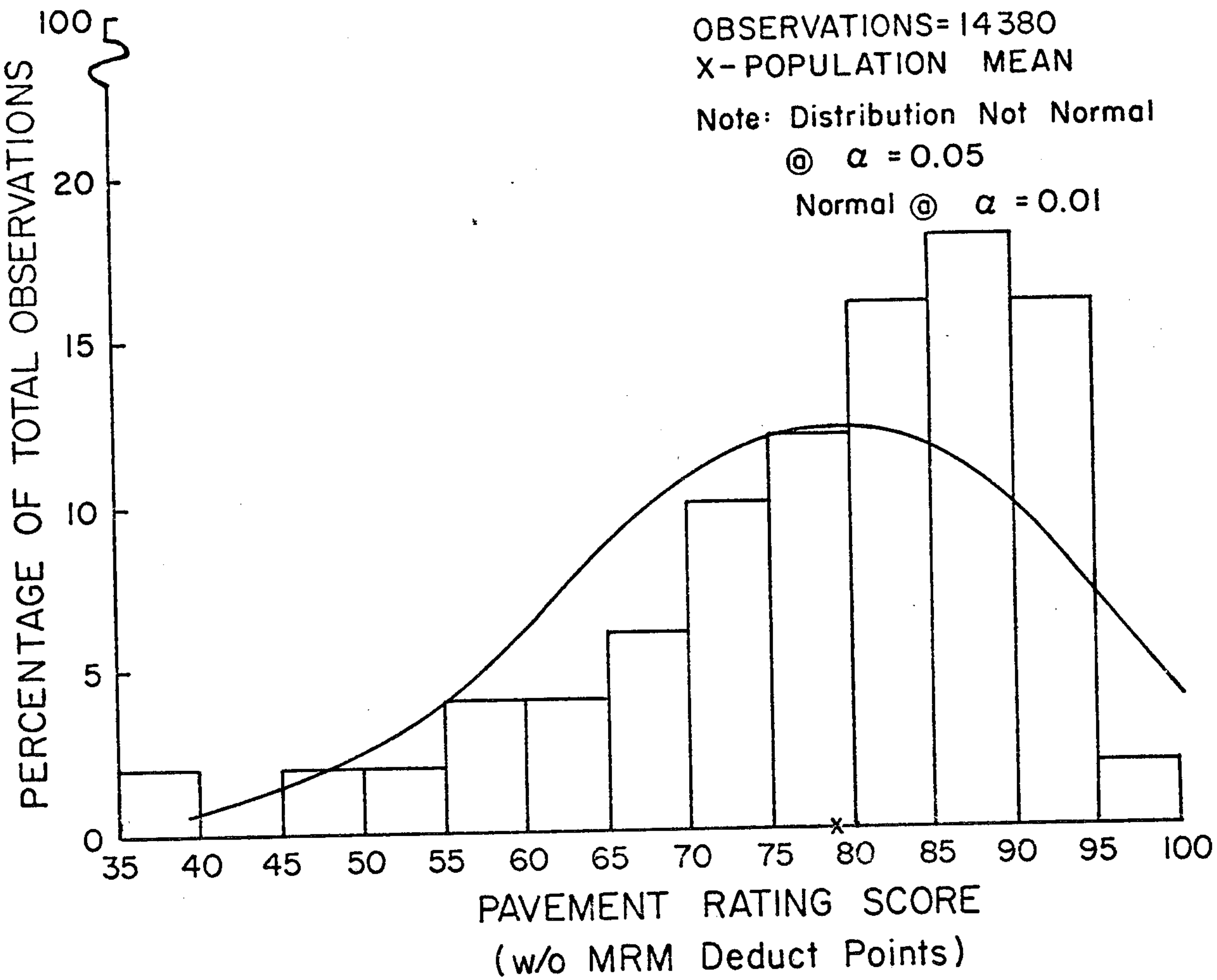


Figure B-8. District 21 Pavement Rating Score Mass Inventory Histogram for FM Highways---1974.

Grouping of Means of Two-Mile Highway Segments for Serviceability Index, Surface Curvature Index, Skid Number, and Pavement Rating Score

The data contained in Table B-12 and Figures B-9 through B-16 represent a statistical summary of the means of four data types obtained from two-mile pavement segments in District 21. The data in Table B-12 were generated using both 1974 and 1975 data but the figures present only 1975 data since the 1974 data were not necessary for this discussion. The term "weighted means" shown on the x-axis of the figures indicates that the data mean for each of the two-mile pavement segments was multiplied by the number of data points in that segment with the results used to generate the histograms and tabular summary statistics.

The two-mile segments from which the means were obtained are described in the main body of this report. Basically, the complete highway system for each highway type was artifically divided into two-mile increments by use of a FORTRAN computer program especially developed for this research. The data contained in each of these two-mile segments were summarized into the number of data points, mean, and standard deviation. The means for each of the two-mile segments were then used to generate the data contained in the table and figures.

A comparison of Figures B-9 through B-16 with Figures 12 through 21 from the main body of the report is of interest. This comparison will show what potential effect will be incurred by sampling data grouped within two-mile segments (as was done in the sampling study) as opposed to sampling individual data points (as was done in the District survey). If comparable histograms are significantly different, then there may be differences in the accuracy of the two sampling procedures.

A comparison of Figures B-9 through B-12 for the Serviceability and Surface Curvature Indices with similar data types in Figures 12 through 15 reveals that the range of the two-mile segment histograms is slightly less than those where all of the data points are used. The overall means are the same but the data are more highly grouped for the two-mile segment plots. It is reasonable to expect this to occur. Generally, it can be stated that the two kinds of histograms are, in fact, not significantly different.

Figures B-13 and B-14 when compared to Figures 16 and 17 for Skid Number data reveal even fewer differences for the two kinds of histograms. Figures B-15 and B-16 when compared to Figures 20 and 21 for Pavement Rating Score data reveal virtually identical plots.

A comparison of Table B-12 to Table B-1 shows that the mean values for the four data types are identical (as would be expected) but the standard deviations presented in Table B-12 were computed on the same basis used to generate the means and thus are much smaller than those shown for all data points in Table B-1.

In summary, the two kinds of histograms and data means are quite similar for the District 21 data types irrespective of whether the means of the two-mile highway segments are plotted or whether individual data points are used.

Table B-12. District 21 Mass Inventory Statistical Summary for Two-Mile Highway Segments

Highway Type	Year	Data Type	Mean	Standard Deviation
IH	1974	SI	3.2	0.4
		SCI	----	----
		SN	0.35	0.05
		PRS	83	1
	1975	SI	3.6	0.4
		SCI	0.2	0.1
		SN	0.38	0.03
		PRS	91	3
US & SH	1974	SI	3.2	0.3
		SCI	0.7	0.3
		SN	0.32	0.04
		PRS	82	4
	1975	SI	3.3	0.4
		SCI	0.6	0.3
		SN	0.34	0.04
		PRS	78	4
FM	1974	SI	2.6	0.3
		SCI	0.8	0.3
		SN	0.34	0.04
		PRS	78	5
	1975	SI	2.6	0.4
		SCI	0.8	0.3
		SN	0.35	0.04
		PRS	75	5

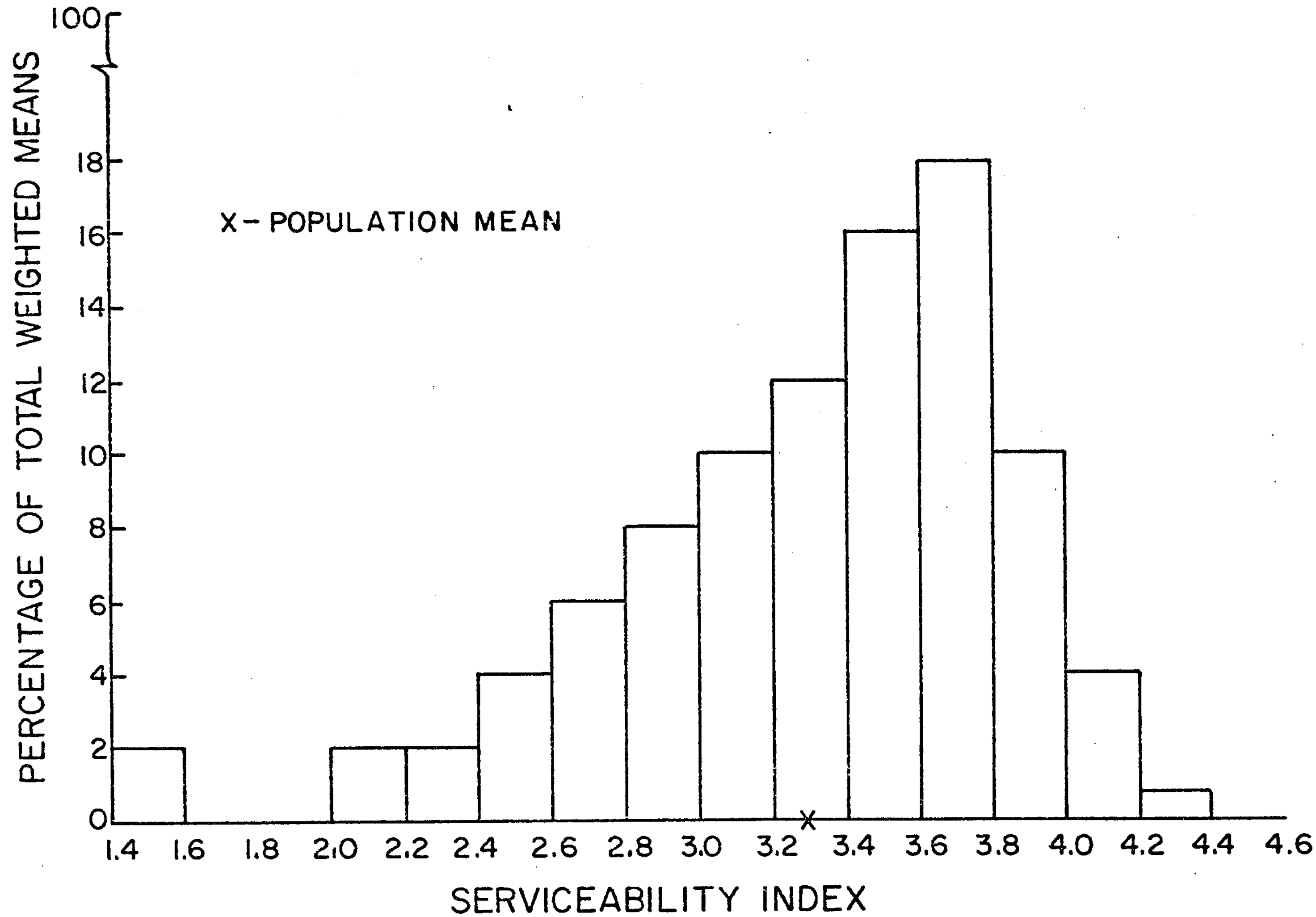


Figure B-9. District 21 Serviceability Index Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for US & SH Highways---1975.

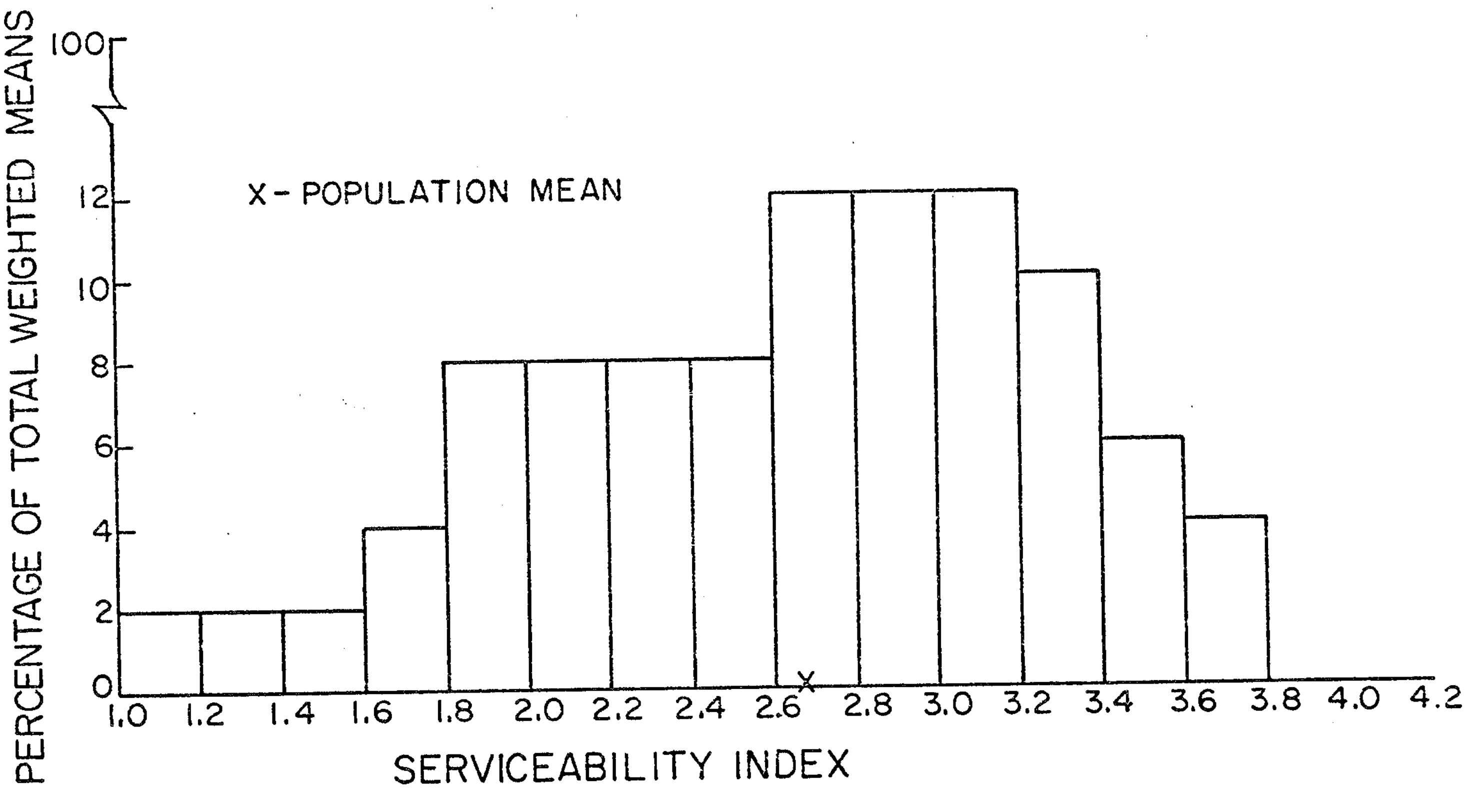


Figure B-10. District 21 Serviceability Index Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for FM Highways---1975.

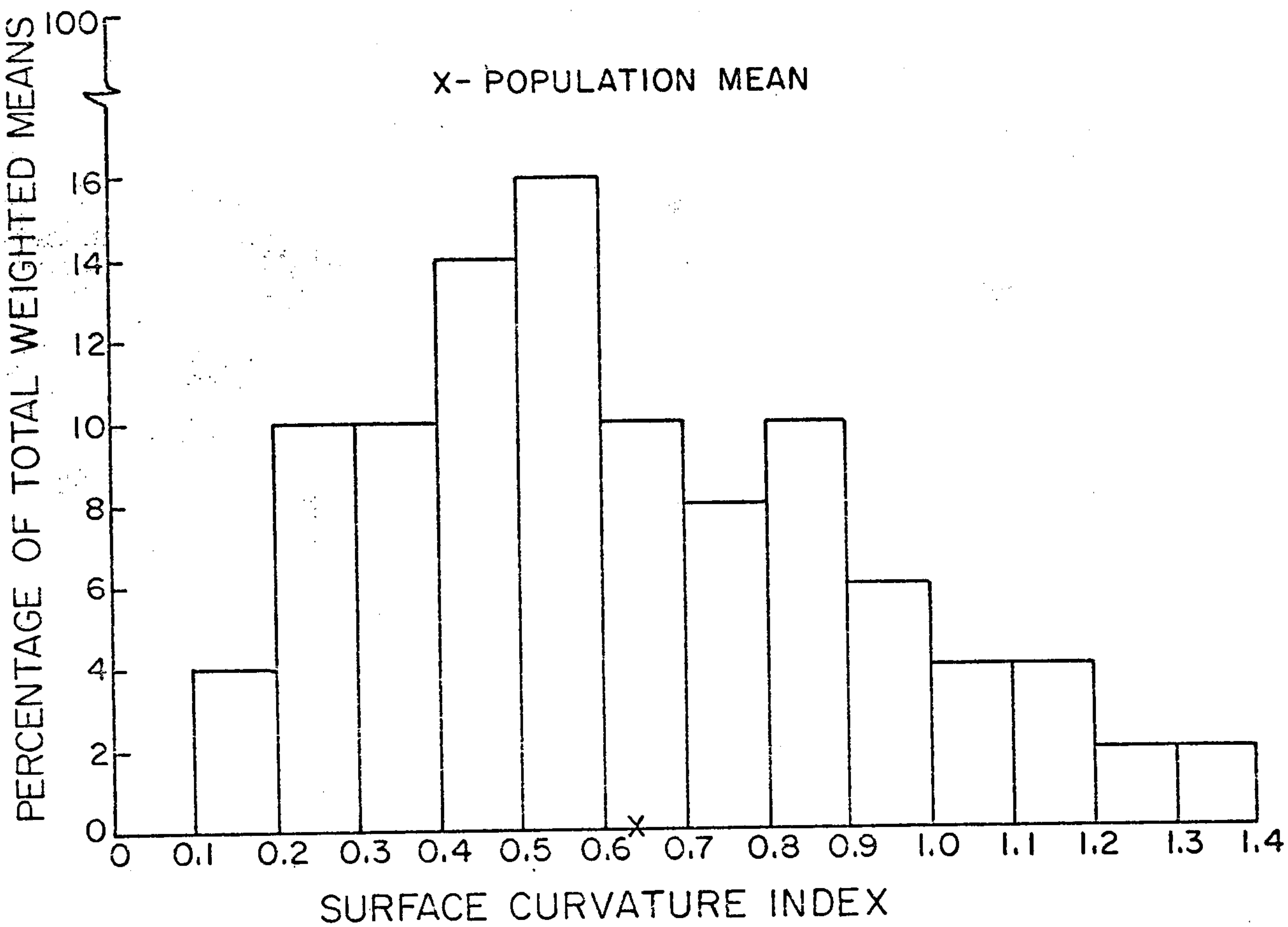


Figure B-11. District 21 Surface Curvature Index Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for US & SH Highways---1975.

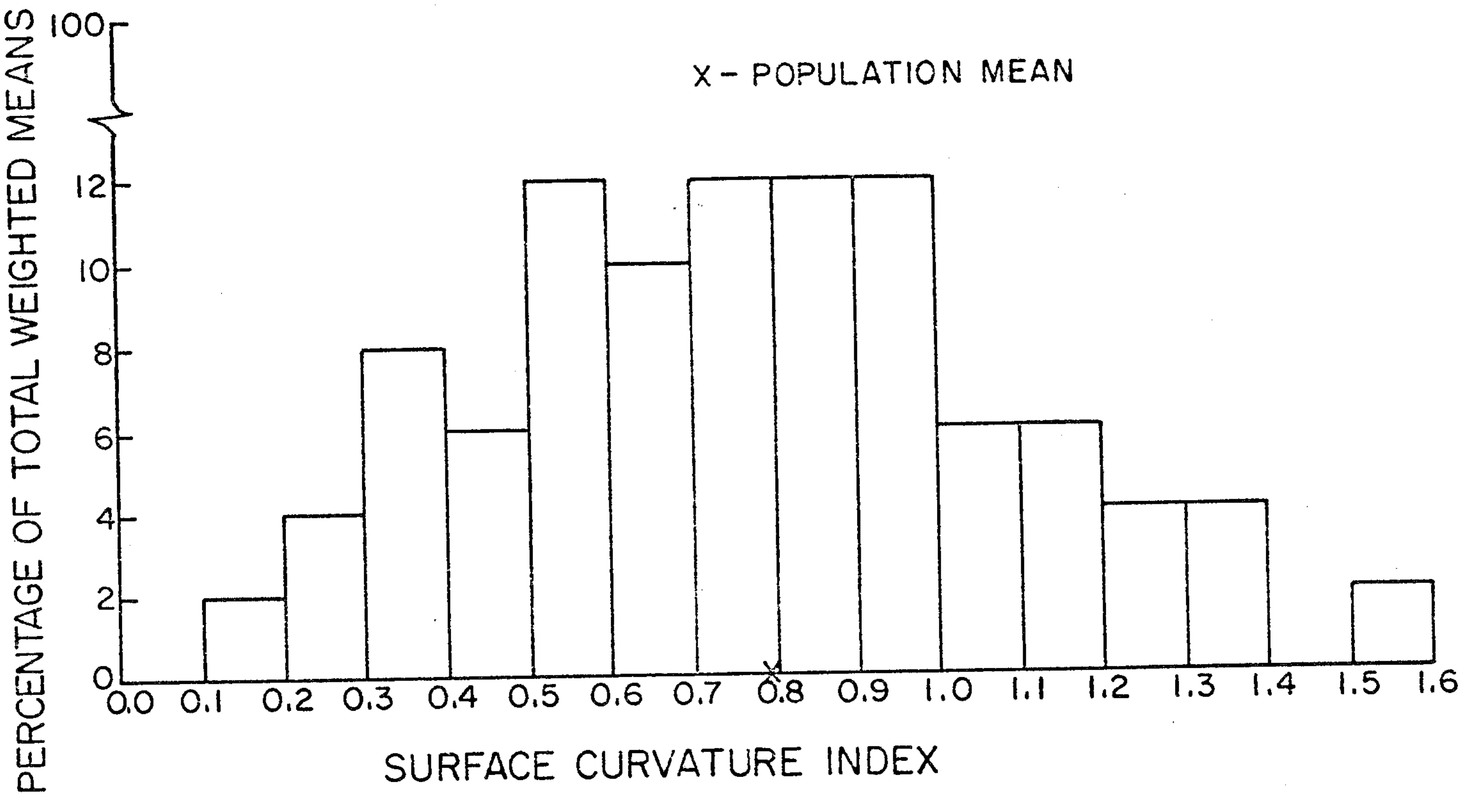


Figure B-12. District 21 Surface Curvature Index Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for FM Highways---1975.

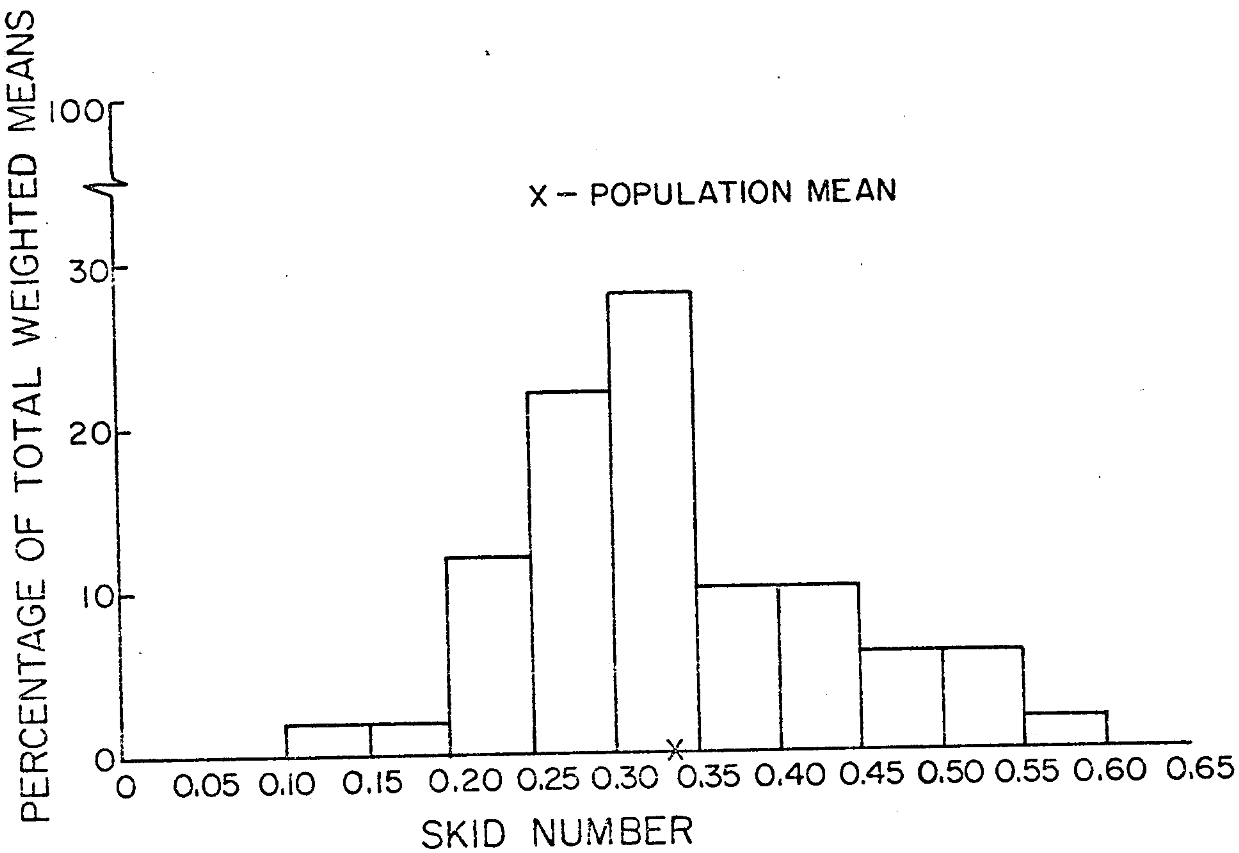


Figure B-13. District 21 Skid Number Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for US & SH Highways---1975.

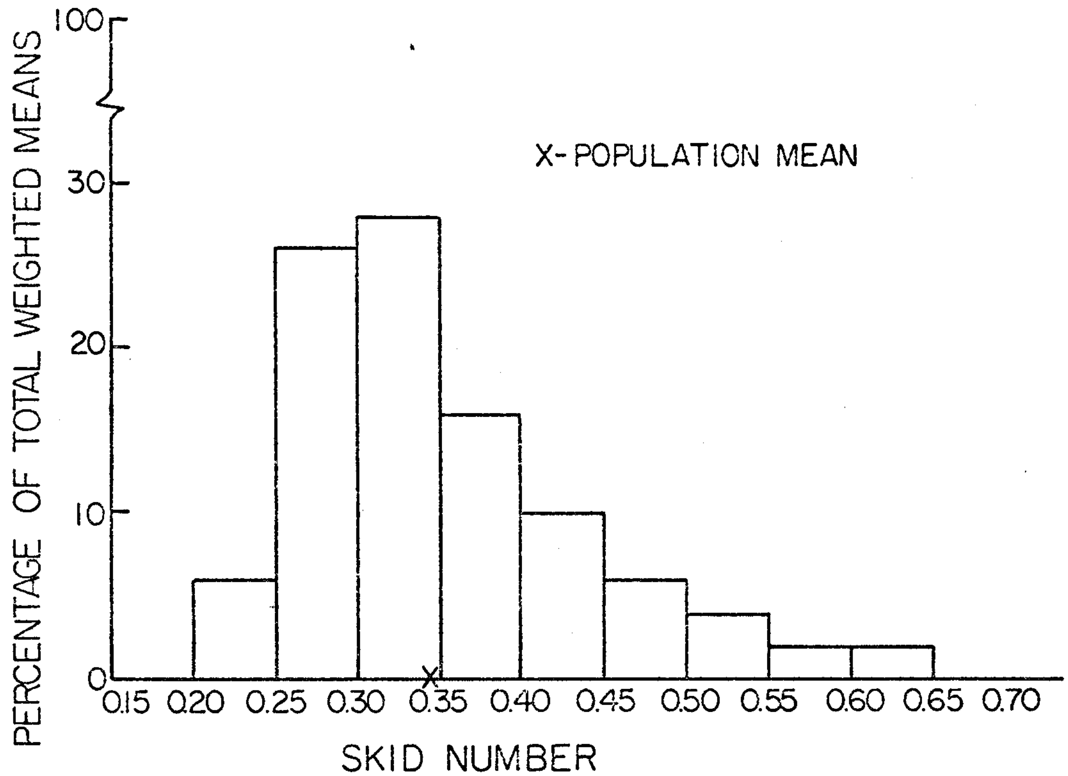


Figure B-14. District 21 Skid Number Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for FM Highways---1975.

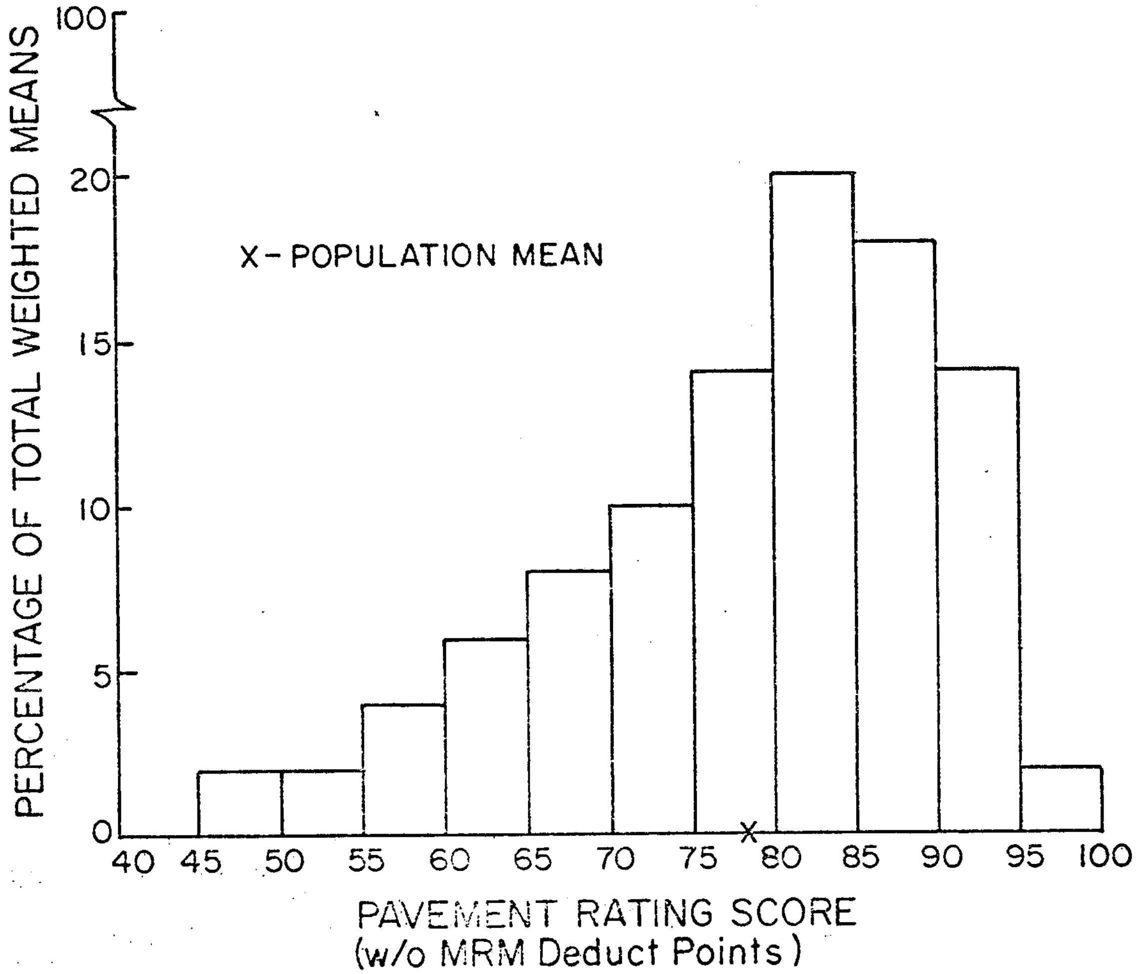


Figure B-15. District 21 Pavement Rating Score Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for US & SH Highways----1975.

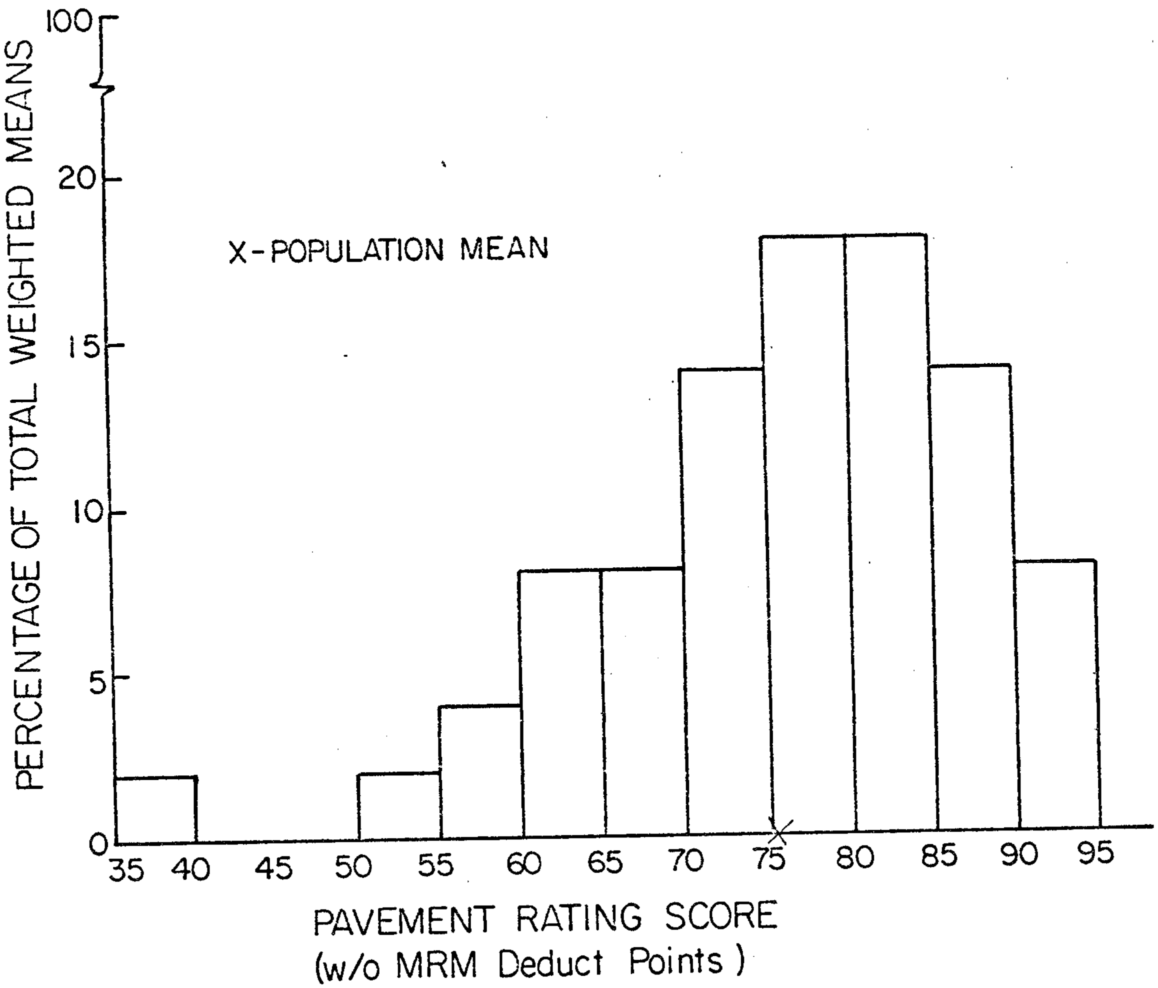


Figure B-16. District 21 Pavement Rating Score Mass Inventory Histogram for Weighted Means of Two-Mile Pavement Segments for FM Highways --- 1975.

Data Grouping for Shoulder, Roadside, Drainage, and Traffic Services Rating Scores

Tables B-13 through B-24 and Figures B-17 through B-32 show how the data for Shoulder, Roadside, Drainage, and Traffic Services Rating Scores were distributed for both 1974 and 1975 in District 21. The tables include data for all three highway types including districtwide and county treatments and the figures are only for US & SH and FM highways (districtwide treatment). The rating scale used to obtain these scores ranges from 1 to 9 with 1 representing an item in very good condition and 9 representing a very poor condition.

The purpose of presenting this information is to examine year-to-year differences and differences between highway types for the complete inventory of District 21 pavements. This information can be used to indicate approximately what may be expected in other districts and where the rating procedure can be improved.

The Shoulder Rating Score (SRS) is composed of either seven separate rating items for a paved shoulder or two items for an unpaved shoulder. If the shoulder is paved, the items of ride, contrast, pavement edge, shoulder edge, cracks, raveling, and vegetation (in the shoulder) are evaluated. If the shoulder is not paved, the two items evaluated are pavement edge and a combination of rutting, corrugations, and loose rock. The Roadside Rating Score (RRS) is composed of four items and these are litter, mowing, vegetation, and slope erosion. The Drainage Rating Score (DRS) is composed of three rating items and these are culverts, roadside drainage, and a combination of ditches, outfalls and channels. Lastly the Traffic Service Rating Score (TSRS) is composed of five rating items and these are guardrails, signs, delineators, striping, and auxiliary markings. More specific definitions and descriptions for the rating items and the calculation of the resulting scores may be found in Reference B-1.

Use of Table B-13 and Figures B-17, B-18, B-25, and B-26 allow a comparison of year-to-year Shoulder Rating Score differences. The Shoulder Rating Score Means decreased approximately 5 points from 1974 to 1975 for US & SH highways and approximately 2 points for FM highways.

Additionally, significant shifts in the histograms occurred. It is doubtful that changes of 5 points would occur within one year. It is probably reasonable to conclude that the majority of the data shift and difference in means is due to rater error. The most likely reason for this error is the same as was discussed previously in this Appendix for Pavement Rating Score. Basically, this error occurs because the evaluation procedure does not require evaluations to be performed at the same location along the roadway each year.

The differences in the county means of Shoulder Rating Score indicate the same districtwide trend. Overall, the average difference from 1974 to 1975 for both highway types was about a 6 point reduction. This ranged from a maximum of a 12 point difference for FM highways in Webb and Zapata counties to a zero difference for US & SH highways in Cameron and Kenedy Counties. Additionally, on an individual county basis, the observed differences were generally greater for FM highways as compared to US & SH highways.

On a districtwide basis, the Roadside Rating Score decreased approximately 5 points from 1974 to 1975 for US & SH highways and approximately 4 points for FM highways. As was observed for Shoulder Rating Score data, sizeable shifts occurred in the histograms shown in Figures B-19, B-20, B-27, and B-28. In this case, no conclusions are drawn about the observed differences due to rater error. The Roadside Rating Score is intended to be quite sensitive to year-to-year variations and the observed differences may be valid.

The distribution of the Roadside Rating Scores fall primarily in a narrow band even though the standard deviations shown in Table B-13 are about equal to those for the other data types. Thus, many of the scores generated for US & SH and FM highways, respectively, are about the same. This indicates that either most of the roadsides in District 21 are about the same or the raters are giving all roadsides, regardless of condition, about the same rating.

On a county basis, all Roadside Rating Scores decreased from 1974 to 1975. The maximum decrease (difference) was 10 points for US & SH highways in Kenedy County. The smallest decreases were 2 points for US & SH highways in Cameron County and FM highways in Willacy County.

Districtwide, the Drainage Rating Score means decreased approximately 9 points for US & SH highways and 10 points for FM highways from 1974 to 1975. As observed for Shoulder Rating Score and Roadside Rating Score data, sizeable shifts occurred in the histograms shown in Figures B-21, B-22, B-29, and B-30. Either a significant deterioration of the adjacent highway drainage occurred within one year for both highway types or the raters performing the evaluation in 1975 were more critical. Additionally, the histograms for this data type indicate that the majority of the Drainage Rating Score data falls within narrow ranges, even more so than the Roadside Rating Score. This either indicates all drainage features in District 21 are equally maintained or the raters evaluated all drainage features, regardless of condition, about the same.

An examination of the individual counties reveals that the differences for the Drainage Rating Score ranged from a minimum of 5 points to a maximum of 11 points with scores decreasing from 1974 to 1975. This is consistent with the districtwide case.

The data for Traffic Services Rating Score is an exception to the three scores previously discussed. The means for both highway types changed very little from 1974 to 1975 for both the districtwide and individual county cases. Additionally, the data contained in each of the histograms are well distributed thus indicating a relatively wide range of scores.

Overall, after reviewing the data for all four of the discussed scores, it is felt that the principal cause of the observed year-to-year differences is that the raters do not stop at the same location along the roadway each year. Additionally, the narrow data spread for the Roadside and Drainage Rating Scores may indicate that raters spend little time on evaluations of these categories.

Table B-13. District 21 Mass Inventory Statistical Summary

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	38	78	4
		RRS	38	72	1
		DRS	38	70	0
		TSRS	38	75	1
	1975	SRS	37	74	2
		RRS	37	66	2
		DRS	37	65	6
		TSRS	37	76	4
US & SH	1974	SRS	1071	72	7
		RRS	1071	74	7
		DRS	1071	70	3
		TSRS	1071	76	4
	1975	SRS	1084	67	8
		RRS	1084	69	9
		DRS	1084	61	6
		TSRS	1084	74	4
FM	1974	SRS	1438	61	12
		RRS	1438	72	4
		DRS	1438	70	4
		TSRS	1438	76	5
	1975	SRS	1475	59	7
		RRS	1475	68	6
		DRS	1475	60	5
		TSRS	1475	75	5

Table B-14. District 21 Mass Inventory Statistical Summary for Two-Mile Highway Segments

Highway Type	Year	Data Type	Mean	Standard Deviation
IH	1974	SRS	78	1
		RRS	72	0
		DRS	70	0
		TSRS	75	0
	1975	SRS	74	1
		RRS	66	0
		DRS	65	1
		TSRS	76	2
US & SH	1974	SRS	72	2
		RRS	74	4
		DRS	70	1
		TSRS	76	1
	1975	SRS	67	3
		RRS	69	4
		DRS	61	2
		TSRS	74	2
FM	1974	SRS	61	2
		RRS	72	2
		DRS	70	1
		TSRS	76	2
	1975	SRS	59	2
		RRS	68	3
		DRS	60	2
		TSRS	75	1

Table B-15. District 21 Mass Inventory Statistical Summary for Brooks County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
	1975	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
US & SH	1974	SRS	69	72	7
		RRS	69	75	6
		DRS	69	70	1
		TSRS	69	76	4
	1975	SRS	68	64	5
		RRS	68	69	9
		DRS	68	63	5
		TSRS	68	76	4
FM	1974	SRS	49	70	1
		RRS	49	72	3
		DRS	49	70	0
		TSRS	49	77	6
	1975	SRS	48	60	1
		RRS	48	66	4
		DRS	48	60	1
		TSRS	48	74	7

Table B-16. District 21 Mass Inventory Statistical Summary for Cameron County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
	1975	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
US & SH	1974	SRS	193	68	8
		RRS	193	73	7
		DRS	193	71	5
		TSRS	193	74	5
	1975	SRS	179	68	7
		RRS	179	71	13
		DRS	179	64	9
		TSRS	179	73	4
FM	1974	SRS	317	57	12
		RRS	317	72	4
		DRS	317	69	6
		TSRS	317	74	6
	1975	SRS	323	61	8
		RRS	323	69	7
		DRS	323	59	7
		TSRS	323	75	6

Table B-17. District 21 Mass Inventory Statistical Summary for Duval County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
	1975	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
US & SH	1974	SRS	186	72	3
		RRS	186	74	7
		DRS	186	70	0
		TSRS	186	76	3
	1975	SRS	202	64	7
		RRS	202	69	5
		DRS	202	60	2
		TSRS	202	73	3
FM	1974	SRS	101	68	2
		RRS	101	73	3
		DRS	101	70	0
		TSRS	101	75	3
	1975	SRS	97	60	5
		RRS	97	66	5
		DRS	97	61	4
		TSRS	97	71	5

Table B-18. District 21 Mass Inventory Statistical Summary for Hidalgo County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
	1975	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
US & SH	1974	SRS	178	72	9
		RRS	178	76	10
		DRS	178	71	4
		TSRS	178	77	5
	1975	SRS	217	68	9
		RRS	217	72	11
		DRS	217	62	8
		TSRS	217	74	4
FM	1974	SRS	433	52	12
		RRS	433	72	6
		DRS	433	72	5
		TSRS	433	75	6
	1975	SRS	431	57	8
		RRS	431	69	6
		DRS	431	61	5
		TSRS	431	75	5

Table B-19. District 21 Mass Inventory Statistical Summary for Jim Hogg County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
	1975	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
US & SH	1974	SRS	52	73	4
		RRS	52	74	5
		DRS	52	70	0
		TSRS	52	75	3
	1975	SRS	52	66	7
		RRS	52	70	7
		DRS	52	61	3
		TSRS	52	73	4
FM	1974	SRS	95	68	2
		RRS	95	71	3
		DRS	95	70	0
		TSRS	95	82	1
	1975	SRS	92	59	2
		RRS	92	68	2
		DRS	92	63	5
		TSRS	92	78	2

Table B-20. District 21 Mass Inventory Statistical Summmary for Kenedy County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
	1975	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
US & SH	1974	SRS	47	77	2
		RRS	47	77	0
		DRS	47	70	0
		TSRS	47	75	3
	1975	SRS	47	77	0
		RRS	47	67	1
		DRS	47	60	0
		TSRS	47	77	4
FM	1974	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
	1975	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----

Table B-21. District 21 Mass Inventory Statistical Summary for Starr County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
	1975	SRS	0	----	-----
		RRS	0	----	-----
		DRS	0	----	-----
		TSRS	0	----	-----
US & SH	1974	SRS	50	75	6
		RRS	50	76	7
		DRS	50	70	0
		TSRS	50	76	5
	1975	SRS	43	68	4
		RRS	43	67	12
		DRS	43	61	5
		TSRS	43	73	5
FM	1974	SRS	175	66	5
		RRS	175	71	3
		DRS	175	70	0
		TSRS	175	78	4
	1975	SRS	172	57	3
		RRS	172	68	3
		DRS	172	60	1
		TSRS	172	75	5

Table B-22. District 21 Mass Inventory Statistical Summary for Webb County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	38	78	4
		RRS	38	72	1
		DRS	38	70	0
		TSRS	38	75	1
	1975	SRS	37	74	2
		RRS	37	66	2
		DRS	37	65	6
		TSRS	37	76	4
US & SH	1974	SRS	141	72	6
		RRS	141	74	6
		DRS	141	70	2
		TSRS	141	78	3
	1975	SRS	143	67	9
		RRS	143	65	8
		DRS	143	61	4
		TSRS	143	74	4
FM	1974	SRS	99	71	3
		RRS	99	72	1
		DRS	99	70	0
		TSRS	99	79	3
	1975	SRS	125	59	7
		RRS	125	64	5
		DRS	125	60	1
		TSRS	125	74	5

Table B-23. District 21 Mass Inventory Statistical Summary for Willacy County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	---	---
		RRS	0	---	---
		DRS	0	---	---
		TSRS	0	---	---
	1975	SRS	0	---	---
		RRS	0	---	---
		DRS	0	---	---
		TSRS	0	---	---
US & SH	1974	SRS	77	74	5
		RRS	77	74	6
		DRS	77	70	0
		TSRS	77	79	4
	1975	SRS	54	71	3
		RRS	54	71	8
		DRS	54	61	5
		TSRS	54	76	4
FM	1974	SRS	142	70	1
		RRS	142	72	1
		DRS	142	70	0
		TSRS	142	78	3
	1975	SRS	154	60	2
		RRS	154	70	2
		DRS	154	60	3
		TSRS	154	75	4

Table B-24. District 21 Mass Inventory Statistical Summary for Zapata County

Highway Type	Year	Data Type	Mileage	Mean	Standard Deviation
IH	1974	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
	1975	SRS	0	----	----
		RRS	0	----	----
		DRS	0	----	----
		TSRS	0	----	----
US & SH	1974	SRS	77	74	3
		RRS	77	73	6
		DRS	77	70	0
		TSRS	77	77	3
	1975	SRS	80	67	6
		RRS	80	70	4
		DRS	80	60	4
		TSRS	80	74	4
FM	1974	SRS	27	70	0
		RRS	27	72	0
		DRS	27	70	0
		TSRS	27	76	4
	1975	SRS	33	58	2
		RRS	33	67	2
		DRS	33	60	0
		TSRS	33	77	3

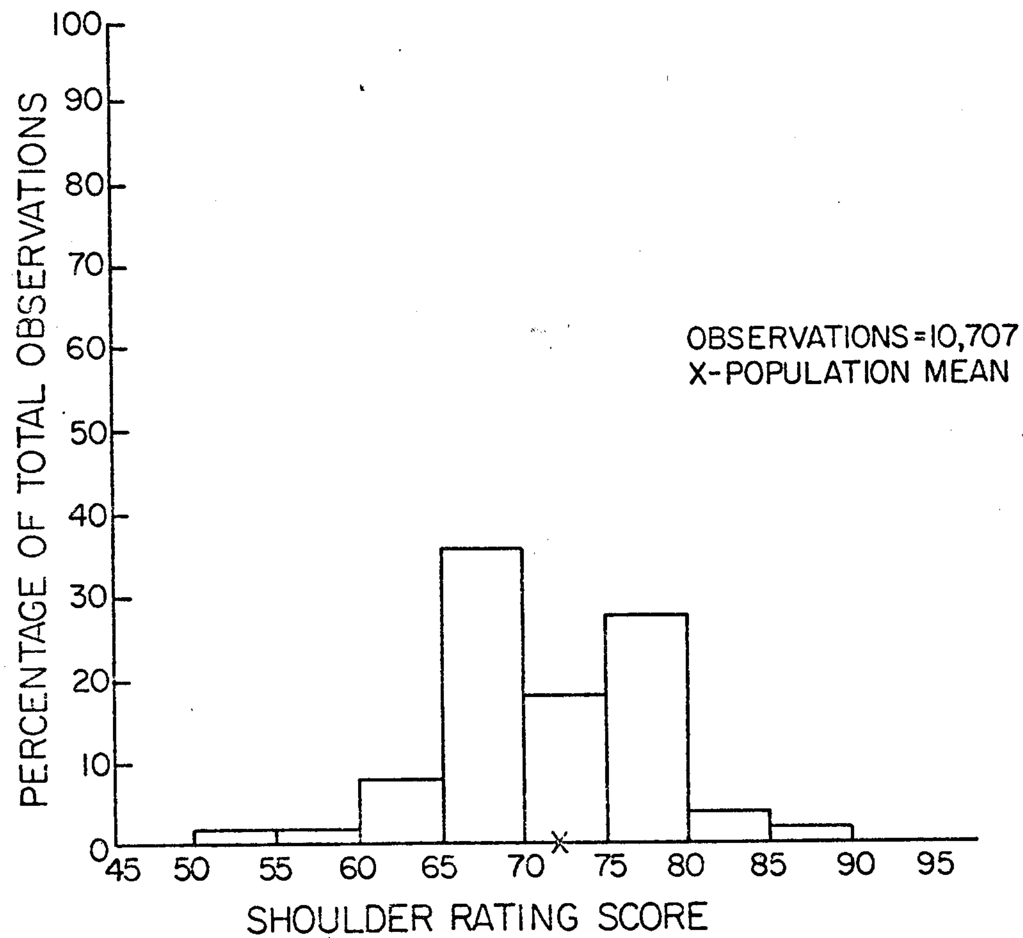


Figure B-17. District Shoulder Rating Score Mass Inventory Histogram for US & SH Highways --- 1974.

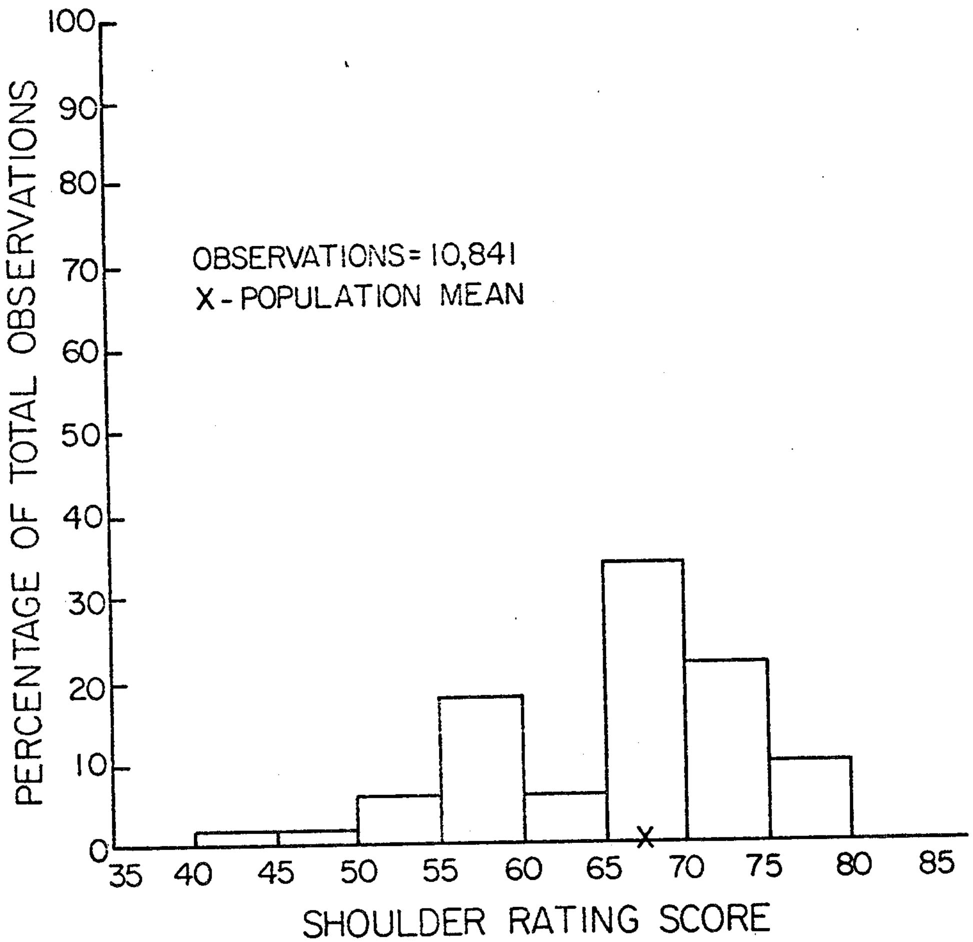


Figure B-18. District 21 Shoulder Rating Score Mass Inventory Histogram for US & SH Highways --- 1975.

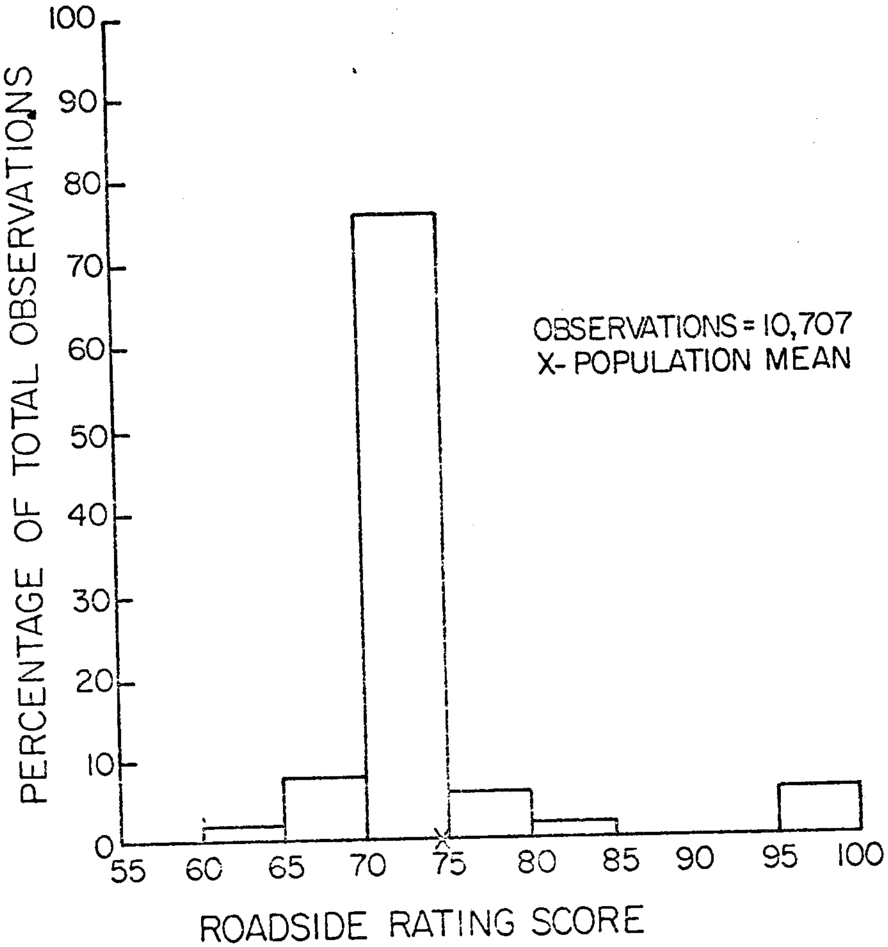


Figure B-19. District 21 Roadside Rating Score Mass Inventory Histogram for US & SH Highways --- 1974.

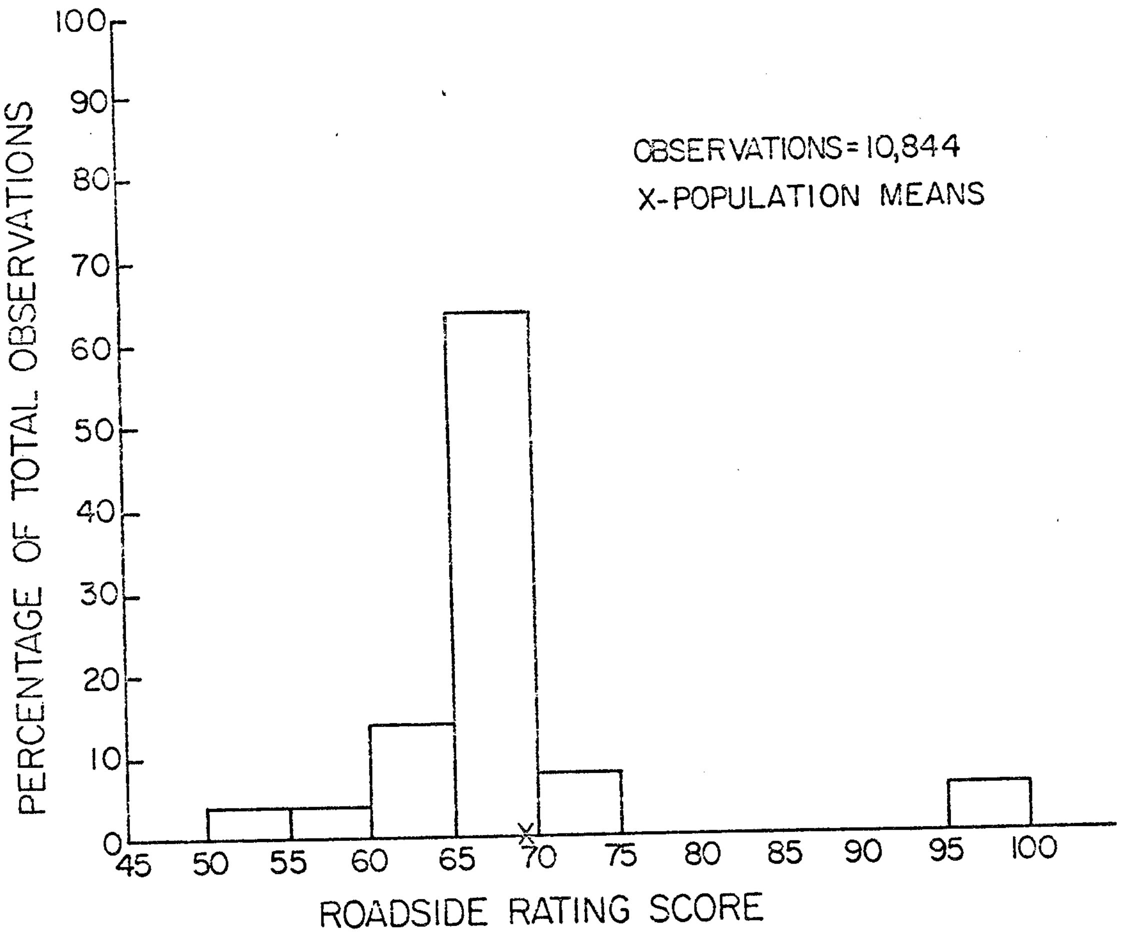


Figure B-20. District 21 Roadside Rating Score Mass Inventory Histogram for US & SH Highways --- 1975.

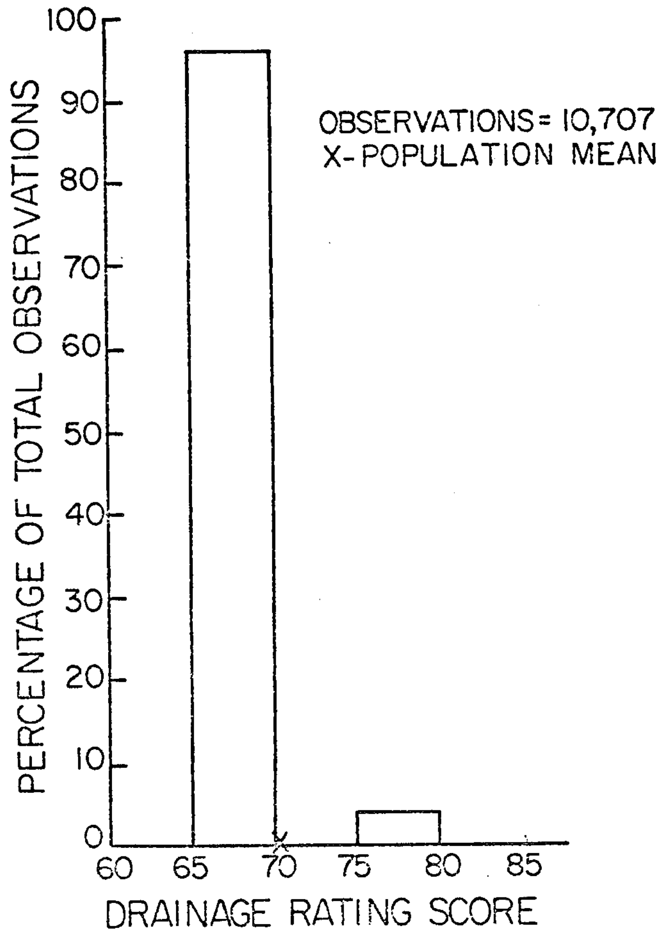


Figure B-21. District 21 Drainage Rating Score Mass Inventory Histogram for US & SH Highways ---- 1974.

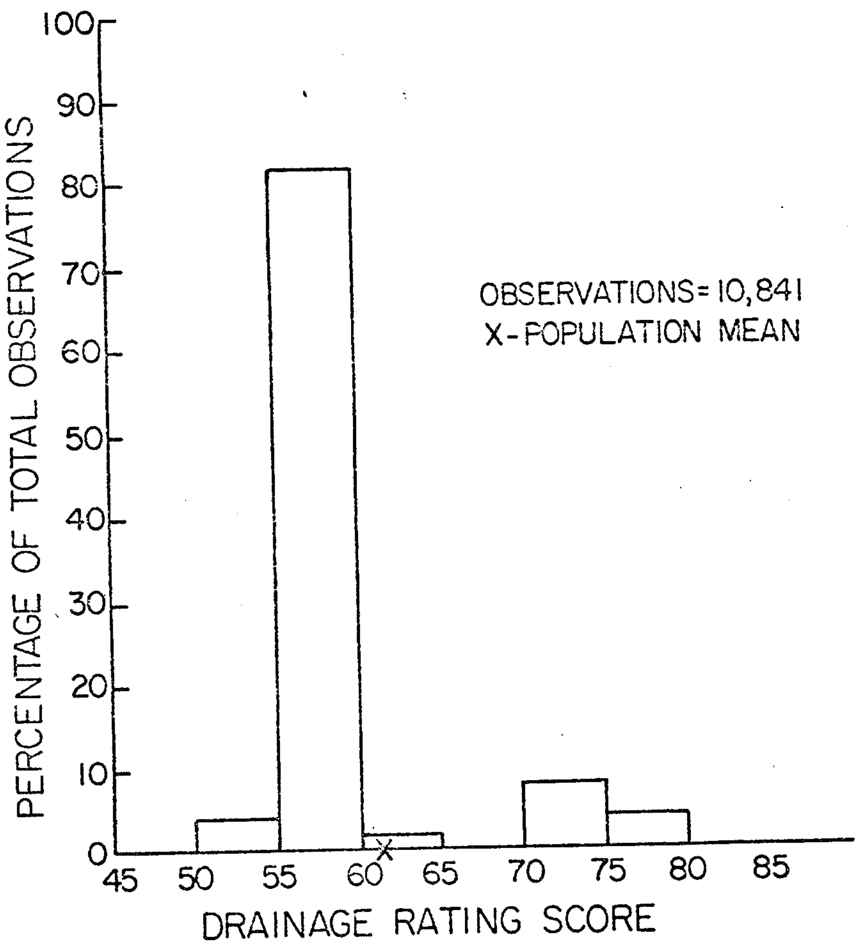


Figure B-22. District 21 Drainage Rating Score Mass Inventory Histogram for US & SH Highways --- 1975.

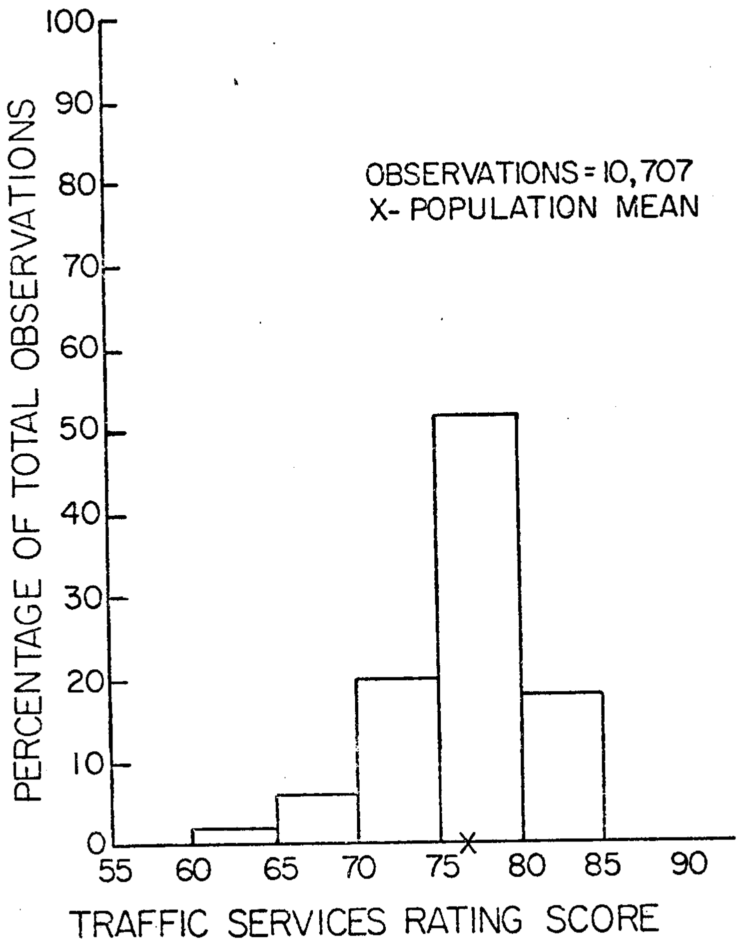


Figure B-23. District 21 Traffic Services Rating Score Mass Inventory Histogram for US & SH Highways ---- 1974.

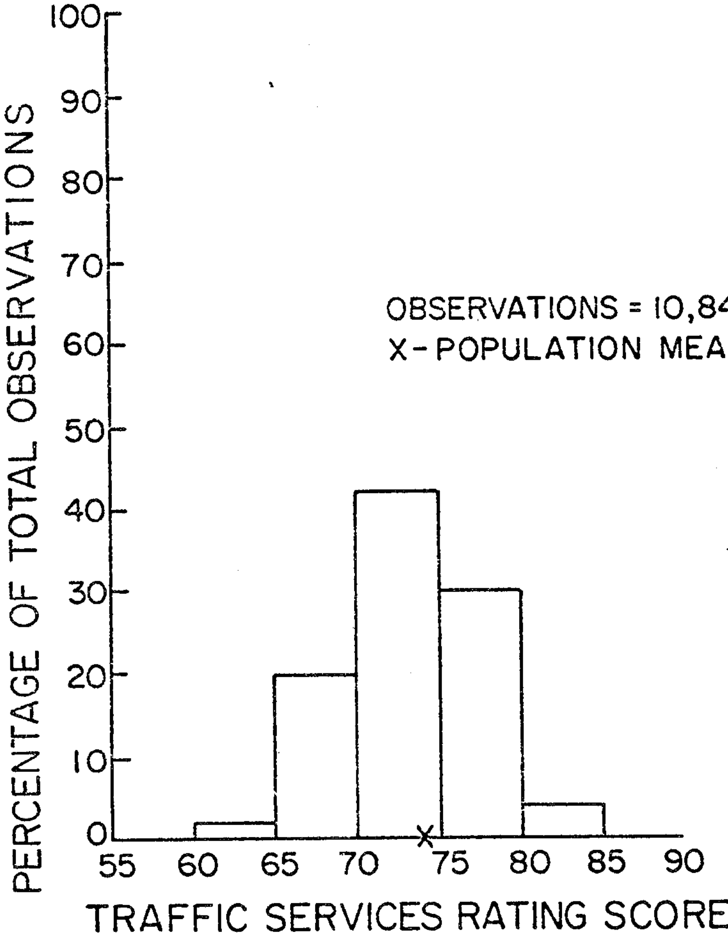


Figure B-24. District 21 Traffic Services Rating Score Mass Inventory Histogram for US & SH Highways --- 1975.

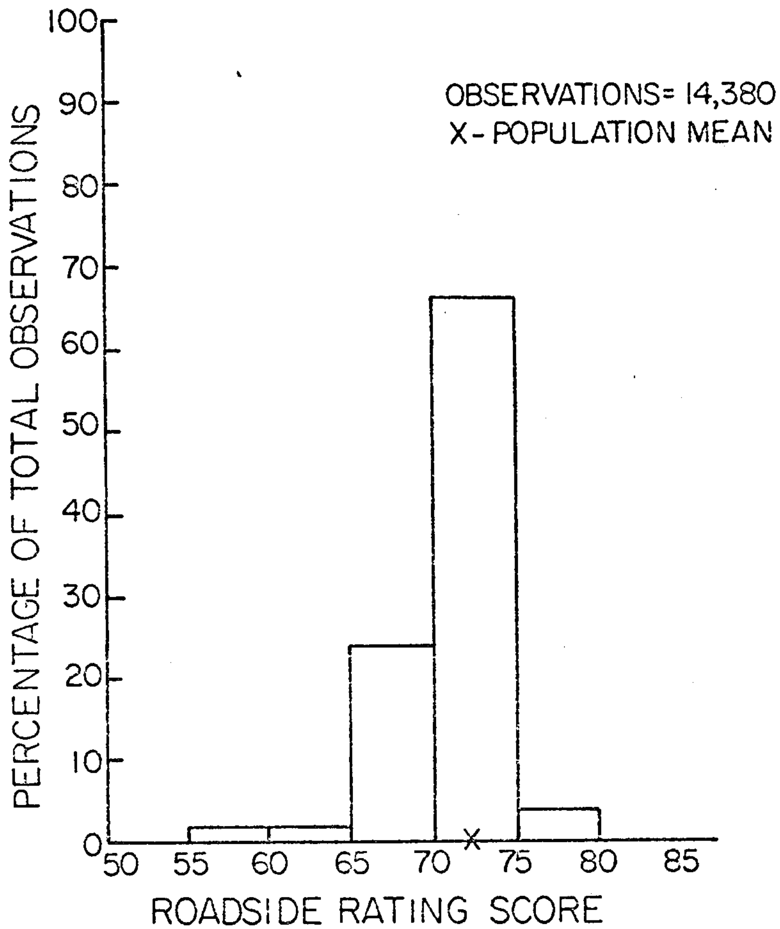


Figure B-27. District 21 Roadside Rating Score Mass Inventory Histogram for FM Highways --- 1974.

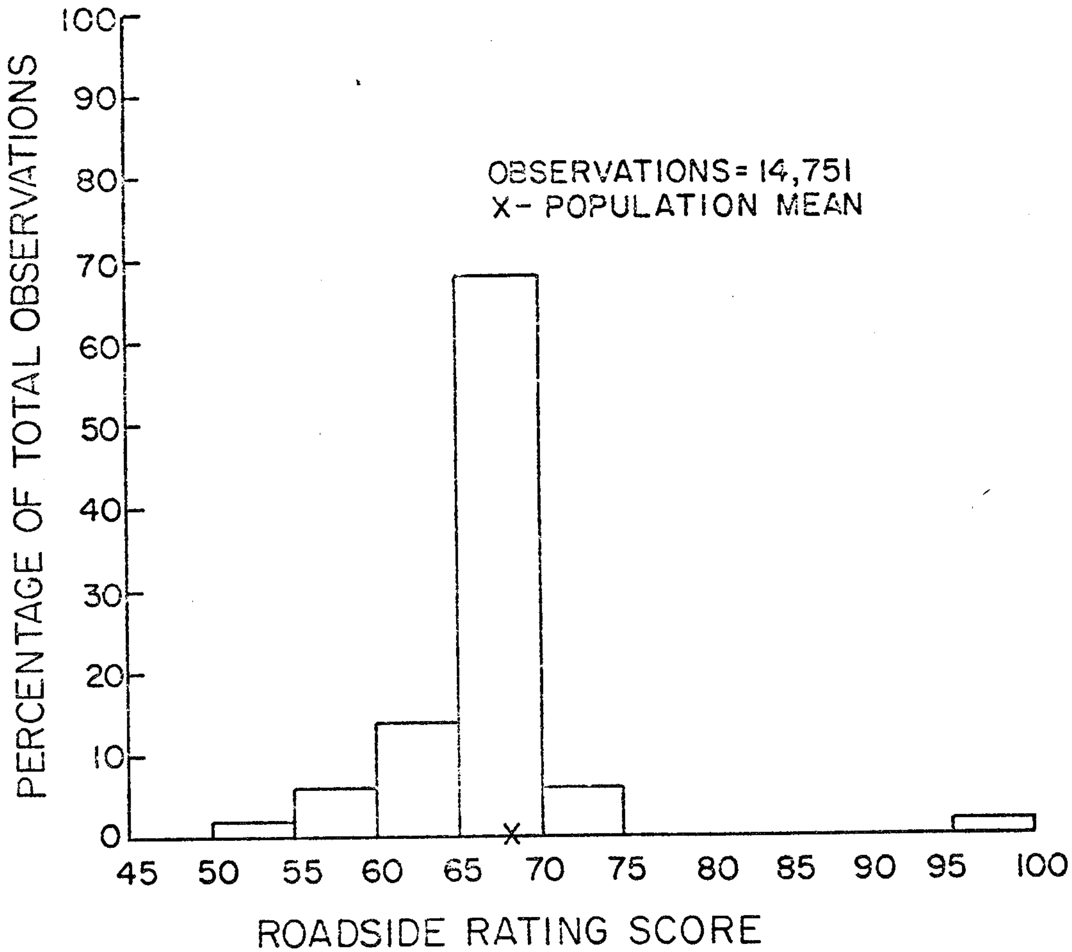


Figure B-28. District 21 Roadside Rating Score Mass Inventory Histogram for FM Highways --- 1975.

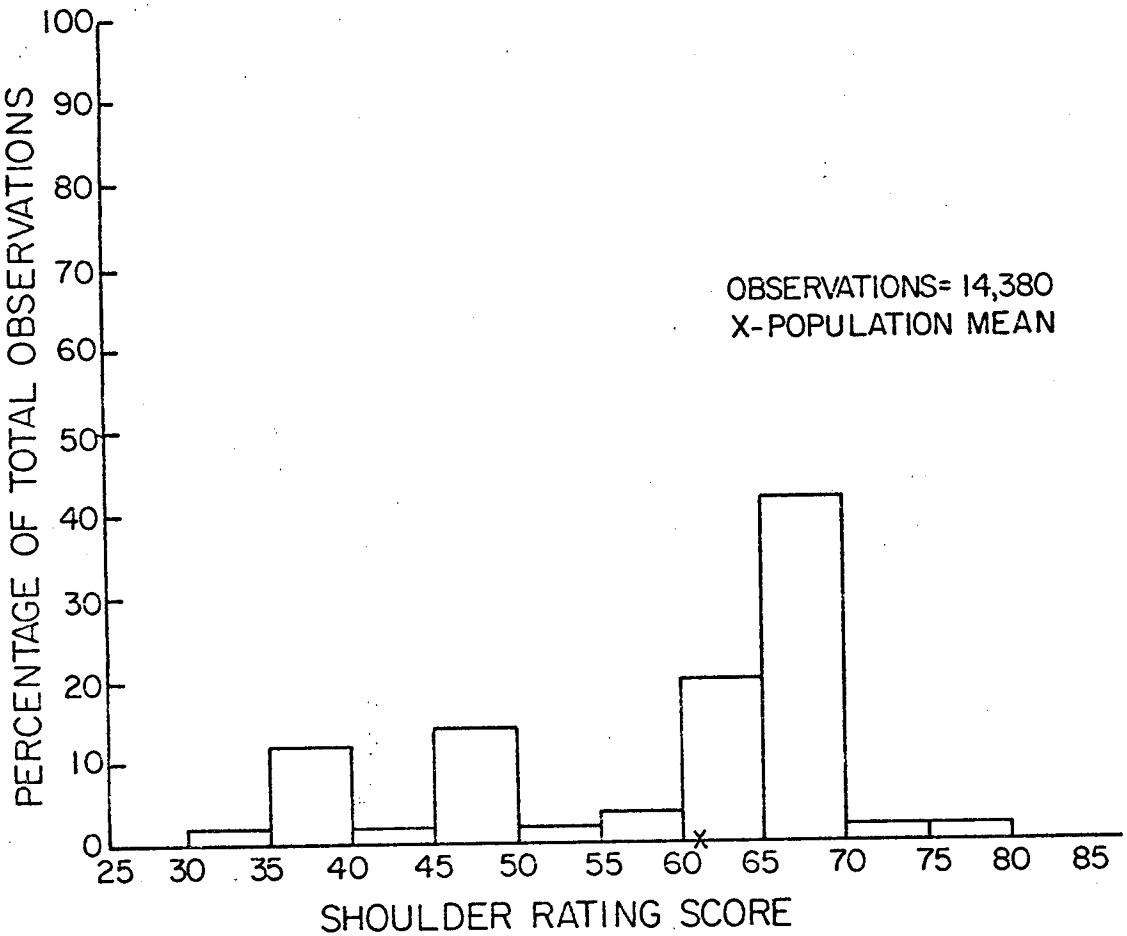


Figure B-25. District 21 Shoulder Rating Score Mass Inventory Histogram for FM Highways ---- 1974.

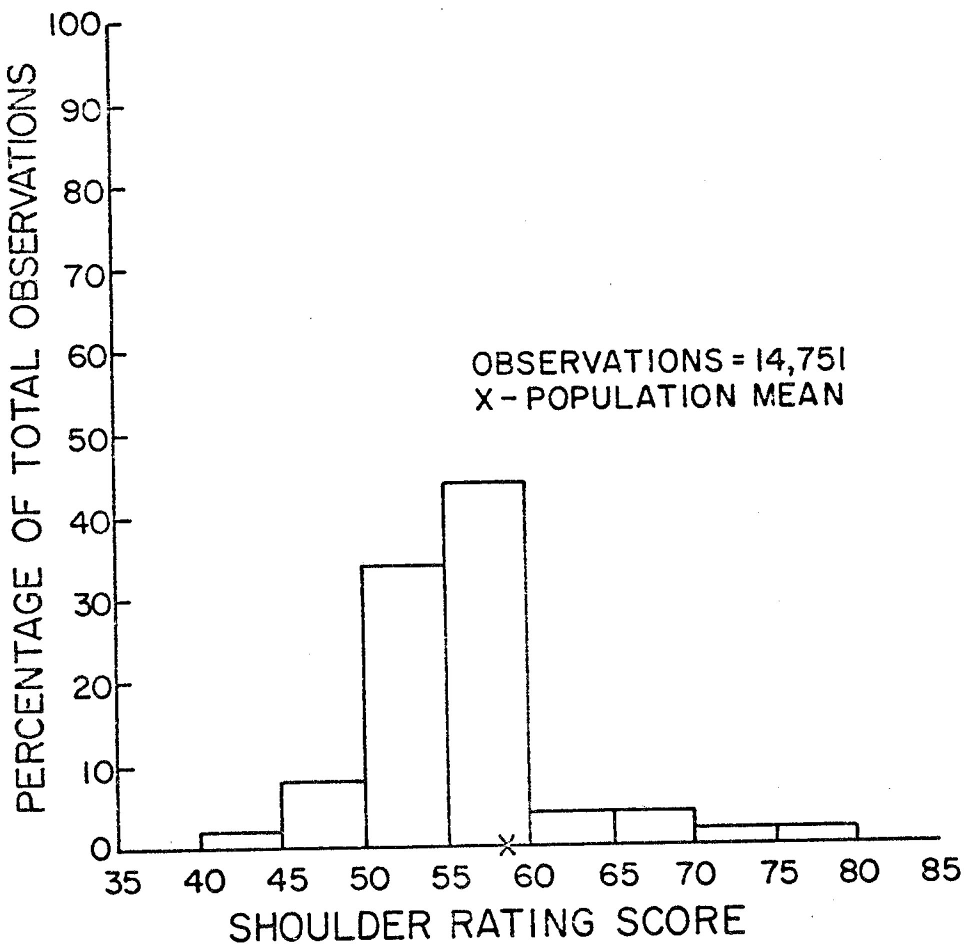


Figure B-26. District 21 Shoulder Rating Score Mass Inventory Histogram for FM Highways --- 1975.

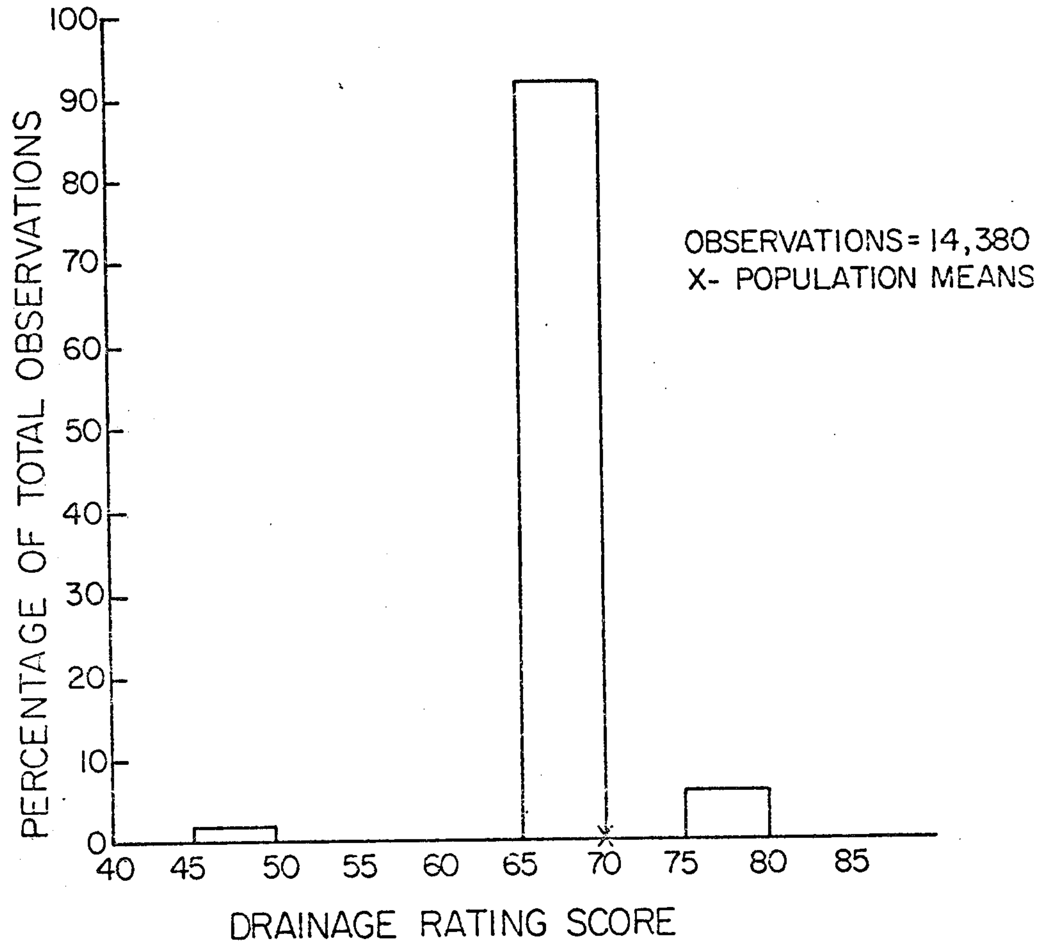


Figure B-29. District 21 Drainage Rating Score Mass Inventory Histogram for FM Highways --- 1974.

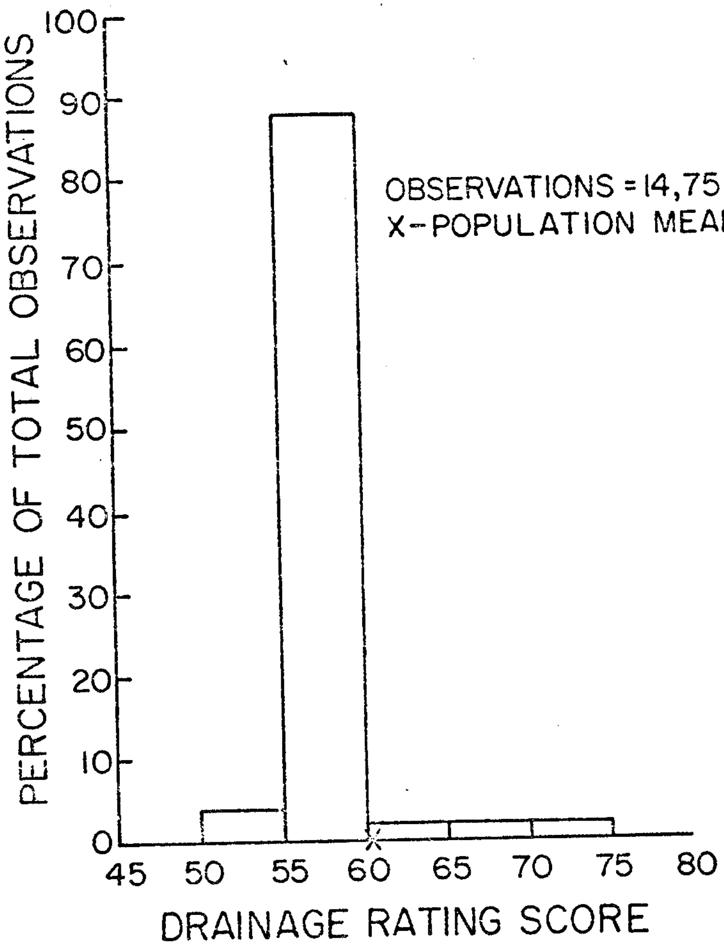


Figure B-30. District 21 Drainage Rating Score Mass Inventory Histogram for FM Highways --- 1975.

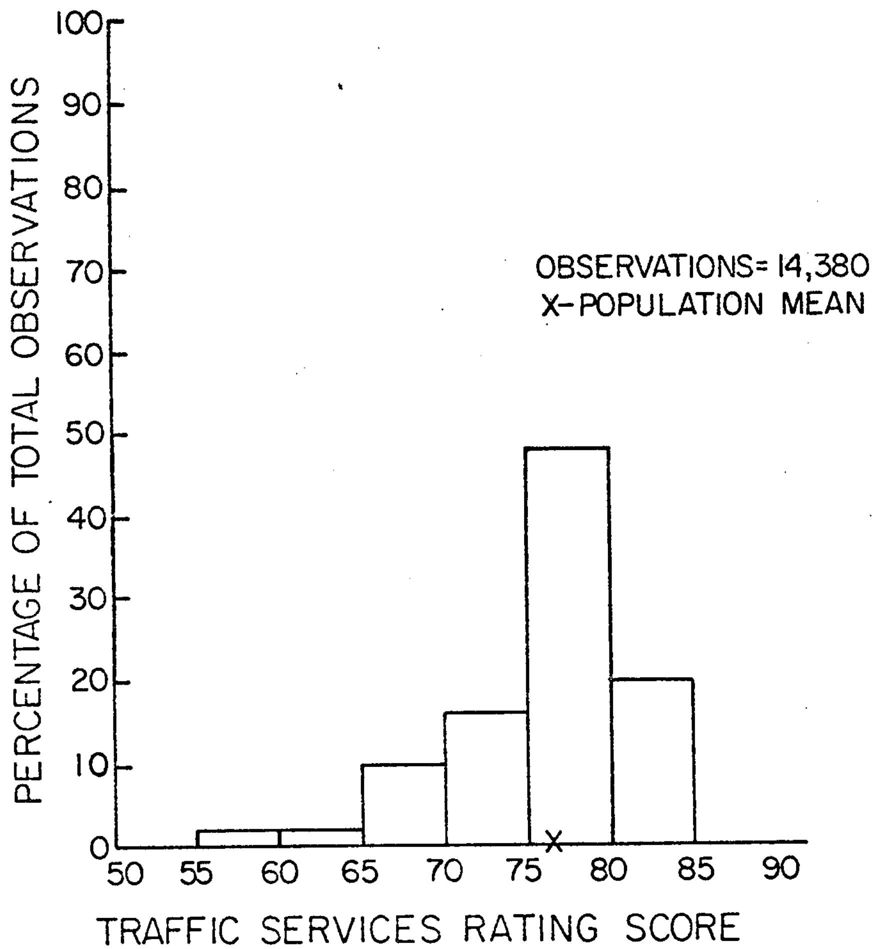


Figure B-31. District 21 Traffic Services Rating Score Mass Inventory Histogram for FM Highways --- 1974.

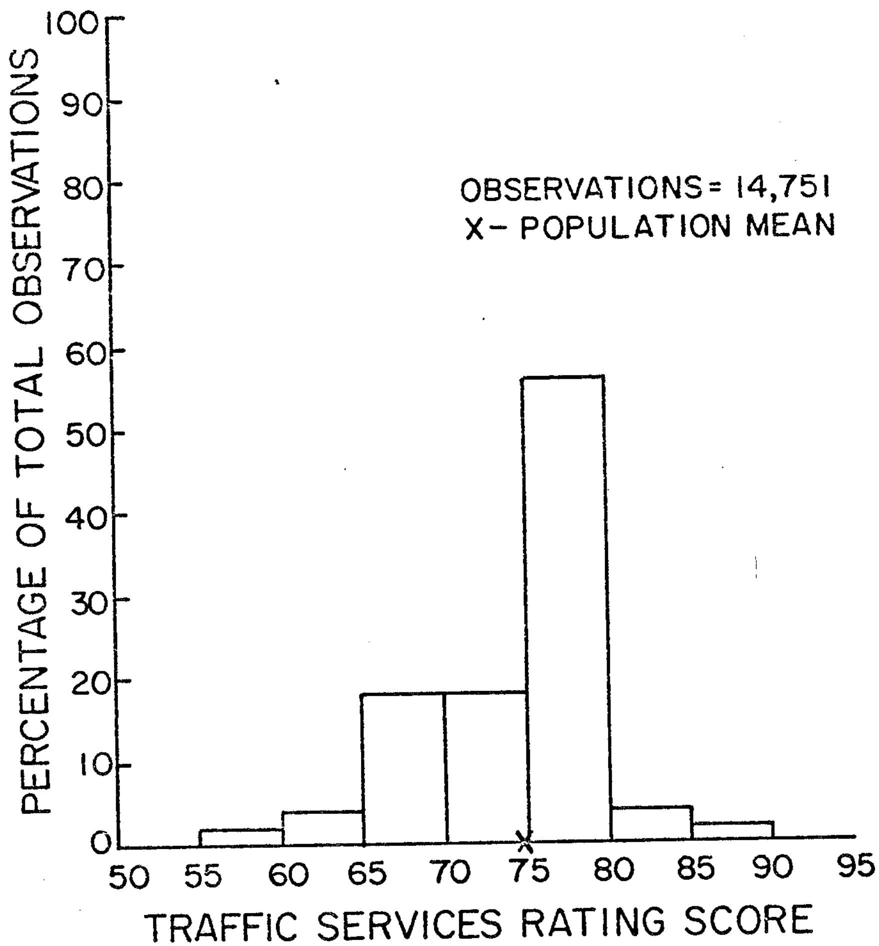


Figure B-32. District 21 Traffic Services Rating Score Mass Inventory Histogram for FM Highways --- 1975.

REFERENCES - APPENDIX B

B-1. J. A. Epps, A. H. Meyer, I. E. Larrimore and H. L. Jones. Roadway Maintenance Evaluation User's Manual. Texas Transportation Institute Research Report 151-2, September 1974.

B-2. K. D. Hankins. Maintenance Rating System Data Plot, Report No. SS 18-1, State Department of Highways and Public Transportation, Transportation Planning Division, April 1976.

Appendix C. Evaluation and Recommended Changes in the Maintenance Rating Procedure for Flexible Pavements

Introduction

Availability of four years of data collected with the use of the maintenance rating procedure contained in TTI Research Report 151-2 "Roadway Maintenance Evaluation User's Manual" allow for additional evaluation of the consistency of the procedure. The rating procedure is used to record the approximate amounts of nine types of pavement distress manifestations. Thus, the amount and severity of a certain kind of distress may be examined or the cumulative effects of all of the distress types may be used to compute a Pavement Rating Score. The variation of the Pavement Rating Score has been discussed in both the main body of the report and Appendix B. The individual distress types will be used in this appendix to further examine the variation of year-to-year results.

Tables C-1 through C-18 are data summaries for each of the nine distress types. The percentage of segments which exhibited a specific kind of observed distress is shown for each combination of area and severity. These percentages are obtained by dividing the number of observed segments in each combination by the total number of segments available for a given highway type and year.

Each of the distress types will be discussed along with recommended revisions to the rating procedure which are based on the data examination. A simplification of the existing procedure is felt necessary to reduce some of the year-to-year observed variation. Four goals were used in determining how this could be done. They are:

1. Eliminate all nondistress related rating items (i.e., roadside, drainage, and traffic services).
2. Continue to evaluate all <u>major</u> types of distress observed on Texas pavements (i.e., eliminate the "unimportant" distress types).
3. Retain the ability to continue to use prior year data (i.e., be able to transform prior rating data to the new format).
4. Attempt to modify the rating procedure as little as possible so those individuals currently using it can easily adjust to the revised procedure.

A discussion of the suggested recommendations for each distress type follows.

<u>Rutting</u>

An examination of Table C-1 reveals that the 1976 data is radically different from the prior years. Direct determination of rut depths were not made for the surveys conducted in 1973 through 1975 and only visual estimations were used. Beginning with the 1976 survey, measurements with a six foot straight edge and ruler were made in the outside wheel path for each of the two-mile pavement segments. These measurements indicated that some rutting (although mostly minor - 0 to 0.5 in.) occurs on about seventy-five percent of all highway segments examined. These field measurements will undoubtedly increase the consistently of obtaining rutting severity from year-to-year. Estimates of the area affected by a given rut depth severity will continue to be difficult.

The data examination suggests a reasonable simplification for determination of rutting. The result of this revised procedure is shown in Table C-2. This procedure has been reduced by one area and one severity category. The "slight" (0 to 0.5 in.) severity category was eliminated leaving only moderate (0.5 in. to 1.0 in.) and severe (greater than 1.0 in.). The area of rutting has been reduced to either 1 to 30 percent of the lane or greater than 30 percent. An area of 30 percent is relatively easy to determine since this is only slightly larger than one wheel path in a lane.

It is of interest to note that the revised rutting procedure would indicate only 5 to 9 percent of Texas pavements would be rutted. The data recording form should be revised to record the actual rut depths measured, thus valuable information would not be lost for each highway segment evaluated.

Raveling

Examination of the four years of raveling percentages in Table C-3 shows that the amount is highly variable. The primary source of this variability is in "slight" (less than 10 percent of surface aggregates dislodged) severity category. The amount of raveling recorded for the "moderate" (10 to 50 percent of surface aggregate dislodged) and "severe" (greater than 50 percent of surface aggregate dislodged) categories were relatively constant over the four year period.

In order to eliminate some of the year-to-year variation, the results of a revised rating procedure are shown in Table C-4. This procedure reduces the area and severity by one category. The area of raveling has been reduced to those suggested for the revised rutting procedure and the "slight" severity category has been eliminated. It is felt that rating the "slight" condition is quite difficult for individuals thus leading to the large amount of year-to-year variability. Additionally, it has been observed that minor pop-outs which occur to some extent on many pavement surfaces are often mistakenly recorded as "slight" raveling.

Flushing

The amount of variability observed in Table C-5 for each of the four years is somewhat different than observed for the previously discussed distress types. The severity category of "slight" is relatively consistent for US & SH and FM highways. The variability primarily occurs in the "moderate" (coarse aggregate and asphalt nearly at same plane) and "severe" (black appearing surface, few aggregate particles visable) categories with the higher percentages being shown for 1976.

To eliminate at least part of this year-to-year variation, the results of a revised rating procedure are shown in Table C-6. As was done for the previous distress types, the area was reduced to two categories and the "slight" severity category eliminated. These changes do not eliminate the large year-to-year variations but the rating procedure is simplified and thus more consistent results may be expected in future years.

Corrugations

Table C-7 shows the results obtained for four years of data for the corrugation distress type. The percentages are generally quite low and variable for all three highway types. The "slight" category is sometimes difficult to judge particularly on surface treatment and seal coat pavement surfaces. It is recommended that this distress type be dropped from the rating procedure.

The results of a simplified rating procedure is shown as Table C-8 although this procedure is not recommended for use. As was done for the other distress types, the area categories were reduced to two and the "slight" (0 to 0.25 in. depth) severity category was eliminated.

Alligator Cracking

Table C-9 shows the results obtained for the alligator cracking distress type. Again, as observed for the previously discussed distress types, a significant amount of variability is observed. The differences shown between "slight" (hairline, less than 1/8 in.) and "moderate" (limited spalling an/or pumping) also vary.

Since alligator cracking is an important indicator of pavement structural integrity, a simplified rating procedure should not necessarily eliminate the "slight" category as was done for the other distress types. Instead, the "slight" and "moderate" categories can be combined along with a reduction in the area categories. The results of these modifications can be seen in Table C-10. The reason for the selection of the 1 to 5 percent and greater than 5 percent area categories should be noted. Pavements with alligator cracking amounts greater than 5 percent are considered to be truely distressed and the cracking is not likely to be of a localized nature.

Longitudinal Cracking

Table C-11 shows the results of the longitudinal cracking distress type. The results for this kind of distress are somewhat different than observed for the other distress types in that, overall, there is only a small amount of year-to-year variation. This is specially true since minor and major maintenance is performed on some of the study pavement segments each year. The major variations occur between "slight" (hairline, less than 1/8 in.) and "moderate" (some spalling, or pumping, or greater than 1/8 in.) severity categories.

To further reduce the data variation, the "slight" and "moderate" severity categories were combined and the area categories were reduced from three to two. The results of these changes can be seen in Table C-12.

Transverse Cracking

Table C-13 shows the results of the transverse cracking distress type. With a few exceptions, as observed for longitudinal cracking, there is an overall consistency in comparing the year-to-year percentages. A major source of variation occurs between the "slight" (hairline, less than 1/8 in.) and "moderate" (some spalling, or pumping, or greater than 1/8 in.) severity types.

To further reduce the data variation, the "slight" and "moderate" severity categories were combined and the area categories were reduced from three to two. The results of these changes can be seen in Table C-14.

Patching

Table C-15 shows the various percentages of patching observed during the four year period. The percentages are rather variable when year-to-year comparisons are made.

To achieve a higher degree of consistency, two simplifying modifications are recommended with the results shown in Table C-16. First, combine the "good" (adequate performance, patch is expected to serve function) and "fair" (marginal performance) severity categories into one category to be called "adequate". The "poor" (patch should replaced as soon as scheduling allows) category will be retained in its present form. Secondly, the three area categories can be reduced from three to two with the break between the two categories being five percent. The 5 percent level is considered to represent the separation between the localized and extensive amounts of distress.

Failures Per Mile

Table C-17 shows the percentages for the three currently used failures per mile severities. Inspection of the table shows that only small amounts of this distress type occurs in Texas. Additionally, it is reasonable to expect moderately sized year-to-year variations since the SDHPT responds quickly in repairing these failures.

Even though only small percentages of this distress type can be expected, a small simplifying change to the current rating procedure is recommended. The number of distress severity categories can be reduced from three to two as shown in Table C-18.

Other Considerations

As shown in Appendix B, the data collected for roadsides, drainage and traffic services exhibit a number of characteristics which result in the data being of marginal value. Coupled with the fact that such data are not distress related and that they are highly variable, it is recommended all data collection related to these items be eliminated.

Some of the pitfalls encountered in collecting information on these three data items should be amplified. For example, much of the information currently collected using the form is included in the maintenance formen's routine inspections. Thus, many of the observed dificiencies will be handled by routine SDHPT maintenance. Additionally, such rating items as "mowing", "litter", etc., are subject to policy and management decisions which may be unknown to the individuals conducting the rating. It is conceivable that a highway segment could be rated low due to tall grass on the right-of-way when in fact a policy decision has dictated that mowing be significantly reduced. Additionally, the information collected by use of the rating procedure takes time to process and analyze. It has been observed that by the time this has occurred routine SDHPT maintenance has often corrected the recorded dificiencies.

The data collected with respect to shoulders is distress related and should continue to be collected in its present form.

Summary and Conclusions

Overall, the year-to-year differences noted for the majority of the distress types are excessive and cannot totally be due to SDHPT major or minor maintenance. Thus, to make the rating procedure easier to use and the results more consistent, a number of recommended changes are offered. These changes in conjunction with the recommended changes in the main body of the report and Appendix B should significantly increase the accuracy and precision of the overall rating procedure. The proposed changes affect each of the distress types and will eliminate "corrugations" completely. The nondistress related items would also be eliminated. These changes will require a new rating form which will also require that the rating manual be revised. If the revision is accomplished, consideration should be given to improving the quality and increasing the number of photographs which depict various distress conditions. The new photographs should be color and reproduced by quality printing methods.

C-1. Percentage of Pavement Segments Which Exhibit Rutting Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments: Distress Area and Data Collection Year															
			1 - 15%				16 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Rutting	IH	Slight	14.3	13.3	5.6	23.8	0	13.3	11.1	52.4	0	0	0	0	14.3	26.6	16.7	76.2
		Moderate	0	0	0	4.8	0	0	0	0	0	0	0	0	0	0	0	4.8
		Severe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	14.3	13.3	5.6	28.6	0	13.3	11.1	52.4	0	0	0	0	14.3	26.6	16.7	81.0
	US & SH	Slight	12.4	19.1	10.2	33.0	5.6	10.6	3.1	32.1	1.1	1.1	0	1.8	19.1	30.8	13.3	66.9
		Moderate	0	0	0	2.8	3.4	4.3	2.0	1.8	0	2.1	0	0.9	3.4	6.4	2.0	5.5
		Severe	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0.9
		Area Total	12.4	19.1	10.2	35.8	9.0	14.9	5.1	33.9	1.1	3.2	0	3.6	22.5	37.2	15.3	73.3
	FM	Slight	17.3	19.2	9.6	35.3	2.9	9.6	3.5	29.4	1.0	1.0	0	0.8	21.2	29.8	13.1	65.5
		Moderate	1.9	0	3.5	5.9	1.9	0	4.4	2.5	0	1.0	0	0	3.8	1.0	7.9	8.4
		Severe	0	0	0	0.8	1.0	0	0	0	0	0	0	0	1.0	0	0	0.8
		Area Total	19.2	19.2	13.1	42.0	5.8	9.6	7.9	31.9	1.0	2.0	0	0.8	26.0	30.8	21.0	74.7

Table C-2. Percentage of Pavement Segments Which Exhibit Rutting Distress as Determined by a Revised Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments											
			Distress Area and Data Collection Year											
			1 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Rutting	IH	Moderate	0	0	0	4.8	0	0	0	0	0	0	0	4.8
		Severe	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	0	0	0	4.8	0	0	0	0	0	0	0	4.8
	US & SH	Moderate	3.4	4.3	2.0	4.6	0	2.1	0	0.9	3.4	6.4	2.0	5.5
		Severe	0	0	0	0	0	0	0	0.9	0	0	0	0.9
		Area Total	3.4	4.3	2.0	4.6	0	2.1	0	1.8	3.4	6.4	2.0	6.4
	FM	Moderate	3.8	0	7.9	8.4	0	1.0	0	0	3.8	1.0	7.9	8.4
		Severe	1.0	0	0	0.8	0	0	0	0	1.0	0	0	0.8
		Area Total	4.8	0	7.9	9.2	0	1.0	0	0	4.8	1.0	7.9	9.2

Note: 1. "Slight" severity category eliminated from original rating procedure.

2. Areas 1 and 2 combined into 1.

Table C-3. Percentage of Pavement Segments Which Exhibit Raveling Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments — Distress Area and Data Collection Year: 1 - 15%				16 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Raveling	IH	Slight	7.1	6.7	0	52.4	14.3	0	0	4.8	0	0	0	0	21.4	6.7	0	57.2
		Moderate	0	0	5.6	0	0	0	0	4.8	0	0	0	0	0	0	5.6	4.8
		Severe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	7.1	6.7	5.6	52.4	14.3	0	0	9.6	0	0	0	0	21.4	6.7	5.6	62.0
	US & SH	Slight	23.6	18.1	9.2	32.1	6.7	2.1	8.2	11.9	1.1	1.1	0	0	31.4	21.3	17.4	44.0
		Moderate	0	1.1	2.0	0.9	0	2.1	2.0	5.5	1.1	0	1.0	0	1.1	3.2	5.0	6.4
		Severe	0	0	0	0	0	0	1.0	0	0	0	0	0.9	0	0	1.0	0.9
		Area Total	23.6	19.2	11.2	33.0	6.7	4.2	11.2	17.4	2.2	1.1	1.0	0.9	32.5	24.5	23.4	51.3
	FM	Slight	23.1	26.9	19.3	35.3	7.7	8.7	5.3	16.0	4.8	1.9	9	0	35.6	37.5	24.6	51.3
		Moderate	3.8	3.8	4.4	2.5	8.7	7.7	7.0	7.6	5.8	2.9	0.9	2.5	18.3	14.4	12.3	12.6
		Severe	0	1.0	0	0	0	0	1.8	1.7	0	1.9	0.9	0	0	2.9	2.7	1.7
		Area Total	26.9	31.7	23.7	37.8	16.4	16.4	14.1	25.3	10.6	6.7	1.8	2.5	53.9	54.8	39.6	65.6

C-4. Percentage of Pavement Segments Which Exhibit Raveling Distress as Determined by a Revised Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments											
			Distress Area and Data Collection Year											
			1 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Raveling	IH	Moderate	0	0	5.6	4.8	0	0	0	0	0	0	5.6	4.8
		Severe	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	0	0	5.6	4.8	0	0	0	0	0	0	5.6	4.8
	US & SH	Moderate	0	3.2	4.0	6.4	1.1	0	1.0	0	1.1	3.2	5.0	6.4
		Severe	0	0	1.0	0	0	0	0	0.9	0	0	1.0	0.9
		Area Total	0	3.2	5.0	6.4	1.1	0	1.0	0.9	1.1	3.2	6.0	7.3
	FM	Moderate	12.5	11.5	11.4	10.1	5.8	2.9	0.9	2.5	18.3	14.4	12.3	12.6
		Severe	0	1.0	1.8	1.7	0	1.9	0.9	0	0	2.9	2.7	1.7
		Area Total	12.5	12.5	13.2	11.8	5.8	4.8	1.8	2.5	18.3	17.3	15.0	14.3

Note: 1. "Slight" severity category eliminated from original rating procedure.

2. Areas 1 and 2 combined into 1.

C-5. Percentage of Pavement Segments Which Exhibit Flushing Distress as Determined by the Current Rating Procedure.

			Percent of Segments															
Distress Type	Highway Type	Distress Severity	Distress Area and Data Collection Year															
			1 - 15%				16 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Flushing	IH	Slight	0	6.7	16.7	28.6	14.3	6.7	11.1	9.5	7.1	0	0	0	21.4	13.4	27.8	38.1
		Moderate	7.1	0	0	0	0	0	11.1	4.8	0	0	0	4.8	7.1	0	11.1	9.6
		Severe	0	0	0	4.8	0	0	0	4.8	0	0	0	0	0	0	0	9.6
		Area Total	7.1	6.7	16.7	33.4	14.3	6.7	22.2	19.1	7.1	0	0	4.8	28.5	13.4	38.9	57.3
	US & SH	Slight	11.2	26.6	19.4	25.7	10.1	7.4	13.3	6.4	4.5	2.1	3.1	0.9	25.8	36.1	35.8	33.0
		Moderate	4.5	2.1	7.1	5.5	5.6	3.2	7.1	14.7	1.1	3.2	3.1	5.5	11.2	8.5	17.3	25.7
		Severe	0	0	1.0	2.8	0	0	1.0	3.7	2.2	1.1	2.0	2.8	2.2	1.1	4.0	9.3
		Area Total	15.7	28.7	27.5	34.0	15.7	10.6	21.4	24.8	7.8	6.4	8.2	9.2	39.2	45.7	57.1	68.0
	FM	Slight	26.0	25.0	28.1	21.0	7.7	9.6	4.4	10.9	0	1.9	0	0	33.7	36.5	32.5	31.9
		Moderate	1.9	1.0	7.0	15.1	5.8	3.8	9.6	11.8	0.9	1.0	1.8	4.2	8.6	5.8	18.4	31.1
		Severe	0	0	0.9	4.2	1.0	0	2.6	3.4	1.0	0	0.9	3.4	2.0	0	4.4	11.0
		Area Total	27.9	26.0	36.0	40.3	14.5	13.4	16.6	26.1	1.9	2.9	2.7	7.6	44.3	42.3	55.3	74.0

C-6. Percentage of Pavement Segments Which Exhibit Flushing Distress as Determined by a Revised Rating Procedure.

			Percent of Segments											
Distress Type	Highway Type	Distress Severity	Distress Area and Data Collection Year											
			1 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Flushing	IH	Moderate	7.1	0	11.1	4.8	0	0	0	4.8	7.1	0	11.1	9.6
		Severe	0	0	0	9.6	0	0	0	0	0	0	0	9.6
		Area Total	7.1	0	11.1	14.4	0	0	0	4.8	7.1	0	11.1	19.2
	US & SH	Moderate	10.1	5.3	14.2	20.2	1.1	3.2	3.1	5.5	11.2	8.5	17.3	25.7
		Severe	0	0	2.0	6.5	2.2	1.1	2.0	2.8	2.2	1.1	4.0	9.3
		Area Total	10.1	5.3	16.2	26.7	3.3	4.3	5.1	8.3	13.4	9.6	21.3	35.0
	FM	Moderate	7.7	4.8	16.6	26.9	0.9	1.0	1.8	4.2	8.6	5.8	18.4	31.1
		Severe	1.0	0	3.5	7.6	1.0	0	0.9	3.4	2.0	0	4.4	11.0
		Area Total	8.7	4.8	20.1	34.5	1.9	1.0	2.7	7.6	10.6	5.8	22.8	42.1

Note: 1. "Slight" severity category eliminated from original rating procedure.

2. Areas 1 and 2 combined into 1.

C-7. Percentage of Pavement Segments Which Exhibit Corrugation Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments — Distress Area and Data Collection Year															
			1 - 15%				16 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Corrugations	IH	Slight	14.3	0	0	0	7.1	0	5.6	0	0	0	0	0	21.4	0	5.6	0
		Moderate	0	0	0	9.5	0	0	0	0	0	0	0	0	0	0	0	9.5
		Severe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	14.3	0	0	9.5	7.1	0	5.6	0	0	0	0	0	21.4	0	5.6	9.5
	US & SH	Slight	4.5	2.1	3.1	2.8	1.1	0	2.0	0	0	0	0	0	5.6	2.1	5.1	2.8
		Moderate	0	0	1.0	0	0	1.1	1.0	0	0	0	1.0	0	0	1.1	3.0	0
		Severe	0	0	0	0	0	0	0	0	1.1	0	0	0	1.1	0	0	0
		Area Total	4.5	2.1	4.1	2.8	1.1	1.1	3.0	0	1.1	0	1.0	0	6.7	3.2	8.1	2.8
	FM	Slight	3.8	6.7	11.4	5.9	2.9	0	4.4	0	1.0	1.0	0.9	0.8	7.7	7.7	16.7	6.7
		Moderate	1.9	1.0	4.4	0.8	1.9	1.0	0.9	0	0	0	0	0	3.8	2.0	5.3	0.8
		Severe	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0.8
		Area Total	5.7	7.7	15.8	7.5	4.8	1.0	5.3	0	1.0	1.0	0.9	0.8	11.5	9.7	22.0	8.3

C-8. Percentage of Pavement Segments Which Exhibit Corrugation Distress as Determined by a Revised Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments — Distress Area and Data Collection Year: 1 - 30%				>30%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Corrugations	IH	Moderate	0	0	0	9.5	0	0	0	0	0	0	0	9.5
		Severe	0	0	0	0	0	0	0	0	0	0	0	0
		Area Total	0	0	0	9.5	0	0	0	0	0	0	0	9.5
	US & SH	Moderate	0	1.1	2.0	0	0	0	1.0	0	0	1.1	3.0	0
		Severe	0	0	0	0	1.1	0	0	0	1.1	0	0	0
		Area Total	0	1.1	2.0	0	1.1	0	1.0	0	1.1	1.1	3.0	0
	FM	Moderate	3.8	2.0	5.3	0.8	0	0	0	0	3.8	2.0	5.3	0.8
		Severe	0	0	0	0.8	0	0	0	0	0	0	0	0.8
		Area Total	3.8	2.0	5.3	1.6	0	0	0	0	3.8	2.0	5.3	1.6

Note: 1. "Slight" severity category eliminated from original rating procedure.

2. Areas 1 and 2 combined into 1.

C-9. Percentage of Pavement Segments Which Exhibit Alligator Cracking Distress as Determined by the Current Rating Procedure.

			Percent of Segments																
			Distress Area and Data Collection Year																
Distress Type	Highway Type	Distress Severity	1 - 5%				6 - 25%				>25%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Alligator Cracking	IH	Slight	0	6.7	0	4.8	0	0	0	0	0	0	0	0	0	6.7	0	4.8
		Moderate	7.1	0	0	0	0	0	0	0	0	0	0	0	7.1	0	0	0
		Severe	0	0	0	0	0	0	0	4.8	0	0	0	0	0	0	0	4.8
		Area Total	7.1	6.7	0	4.8	0	0	0	4.8	0	0	0	0	7.1	6.7	0	9.6
	US & SH	Slight	9.0	2.1	5.1	10.1	0	0	2.0	2.8	3.4	1.1	1.0	0.9	12.4	3.2	8.1	13.8
		Moderate	1.1	0	1.0	10.1	2.2	0	7.1	6.4	1.1	1.1	0	0.9	4.4	1.1	8.1	17.4
		Severe	0	0	0	1.8	3.4	0	1.0	1.8	0	0	0	1.8	3.4	0	1.0	5.4
		Area Total	10.1	2.1	6.1	22.0	5.6	0	10.1	11.0	4.5	2.2	1.0	3.6	20.2	4.3	17.2	36.6
	FM	Slight	11.5	5.8	7.9	14.3	1.0	0	2.6	5.0	1.9	0	1.8	0	14.4	5.8	12.3	19.3
		Moderate	1.0	0	2.6	8.4	5.8	0	0	4.2	1.9	0	1.8	1.7	8.7	0	4.4	14.3
		Severe	1.0	1.0	0	0	0	0	0	0.8	1.0	0	0	0	2.0	1.0	0	0.8
		Area Total	13.5	6.8	10.5	22.7	6.8	0	2.6	10.0	4.8	0	3.6	1.7	25.1	6.8	16.7	34.4

C-10. Percentage of Pavement Segments Which Exhibit Alligator Cracking Distress as Determined by a Revised Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments: Distress Area and Data Collection Year: 1 - 5%				>5%				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Alligator Cracking	IH	Moderate	7.1	6.7	0	4.8	0	0	0	0	7.1	6.7	0	4.8
		Severe	0	0	0	0	0	0	0	4.8	0	0	0	4.8
		Area Total	7.1	6.7	0	4.8	0	0	0	4.8	7.1	6.7	0	9.6
	US & SH	Moderate	10.1	2.1	6.1	20.2	6.7	2.2	10.1	11.0	16.8	4.3	16.2	31.2
		Severe	0	0	0	1.8	3.4	0	1.0	3.6	3.4	0	1.0	5.4
		Area Total	10.1	2.1	6.1	22.0	10.1	2.2	11.1	14.6	20.2	4.3	17.2	36.6
	FM	Moderate	12.5	5.8	10.5	22.7	10.6	0	6.2	10.9	23.1	5.8	16.7	33.6
		Severe	1.0	1.0	0	0	1.0	0	0	0.8	2.0	1.0	0	0.8
		Area Total	13.5	6.8	10.5	22.7	11.6	0	6.2	11.7	25.1	6.8	16.7	34.4

Note: 1. "Moderate" and "slight" severity categories combined from original rating procedure.

2. Combined areas 2 and 3 into 2.

C-11. Percentage of Pavement Segments Which Exhibit Longitudinal Cracking Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments — Distress Area and Data Collection Year: 10-99 Lin. ft/Sta				100-199 Lin. ft/Sta				>200 Lin. ft/Sta				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Longitudinal Cracking	IH	Slight	28.6	20.0	16.7	9.5	0	6.7	11.1	9.5	0	6.7	5.6	0	28.6	33.4	33.4	19.0
		Moderate	14.3	0	0	14.3	0	0	5.6	4.8	0	0	0	0	14.3	0	5.6	19.1
		Severe	0	0	5.6	4.8	0	0	0	0	0	0	0	0	0	0	5.6	4.8
		Area Total	42.9	20.0	22.3	28.6	0	6.7	16.7	14.3	0	6.7	5.6	0	42.9	33.4	44.6	42.9
	US & SH	Slight	22.5	20.2	15.3	19.3	4.5	8.5	9.2	6.4	3.4	0	1.0	0	30.4	28.7	25.5	25.7
		Moderate	2.2	2.1	5.1	15.6	6.7	8.5	12.2	8.3	6.7	1.1	4.1	0	15.6	11.7	21.4	23.9
		Severe	0	0	0	0.9	0	0	0	0.9	2.2	1.1	4.1	0.9	2.2	1.1	4.1	2.7
		Area Total	24.7	22.3	20.4	35.8	11.2	17.0	21.4	15.6	12.3	2.2	9.2	0.9	48.2	41.5	51.0	52.3
	FM	Slight	16.3	19.2	23.7	21.8	5.8	5.8	2.6	4.2	3.8	1.0	4.4	0	25.9	26.0	30.7	26.0
		Moderate	1.9	1.9	0.9	9.2	2.9	2.9	3.5	5.9	1.9	0	1.8	0.8	6.7	4.8	6.2	15.9
		Severe	0	0	0	0	1.0	0	1.8	0	1.0	0	0	0	2.0	0	1.8	0
		Area Total	18.2	21.1	24.6	31.0	9.7	8.7	7.9	10.1	6.7	1.0	6.2	0.8	34.6	30.8	38.7	41.9

C-12. Percentage of Pavement Segments Which Exhibit Longitudinal Cracking Distress as Determined by a Revised Rating Procedure.

			Percent of Segments											
Distress Type	Highway Type	Distress Severity	Distress Area and Data Collection Year											
			1-100 Lin Ft/Sta				>100 Lin Ft/Sta				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Longitudinal Cracking	IH	Moderate	42.9	20.0	16.7	23.8	0	13.4	22.3	14.3	42.9	33.4	39.0	38.1
		Severe	0	0	5.6	4.8	0	0	0	0	0	0	5.6	4.8
		Area Total	42.9	20.0	22.3	28.6	0	13.4	22.3	14.3	42.9	33.4	44.6	42.9
	US & SH	Moderate	24.7	22.3	20.4	34.9	21.3	18.1	26.5	14.7	46.0	40.4	46.9	49.6
		Severe	0	0	0	0.9	2.2	1.1	4.1	1.8	2.2	1.1	4.1	2.7
		Area Total	24.7	22.3	20.4	35.8	23.5	19.2	30.6	16.5	48.2	41.5	51.0	52.3
	FM	Moderate	18.2	21.1	24.6	31.0	14.4	9.7	12.3	10.9	32.6	30.8	36.9	41.9
		Severe	0	0	0	0	2.0	0	1.8	0	2.0	0	1.8	0
		Area Total	18.2	21.1	24.6	31.0	16.4	9.7	14.1	10.9	34.6	30.8	38.7	41.9

Notes: 1. "Moderate" and "Slight" severity categories combined.

2. Combined areas 2 and 3 into 2.

C-13. Percentage of Pavement Segments Which Exhibit Transverse Cracking Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments															
			Distress Area and Data Collection Year															
			1-4 No./Sta				5-9 No./Sta				>10 No./Sta				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Transverse Cracking	IH	Slight	21.4	13.3	22.2	4.8	7.1	0	11.1	9.5	0	6.7	5.6	0	28.5	20.0	38.9	14.3
		Moderate	7.1	0	0	9.5	7.1	6.7	5.6	9.5	0	0	0	0	14.2	6.7	5.6	19.0
		Severe	0	0	0	4.8	0	0	0	4.8	0	0	0	0	0	0	0	9.6
		Area Total	28.5	13.3	22.2	19.1	14.2	6.7	16.7	23.8	0	6.7	5.6	0	42.7	26.7	44.5	42.9
	US & SH	Slight	18.0	10.6	8.2	12.8	9.0	10.6	12.2	5.5	3.4	2.1	3.1	1.8	30.4	23.3	23.5	20.1
		Moderate	2.2	2.1	3.1	5.5	6.7	4.3	10.2	14.7	4.5	8.5	10.2	4.6	13.4	14.9	23.5	24.8
		Severe	0	0	1.0	3.7	4.5	2.1	2.0	0	3.4	2.1	2.0	1.8	7.9	4.2	5.0	5.5
		Area Total	20.2	12.7	12.3	22.0	20.2	17.0	24.4	20.2	11.3	12.7	15.3	8.2	51.7	42.4	52.0	50.4
	FM	Slight	14.4	11.5	15.8	10.9	4.8	2.9	5.3	1.7	1.0	2.9	1.8	0.8	20.2	17.3	22.9	13.4
		Moderate	1.0	0	1.8	4.2	1.9	1.9	2.6	2.5	3.8	1.0	1.8	1.7	6.7	2.9	6.2	8.4
		Severe	0	0	0	0	0	0	0	0	1.9	0	1.8	0	1.9	0	1.8	0
		Area Total	15.4	11.5	17.6	15.1	6.7	4.8	7.9	4.2	6.7	3.9	5.4	2.5	28.8	20.2	30.9	21.8

C-14. Percentage of Pavement Segments Which Exhibit Transverse Cracking Distress as Determined by a Revised Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments											
			Distress Area and Data Collection Year											
			1 - 4 No./Sta				>4 No./Sta				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Transverse Cracking	IH	Moderate	28.5	13.3	22.2	14.3	14.2	13.4	22.3	19.0	42.7	26.7	44.5	33.3
		Severe	0	0	0	4.8	0	0	0	4.8	0	0	0	9.6
		Area Total	28.5	13.3	22.2	19.1	14.2	13.4	22.3	23.8	42.7	26.7	44.5	42.9
	US & SH	Moderate	20.2	12.7	11.3	18.3	23.6	25.5	35.7	26.6	43.8	38.2	47.0	44.9
		Severe	0	0	1.0	3.7	7.9	4.2	4.0	1.8	7.9	4.2	5.0	5.5
		Area Total	20.2	12.7	12.3	22.0	31.5	29.7	39.7	28.4	51.7	42.4	52.0	50.4
	FM	Moderate	15.4	11.5	17.6	15.1	11.5	8.7	11.5	6.7	26.9	20.2	29.1	21.8
		Severe	0	0	0	0	1.9	0	1.8	0	1.9	0	1.8	0
		Area Total	15.4	11.5	17.6	15.1	13.4	8.7	13.3	6.7	28.8	20.2	30.9	21.8

Notes: 1. "Moderate" and "slight" severity categories combined.

2. Combined areas 2 and 3 into 2.

C-15. Percentage of Pavement Segments Which Exhibit Patching Distress as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	1 - 5% Area 73	74	75	76	6 - 15% Area 73	74	75	76	>15% Area 73	74	75	76	Severity Total 73	74	75	76
Patching	IH	Good	0	6.7	5.6	4.8	0	13.3	5.6	0	0	0	11.1	0	0	20.0	22.3	4.8
		Fair	7.1	6.7	0	4.8	0	0	0	9.5	0	0	0	0	7.1	6.7	0	14.3
		Poor	7.1	0	5.6	0	0	0	0	0	0	0	0	4.8	7.1	0	5.6	4.8
		Area Total	14.2	13.4	11.2	9.6	0	13.3	5.6	9.5	0	0	11.1	4.8	14.2	26.7	27.9	23.9
	US & SH	Good	11.2	25.5	23.5	17.4	3.4	5.3	14.3	5.5	2.2	2.1	4.1	2.8	16.8	32.9	41.9	25.7
		Fair	10.1	1.1	7.1	5.5	3.4	9.6	2.0	3.7	1.1	4.3	4.1	2.8	14.6	15.0	13.2	12.0
		Poor	0	1.1	0	0.9	0	0	1.0	0.9	0	1.1	2.0	0.9	0	2.2	3.0	2.7
		Area Total	21.3	27.7	30.6	23.8	6.8	14.9	17.3	10.1	3.3	7.5	10.2	6.5	31.4	50.1	58.1	40.4
	FM	Good	16.3	19.2	19.3	21.0	2.9	3.8	10.5	6.7	3.8	2.9	15.8	5.0	23.0	25.9	45.6	32.7
		Fair	5.8	15.4	7.0	8.4	6.7	16.3	7.0	5.9	4.8	7.7	3.5	3.4	17.3	39.4	17.5	17.7
		Poor	5.8	1.9	1.8	1.7	2.9	2.9	0.9	2.5	1.9	4.8	4.4	2.5	10.6	9.6	7.1	6.7
		Area Total	27.9	36.5	28.1	31.1	12.5	23.0	18.4	15.1	10.5	15.4	23.7	10.9	50.9	74.9	70.2	57.1

Percent of Segments — Distress Area and Data Collection Year

C-16. Percentage of Pavement Segments Which Exhibit Patching Distress as Determined by a Revised Rating Procedure.

	Percent of Segments													
Distress Type	Highway Type	Distress Severity	Distress Area and Data Collection Year											
			1 - 5% Area				>5% Area				Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Patching	IH	Adequate	7.1	13.4	5.6	9.6	0	13.3	16.7	9.5	7.1	26.7	22.3	19.1
		Poor	7.1	0	5.6	0	0	0	0	4.8	7.1	0	5.6	4.8
		Area Total	14.2	13.4	11.2	9.6	0	13.3	16.7	14.3	14.2	26.7	27.9	23.9
	US & SH	Adequate	21.3	26.6	30.6	22.9	10.1	21.3	24.5	14.8	31.4	47.9	55.1	37.7
		Poor	0	1.1	0	0.9	0	1.1	3.0	1.8	0	2.2	3.0	2.7
		Area Total	21.3	27.7	30.6	23.8	10.1	22.4	27.5	16.6	31.4	50.1	58.1	40.4
	FM	Adequate	22.1	34.6	26.3	29.4	18.2	30.7	36.8	21.0	40.3	65.3	63.1	50.4
		Poor	5.8	1.9	1.8	1.7	4.8	7.7	5.3	5.0	10.6	9.6	7.1	6.7
		Area Total	27.9	36.5	28.1	31.1	23.0	38.4	42.1	26.0	50.9	74.9	70.2	57.1

Notes: 1. "Good" and "Fair" severity categories combined into "adequate".

2. Combined areas 2 and 3 into 2.

C-17. Percentage of Pavement Segments Which Exhibit Failures as Determined by the Current Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments															
			Data Collection Year												Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Failures Per Mile	IH	1-5	0	0	0	0												
		6-10	0	0	0	0												
		>10	0	0	0	0												
		Total	0	0	0	0												
	US & SH	1-5	0	1.1	5.1	1.8												
		6-10	0	0	0	0												
		>10	0	0	0	0												
		Total	0	1.1	5.1	1.8												
	FM	1-5	4.8	5.8	9.6	4.2												
		6-10	0	0	2.6	0.8												
		>10	0	1.0	0.9	0.8												
		Total	4.8	6.8	13.1	5.8												

C-18. Percentage of Pavement Segments Which Exhibit Failures as Determined by a Revised Rating Procedure.

Distress Type	Highway Type	Distress Severity	Percent of Segments: Data Collection Year								Severity Total			
			73	74	75	76	73	74	75	76	73	74	75	76
Failures Per Mile	IH	1-5	0	0	0	0								
		>5	0	0	0	0								
		Total	0	0	0	0								
	US & SH	1-5	0	1.1	5.1	1.8								
		>5	0	0	0	0								
		Total	0	1.1	5.1	1.8								
	FM	1-5	4.8	5.8	9.6	4.2								
		>5	0	1.0	3.5	1.6								
		Total	4.8	6.8	13.1	5.8								

Note: 1. Combined "6-10" and ">10" into ">5".

APPENDIX D. AN ANALYSIS TO DETERMINE THE REQUIRED NUMBER OF SAMPLES REQUIRED WITHIN A TWO-MILE HIGHWAY SEGMENT

Introduction

One of the requirements in conducting statewide sampling of performance data is how many samples for a given type of data should be taken within a specified length of highway. Some data types do not require such determinations. For example, the Mays Ride Meter instrument is used to determine Serviceability Index values at preset reporting intervals. For those data types which do require such determinations, there are several methods which can be used to determine the "best" or optimal sampling plan. Two possible approaches are presented in this Appendix. The first one presented is based on utility theory and is a way that both the cost and sampling variability can be objectively combined. The second approach only considers the actual and tolerable variability of the data in determining the required number of samples.

An estimate of the variability of the data to be sampled is basic in any procedure used to determine the required number of samples. This estimate of variability is either the standard deviation or the coefficient of variation. By using simple random sampling and an estimate of the data variability, the sampling precision for a given number of samples can be determined. As the number of samples increases, the sampling precision increases. The sampling precision for a simple random sample is measured by the standard error or as developed in the main body of this report the coefficient of sampling variation. For a random sample these two measures can be determined by the following:

$$SE = \frac{S}{\sqrt{N}} \qquad \text{(D-1)}$$

where:

SE = standard error of a randomly obtained number of samples for a specified length of highway

S = standard deviation of a population of data contained in the specified length of highway

N = number of samples taken in the specified length of highway

and

$$CSV = \frac{CV}{\sqrt{N}} \qquad \text{(D-2)}$$

where:

CSV = coefficient of sampling variation of a randomly obtained number of samples for a specified length of highway

CV = coefficient of variation of a population of data contained in the specified length of highway

N = number of samples taken in the specified length of highway

By using these equations which relate a measure of sampling error with data variability and sample size, we can now begin to see the relative benefits of various numbers of samples. This is first demonstrated in Table D-1 which shows how the standard error for Serviceability Index and Pavement Rating Score decreases for various levels of standard deviation and number of samples. It is apparent that the initial reduction in standard error is quite large between one to five samples. This trend is more graphically shown in Figure D-1 which is plot of the coefficient of sampling variation and the number of samples for various levels of coefficient of variation.

Both Table D-1 and Figure D-1 can be used to obtain a rough estimate of an appropriate number of samples if "typical" standard deviations and

Table D-1. Serviceability Index and Pavement Rating Score Standard Errors for Various Levels of Standard Deviation and Number of Samples

Number of Samples	Serviceability Index Standard Error for Various Levels of Standard Deviation.				
	0.2	0.4	0.6	0.8	1.0
1	0.20	0.40	0.60	0.80	1.00
2	0.14	0.28	0.42	0.57	0.71
3	0.12	0.23	0.35	0.46	0.58
4	0.10	0.20	0.30	0.40	0.50
5	0.09	0.18	0.27	0.36	0.45
10	0.06	0.13	0.19	0.25	0.32
15	0.05	0.10	0.15	0.21	0.29
20	0.04	0.09	0.13	0.18	0.22
30	0.04	0.07	0.11	0.15	0.18
40	0.03	0.06	0.09	0.13	0.16

Number of Samples	Pavement Rating Score Standard Error for Various Levels of Standard Deviation				
	5	10	15	20	25
1	5.0	10.0	15.0	20.0	25.0
2	3.5	7.1	10.6	14.1	17.7
3	2.9	5.8	8.7	11.5	14.4
4	2.5	5.0	7.5	10.0	12.5
5	2.2	4.5	6.7	8.9	11.2
10	1.6	3.2	4.7	6.3	7.9
15	1.3	2.6	3.9	5.2	6.5
20	1.1	2.2	3.4	4.5	5.6
30	0.9	1.8	2.7	3.7	4.6
40	0.8	1.6	2.4	3.2	4.0

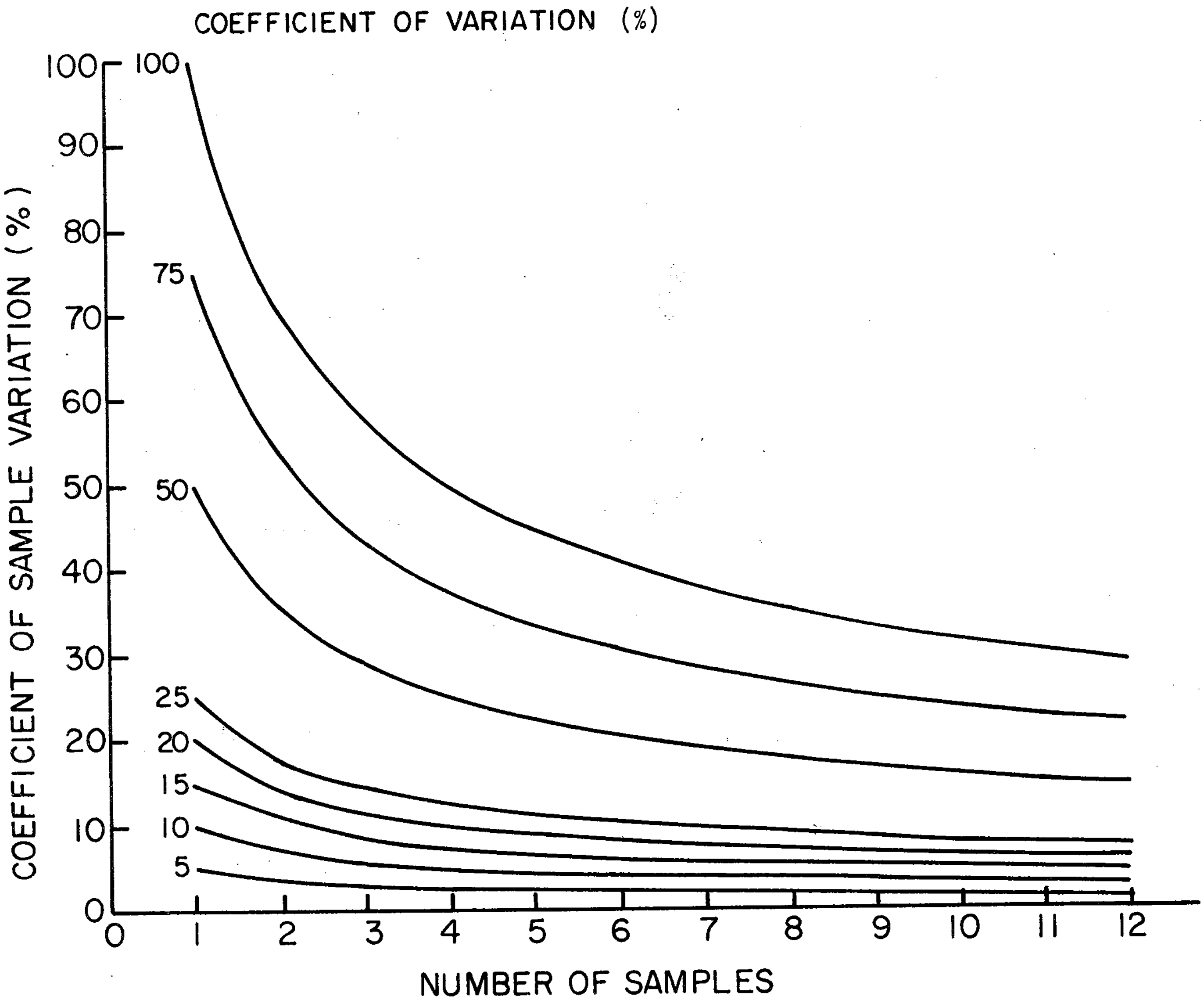


Figure D-1. Coefficient of Sampling Variation Versus Number of Samples for Various Coefficient of Variation Levels coefficients of variation are known for various data types. Typical values derived from the mass inventory survey accomplished in District 21 are listed in Table D-2 for various data and highway type combinations. The lower values for the ranges shown were determined by examining the data contained in two-mile segments throughout the district. The lower values may not be conservative since the number of individual data points in each two-mile segment were generally quite small. The larger values are based on the districtwide standard deviations and coefficients of variation and should represent reasonable upper limits for each of the data types.

The two more detailed procedures which can be used to estimate required numbers of samples will now be presented.

Utility Method

Utility theory was used in the main body of the report to select an optimal range of sample sizes. These sample sizes can then be used to determine the number of highway segments required to estimate districtwide values of pavement performance related data. We now want to take this process one step further and determine the optimal number of samples (or stops) required to adequately estimate the data mean within any highway segment.

The procedure used to maximize utility thus determining the optimal number of samples is virtually identical to that developed previously in this report. The decision criteria used are data collection costs and sampling variation. The data collection costs are represented by cost ratios and were assumed to be linear with increasing numbers of samples. Thus, one sample has a cost ratio of one, two samples a cost ratio of two,

Table D-2. Ranges of Measures of Variability Obtained From District 21 Data

Data Type	Highway Type	Range of Measures of Variability	
		Standard Deviation	Coefficient of Variation
SI	US & SH	0.3 - 0.7	9 - 22
	FM	0.3 - 0.8	12 - 31
SCI	US & SH	0.3 - 0.5	43 - 71
	FM	0.3 - 0.4	38 - 50
SN	US & SH	0.04 - 0.10	12 - 31
	FM	0.04 - 0.09	11 - 26
PRS	US & SH	4 - 14	5 - 18
	FM	5 - 16	6 - 21

etc. The sampling variability was measured by the coefficient of sampling variation as determined by use of Equation D-2.

The utility curves used to determine all utilities are shown in Figure D-2. Three separate curves were used in this figure to evaluate the effect of varying the cost ratios at which zero utility occurs. All three of these curves are "risk neutral". The coefficient of sampling variation utility curve has a utility of zero when the coefficient is 100 percent. This recognizes that data populations within highway segments require larger numbers of samples when the variation of such populations are large. Additionally, influencing the lower utility limit is that a range of coefficients of variation were examined with the largest being 100 percent.

To determine the optimal number of samples, the two decision criteria were combined by use of an additive model which is identical to the one shown as Equation 5:

$$SU = W_1U_1 + W_2U_2 \qquad \text{(D-3)}$$

where:

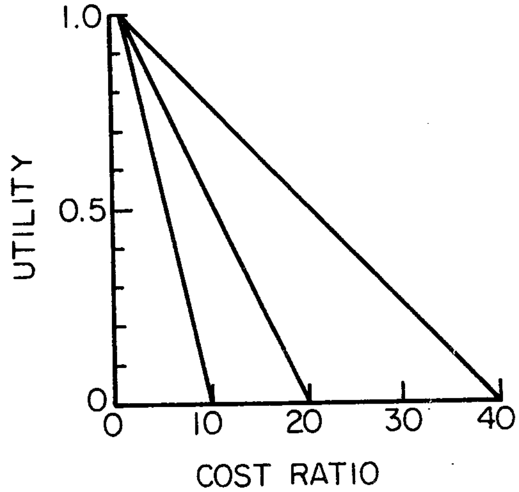
SU = sampling utility

U_1 = utility determined by use of the cost ratio associated with various numbers of samples

U_2 = utility determined by use of the coefficient of sampling variation associated with various numbers of samples

W_1, W_2 = utility weighting factors with requirement that $\sum_{i=1}^{2} W_i = 1$

The difference between the two models is that the cost and sampling variability were independent of data type for this application. This additive relationship between the two decision criteria was used to determine the maximum sampling utility for various levels of coefficients of variation



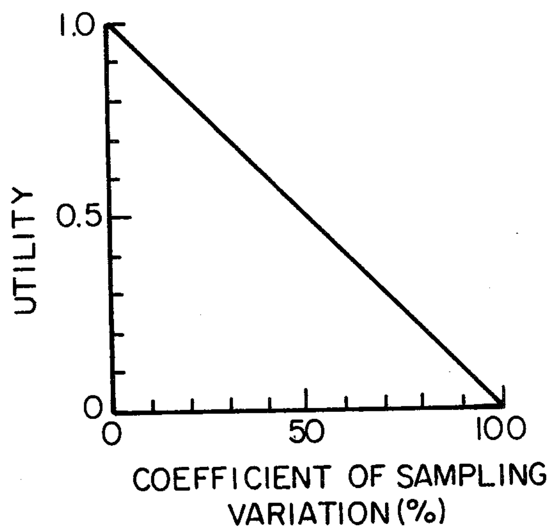


Figure D-2. Decision Criteria Utility Curves and utility weighting factors.

Figures D-3 through D-5 show the results of using the above utility model. The three figures were each developed for a different maximum number of tolerable samples, i.e., it is recognized that the optimal number of samples as determined by this procedure is dependent on the maximum number of samples a person is willing to collect for a specified length of highway. The maximum number of samples used were 10, 20, and 40. The utility weights shown in each of the three figures significantly influence the optimum. In general, if the utility due to cost is weighted more heavily than the utility due to sampling variation, the optimal sample decreases. Conversely, the optimal sample increases if the utility due to sampling variation is weighted more heavily.

Table D-3 is a summary of the information shown in Figures D-3 through D-5. In this table the optimal number of samples are shown for various levels of coefficients of variation, utility weights, and maximum number of samples. It is observed that the optimal number of samples increase with increasing coefficients of variation. Additionally, for some of the lower coefficient of variation levels, a maximum sampling utility is not achieved. Thus, the optimal number of samples for these cases are reported as being equal to one. The optimal sampling utilities are also shown and decrease with increasing coefficient of variation values.

An example which demonstrates the use of the information contained in Table D-3 can be illustrated for Pavement Rating Score data. Assume that the maximum number of samples to be considered for a two-mile highway segment is twenty and that the variability of Pavement Rating Score is expected to be twenty percent. Additionally, you are more inclined to reduce data variability as opposed to sampling cost (W_1 = 0.25, W_2 = 0.75).

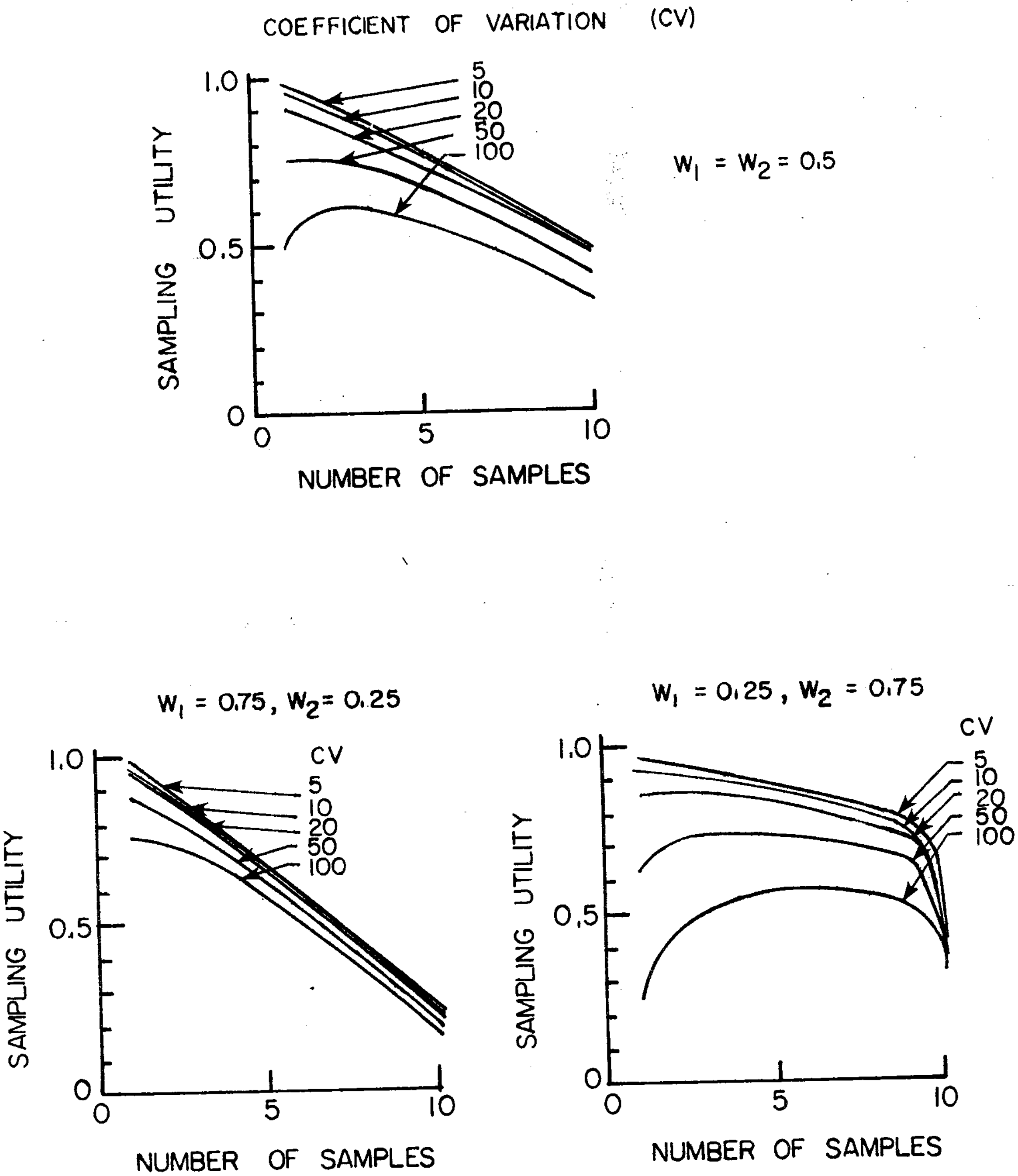


Figure D-3. Utility Determination of Optimal Number of Samples for a Maximum Sample Size Equal to Ten

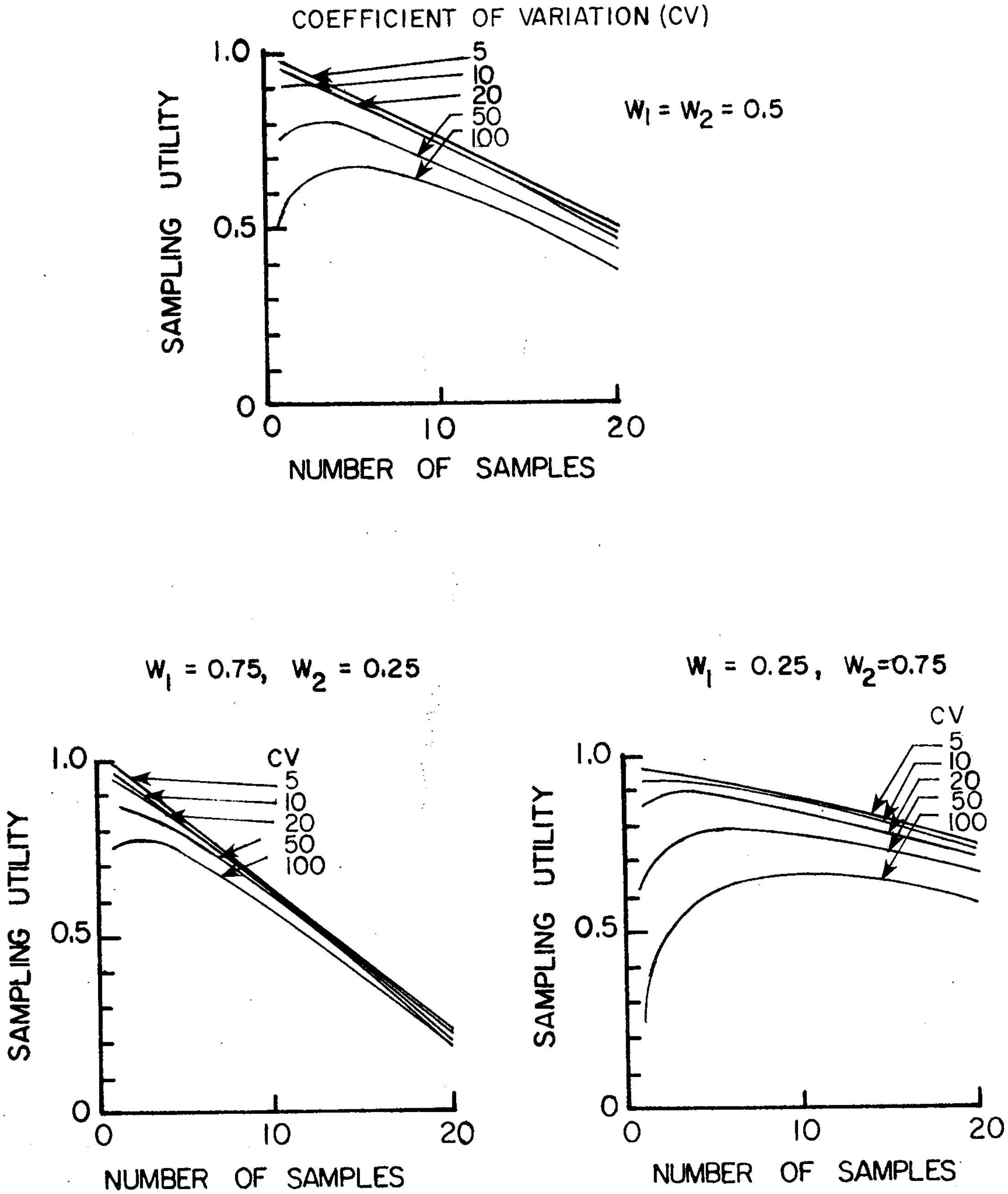


Figure D-4. Utility Determination of Optimal Number of Samples for a Maximum Sample Size Equal to Twenty

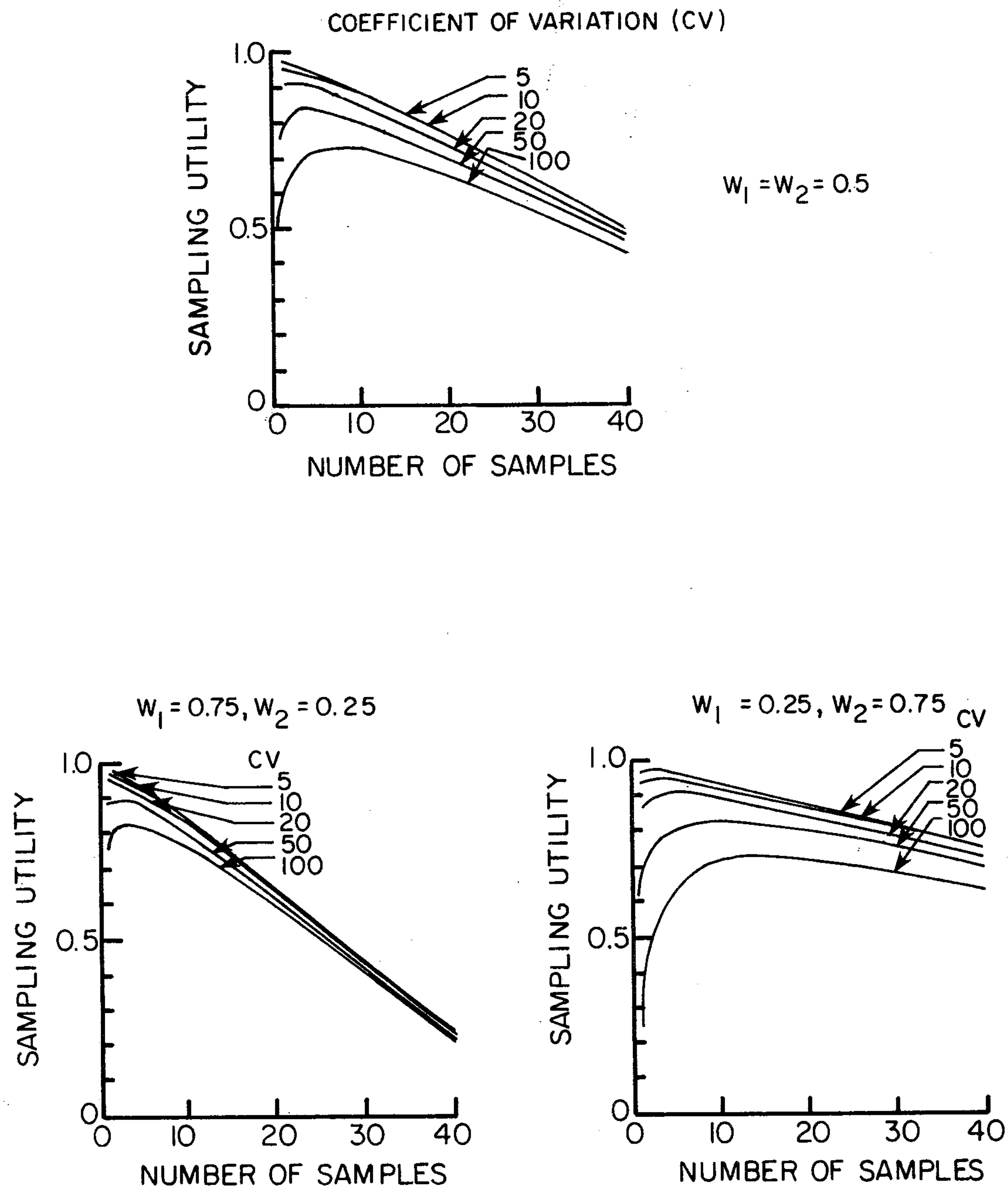


Figure D-5. Utility Determination of Optimal Number of Samples for a Maximum Sample Size Equal to Forty

Table D-3. Summary of Optimum Number of Samples

Maximum Number of Samples	Utility Weights W_1	Utility Weights W_2	Coefficient of Variation (%)	Optimum Sampling Utility	Optimum Number of Samples
10	0.75	0.25	5	-	1
			10	-	1
			20	-	1
			50	-	1
			100	-	1
	0.50	0.50	5	-	1
			10	-	1
			20	-	1
			50	0.77	2
			100	0.60	3
	0.25	0.75	5	-	1
			10	-	1
			20	0.87	2
			50	0.73	3
			100	0.56	6

Table D-3. Continued

Maximum Number of Samples	Utility Weights		Coefficient of Variation (%)	Optimum Sampling Utility	Optimum Number of Samples
	W_1	W_2			
20	0.75	0.25	5	-	1
			10	-	1
			20	-	1
			50	-	1
			100	0.78	2
	0.50	0.50	5	-	1
			10	-	1
			20	0.90	2
			50	0.80	3
			100	0.67	5
	0.25	0.75	5	-	1
			10	0.93	2
			20	0.87	3
			50	0.78	7
			100	0.65	10

Table D-3. Continued

Maximum Number of Samples	Utility Weights		Coefficient of Variation (%)	Optimum Sampling Utility	Optimum Number of Samples
	W_1	W_2			
40	0.75	0.25	5	-	1
			10	-	1
			20	-	1
			50	0.89	3
			100	0.82	4
	0.50	0.50	5	-	1
			10	0.95	2
			20	0.92	3
			50	0.84	4
			100	0.74	7
	0.25	0.75	5	0.97	2
			10	0.94	4
			20	0.91	5
			50	0.82	9
			100	0.72	15

Therefore, at least three stops should be made within each two-mile segment. This may be rounded up to require that stops be made each one-half mile within the segment.

It is apparent that determination of optimal samples which consider multiple decision criteria are a function of various factors and as such there are no absolutes in making such determinations.

Precision Method

A method which uses probability considerations can also provide an indication of the required number of samples for a sampling plan. The method is based on the fact that the precision of the data estimates improve as the number of samples increase.

The population mean for a given data type and length of highway lies within an interval defined by the following probability statement:

$$P(\bar{x} - Z_{1-\alpha/2}\,SE \leq \mu \leq \bar{x} + Z_{1-\alpha/2}\,SE) = 1 - \alpha \qquad \text{(D-4)}$$

where:

$\bar{x}$ = sample mean

$Z_{1-\frac{\alpha}{2}}$ = standard normal variable at a specified level of significance

SE = $S/\sqrt{N}$ = sample error of a randomly obtained number of samples

S = population standard deviation

μ = population mean

α = level of significance

By use of Equation D-4 we can specify with a 100 $(1-\alpha)$ percent confidence level that the population mean will fall within an interval length of $\pm d$ which is equal to $\pm Z_{1-\alpha/2}\, S/\sqrt{N}$. This interval length also represents the precision of the estimate. By rearranging terms the required number of samples for a given confidence level is:

$$N = \left[\frac{z_{1-\alpha/2}\ S}{d}\right]^2 \qquad \text{(D-5)}$$

To calculate the required number of samples by use of Equation D-5, the population standard deviation must be known or estimated and the data precision and confidence level selected. These three inputs can also be used in conjunction with Figure D-6 to determine the required number of samples. Equation D-5 was used to develop this figure which is a plot of several S/d ratios for various confidence levels. A maximum sample size of 25 was used in the figure and for situations where larger numbers of samples may be required the equation can be utilized.

An example which demonstrates the use of this method will be made by using the Pavement Rating Score data type and Figure D-6. Assume that an estimate of the mean Pavement Rating Score is required for a two-mile highway segment. For this segment the standard deviation is estimated to be 5 PRS units and the precision is requested to be no larger than ± 2.5 PRS units. The S/d ratio is therefore set at 5/2.5 = 2.0. If an acceptable confidence level is 75 percent, the required number of samples (stops) are five.

In actual practice separate estimates for individual two-mile segments would not be made for mass inventory surveys. This type of method could more realistically be used in determining the number of samples required to sample a specified highway length (e.g. two-miles) for data types collected on the three types of highways (IH, US & SH, FM) in a district or statewide.

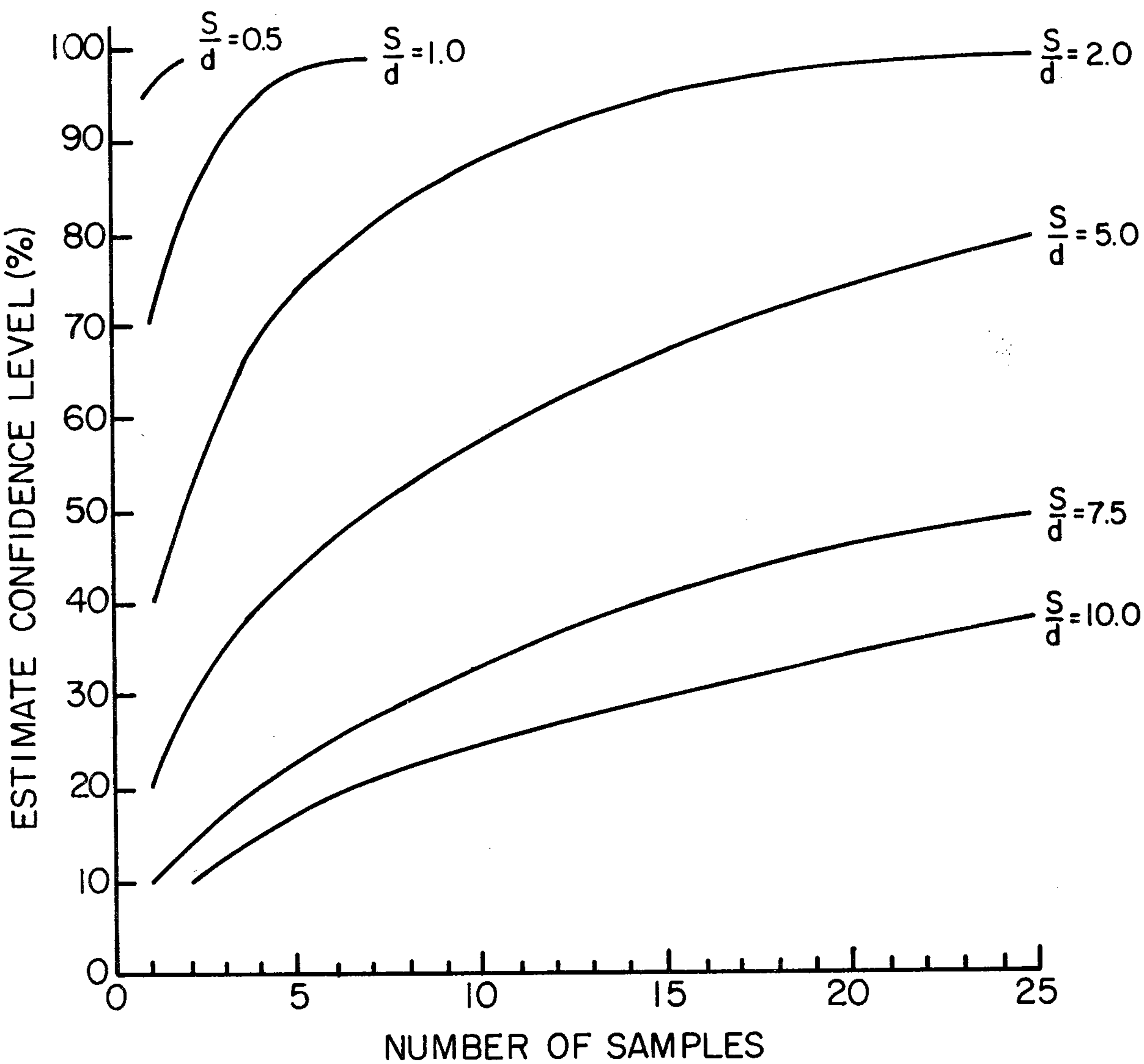


Figure D-6. Precesion Method for Determining the Required Number of Samples