DEVELOPMENT OF A PROCEDURE FOR ROUTE SEGMENTATION USING PREDICTED LAYER THICKNESSES FROM RADAR MEASUREMENTS

FLORIDA DOT STATE PROJECT 99700-7550, PHASE 2A

FINAL REPORT PREPARED BY:

EMMANUEL G. FERNANDO, PhD., P.E.
Assistant Research Engineer
Texas Transportation Institute

and

TENG-SOO CHUA
Graduate Research Assistant
Texas Transportation Institute

THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS 77843

September 1993

CHAPTER 1. INTRODUCTION

Massive quantities of data can be accumulated very quickly with current ground penetrating radar equipment and software (e.g., approximately 1 trace every 2 feet at 35 mph). Depending on the size of a given network, and the frequency of sampling, the processing of radar data can yield a voluminous amount of layer thickness information on the network surveyed. For example, given a sampling rate of 1 trace every 2 feet, and a 100 mile network, layer thickness estimates for 264,000 points along the network can be generated for each lane surveyed. To be useful for pavement management applications, a post-processing stage is important, during which time, the given network is subdivided into homogeneous sections or segments based on the radar predictions. Summary data, such as mean surface and base thicknesses on the different sections, can then be reported, which would be more useful for pavement management applications than a mere listing of layer thickness estimates at individual points along the network. Consequently, a procedure for route segmentation based on the predictions from the radar analysis is required in order for the processed data to be more functional.

A computerized procedure for route segmentation in the post-processing stage is discussed in this report. The program developed uses the cumulative difference approach as the basis for delineation. This methodology has previously been applied for delineating pavement sections based on measured surface deflections, or backcalculated layer stiffnesses along a given route. Other criteria, such as minimum section length, and minimum difference between means of adjacent segments, are also used. The important features of the procedure are presented in the subsequent chapters. In addition, sample applications are provided using measured radar data from in-service pavements to illustrate the procedure. A user's guide to the computer program is also provided in an appendix.

CHAPTER 2. DELINEATION OF HOMOGENEOUS SEGMENTS FROM RADAR PREDICTIONS

The analysis of continuous radar data taken over a given route will generate predictions of layer thicknesses and dielectric constants at specified intervals over the given route. For pavement management purposes, it would be necessary to divide the given route into a number of homogeneous sections based on the interpretation of the radar predictions. For instance, examination of a plot of predicted asphalt thickness versus distance along the given route will likely show variations in asphalt thickness. For pavement rehabilitation purposes, it would be useful to divide the route into a number of segments within which the predicted asphalt thicknesses are more or less uniform.

As part of Florida Study 99700-7550, "Development of a Procedure for the Automated Collection of Flexible Pavement Layer Thicknesses and Materials," a computer program was developed to carry out the segmentation of continuous radar data based on the cumulative difference approach. This methodology is discussed in the 1986 AASHTO pavement design guide as a recommended procedure for delineating sections using measured surface deflections. The principles behind this methodology are illustrated in Figure 2-1. In this figure, the values of a response variable, r_1, r_2, and r_3, along a hypothetical project of length L_s, are plotted (Figure 2-1a). The cumulative area at any point within the project can be calculated by integrating the response variable over the distance associated with the given point. For example, at the point, x, shown in Figure 2-1b, the cumulative area is given by the integral:

$$A_x = \int_0^{x_1} r_1 \, dx + \int_{x_1}^{x} r_2 \, dx \qquad (2\text{-}1)$$

If the cumulative area with distance along the project is plotted, a graph such as that shown by the solid line in Figure 2-1b results. However, if the cumulative area is computed based on the average response

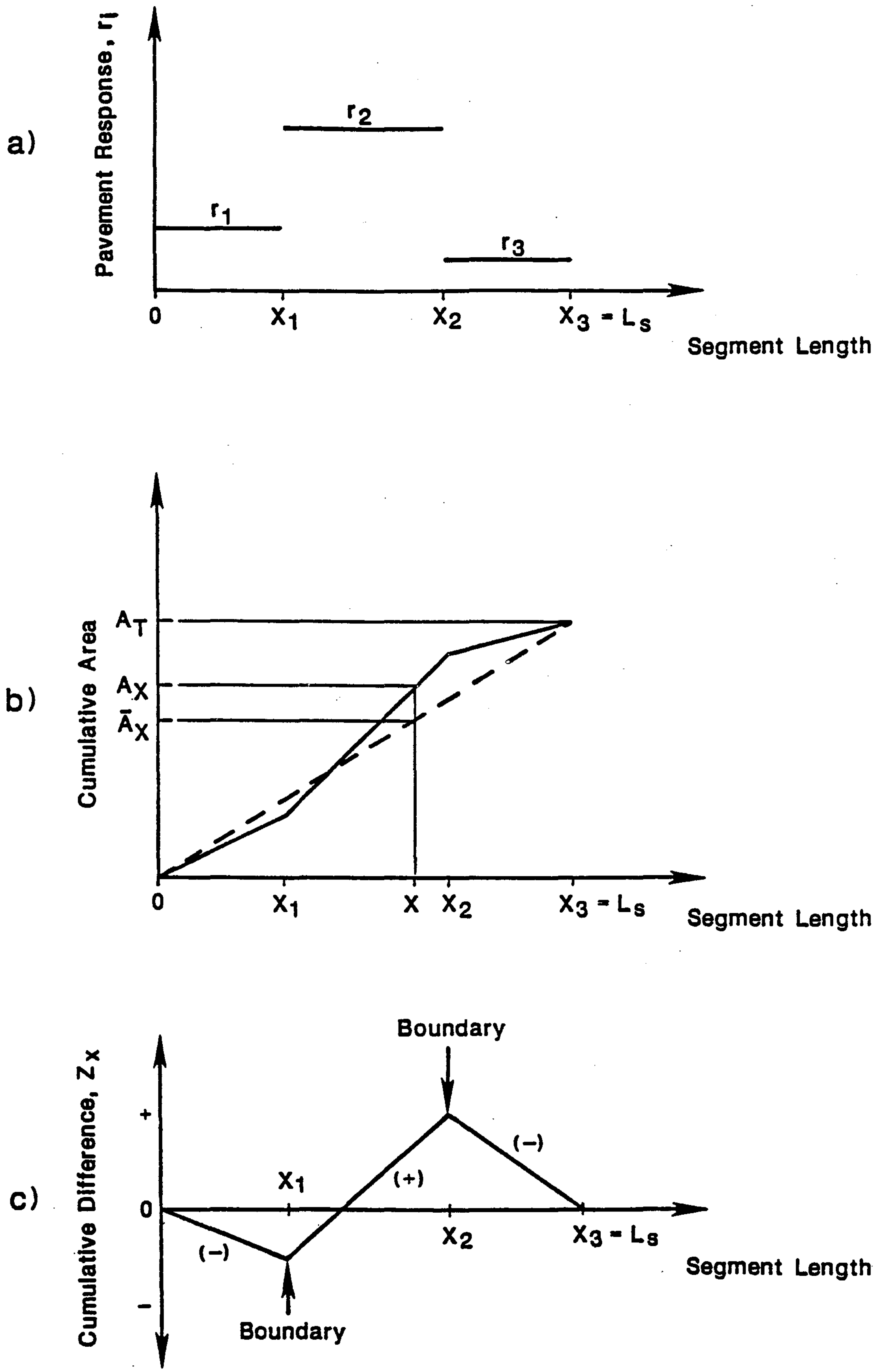


Figure 2-1. Cumulative difference approach to unit delineation (after 1986 AASHTO Pavement Design Guide).

along the project length, a graph such as that shown by the dashed line in Figure 2-1b results. For example, at the point, *x*, shown in Figure 2-1b, the cumulative area based on average response, is given by:

$$\overline{A}_x = \int_0^x \overline{r}\, dx = \overline{r}\, x \tag{2-2}$$

where,

$$\overline{r} = \frac{\int_0^{x_1} r_1\, dx + \int_{x_1}^{x_2} r_2\, dx + \int_{x_2}^{x_3} r_3\, dx}{L_s} = \frac{A_s}{L_s} \tag{2-3}$$

where, A_s, is the cumulative area over the project length. From the preceding equations, the cumulative difference, Z_x, at any point within the project is evaluated as follows:

$$Z_x = A_x - \overline{A}_x \tag{2-4}$$

If the cumulative difference, Z_x, is plotted with distance along the project, a graph such as that shown in Figure 2-1c results. By examining this graph, one observes that the location of unit boundaries correspond to points at which the slope of Z_x changes sign. The application of this concept to the segmentation of radar data is discussed in the following.

SAMPLE APPLICATION OF THE CUMULATIVE DIFFERENCE METHOD

Consider the predicted profile of asphalt thickness shown in Figure 2-2. The predictions shown were obtained from analysis of radar data taken on a 2-mile in-service pavement section along US 71 in

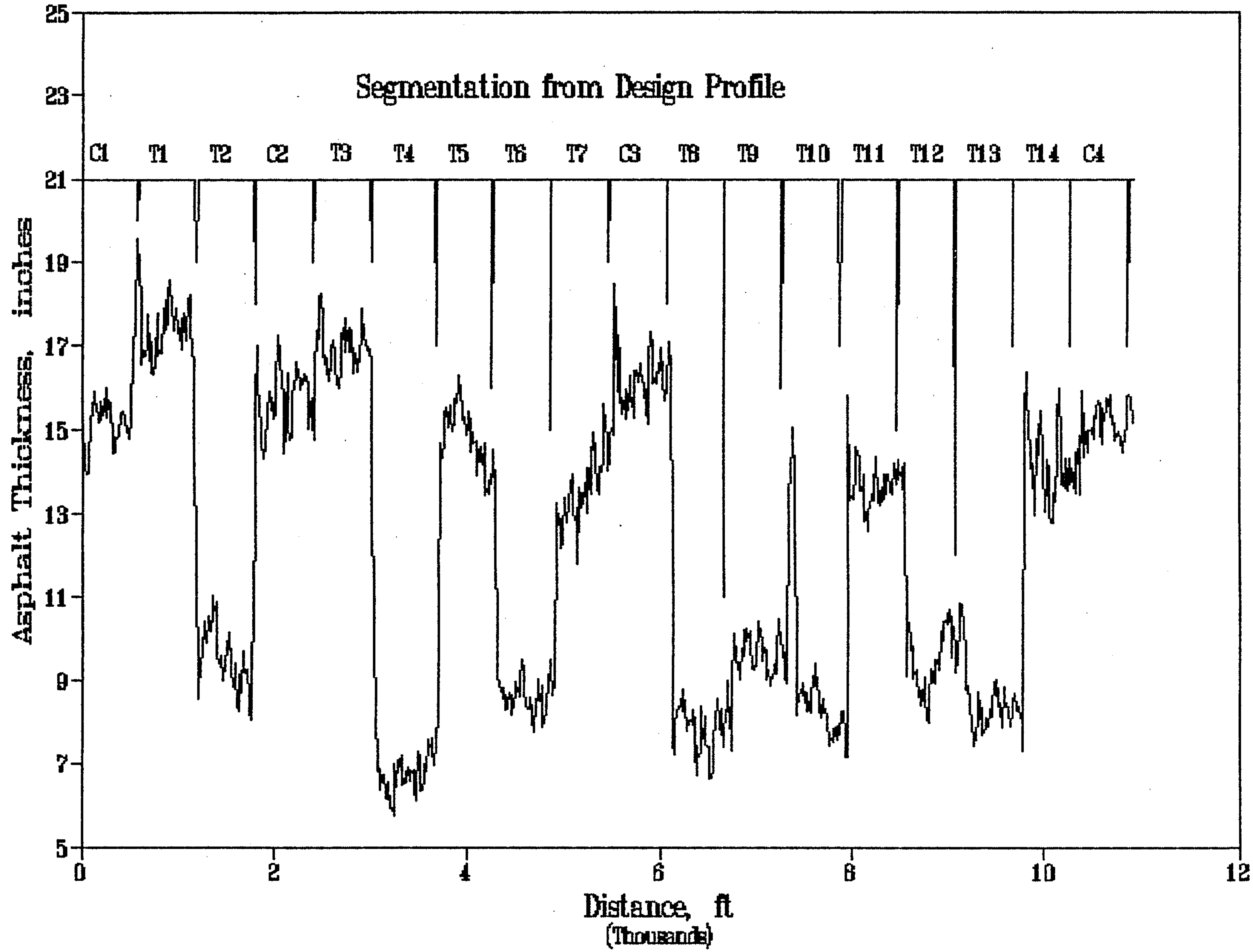


Figure 2-2. Predicted asphalt thickness profile for a 2-mile in-service pavement section.

Alexandria, Louisiana. From this figure, one observes that there are sharp changes in asphalt thickness on this 2-mile project, which actually consists of 18 test sections of different base material types and layer thicknesses. The different test sections are also indicated in Figure 2-2. Since the actual segmentation of the project is known, it would represent an ideal proving ground for verifying the effectiveness of the cumulative difference method for route segmentation based on radar predictions.

Consequently, using asphalt thickness as the response variable, the cumulative difference method was applied to delineate homogeneous units within this 2-mile project. Figure 2-3 shows a plot of the cumulative difference, Z_x, superimposed on the previous plot of predicted asphalt thickness profile. From this figure, it is evident that locations at which sharp changes in asphalt thickness occur correspond to points at which the slope of Z_x changes sign.

In using the cumulative difference method for segmenting radar data, it was recognized that, for practical purposes, some constraints need to be placed on the length of a delineation unit to filter out what may be considered as highly localized irregularities, and to have, for example, homogeneous units that will be viable rehabilitation projects. In view of this, a minimum section length of 200 feet was assumed for the segmentation of the radar data shown in Figure 2-2. In addition, a constraint was placed on the minimum difference in mean thicknesses between adjacent sections. For the purpose of illustrating the concept, a minimum difference of 0.50 inches was used. Obviously, these constraints may change depending on the particular pavement management application, and on Department policy.

The following steps were followed in the application of the cumulative difference method reported herein:

1. The method is used with the predicted asphalt thicknesses, and a plot is made of the predicted thicknesses, and cumulative difference, Z_x, as illustrated in Figure 2-3.
2. The radar data is divided into homogeneous units by locating points on the plot where the sign of the slope of Z_x changes. In addition, checks are made to verify that the constraints specified previously are satisfied. For example, note that by the cumulative difference

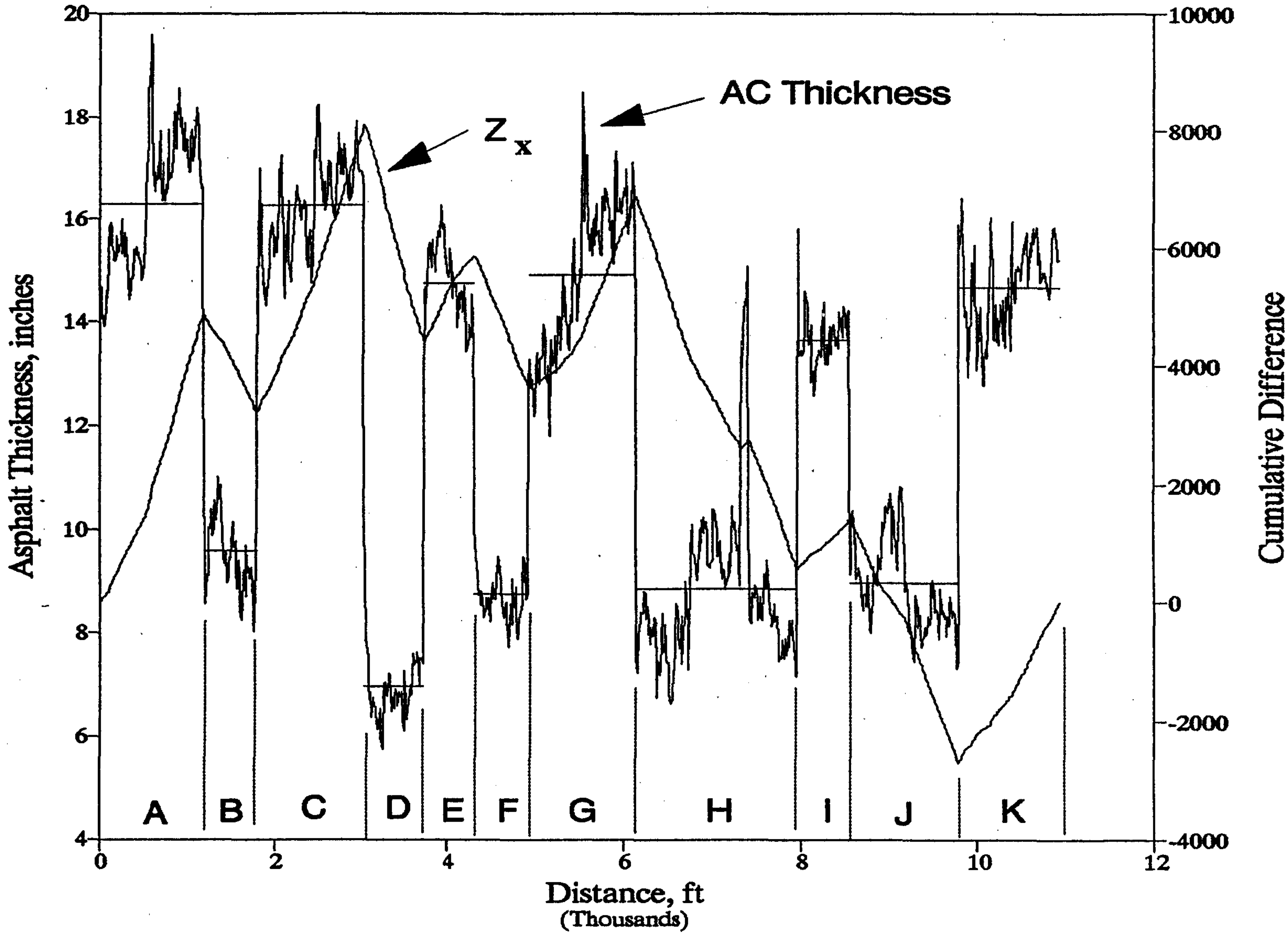


Figure 2-3. Results from initial run of delineation program.

method, there should be a section at approximately 7500 feet in Figure 2-3. However, the length of the unit that results will be less than the minimum section length of 200 feet so that the section is merged with the adjacent units. This step produces a segmentation of the predicted thickness profile into homogeneous units as illustrated in Figure 2-3.

3. The mean thickness of each section is calculated. In Figure 2-3, the horizontal bars correspond to the mean thicknesses of the different sections determined. Where the difference in mean thicknesses of adjacent sections is less than 0.50 inches, such sections are combined into a single unit. The length of the unit so formed is subdivided no longer.
4. Should there be remaining sections which can further be subdivided, the cumulative difference program is run on each of these sections. Steps 2 and 3 are repeated for each section, and this process of successive delineation continues until no more sections can be subdivided. At this stage, the route is considered to be fully segmented.

Figures 2-3 to 2-5 illustrate the results obtained using the procedure just described. Figure 2-3 shows the results from the initial pass of the delineation program. Based on this run, the project was divided into 11 units (A to K) with mean asphalt thicknesses indicated by the horizontal bars in Figure 2-3. The delineation program was then run on each of the 11 units established from the first pass. The results from this second pass are shown in Figure 2-4. It is observed that a majority of the sections determined from the initial pass undergo further segmentation during the second pass, specifically, units A, B, C, E, G, H, J, and K. Most of these get subdivided into 2 parts, with the exception of units H and J, which get subdivided into 3 parts.

Figure 2-5 shows the results from the third pass. At this cycle, only units G and H undergo further segmentation. Because of the constraints established, no further segmentation is possible after the third pass.

Table 2-1 shows the final delineation of the project, showing in sequence, the homogeneous units determined, their limits, and the means and standard deviations of the predicted asphalt thicknesses within each

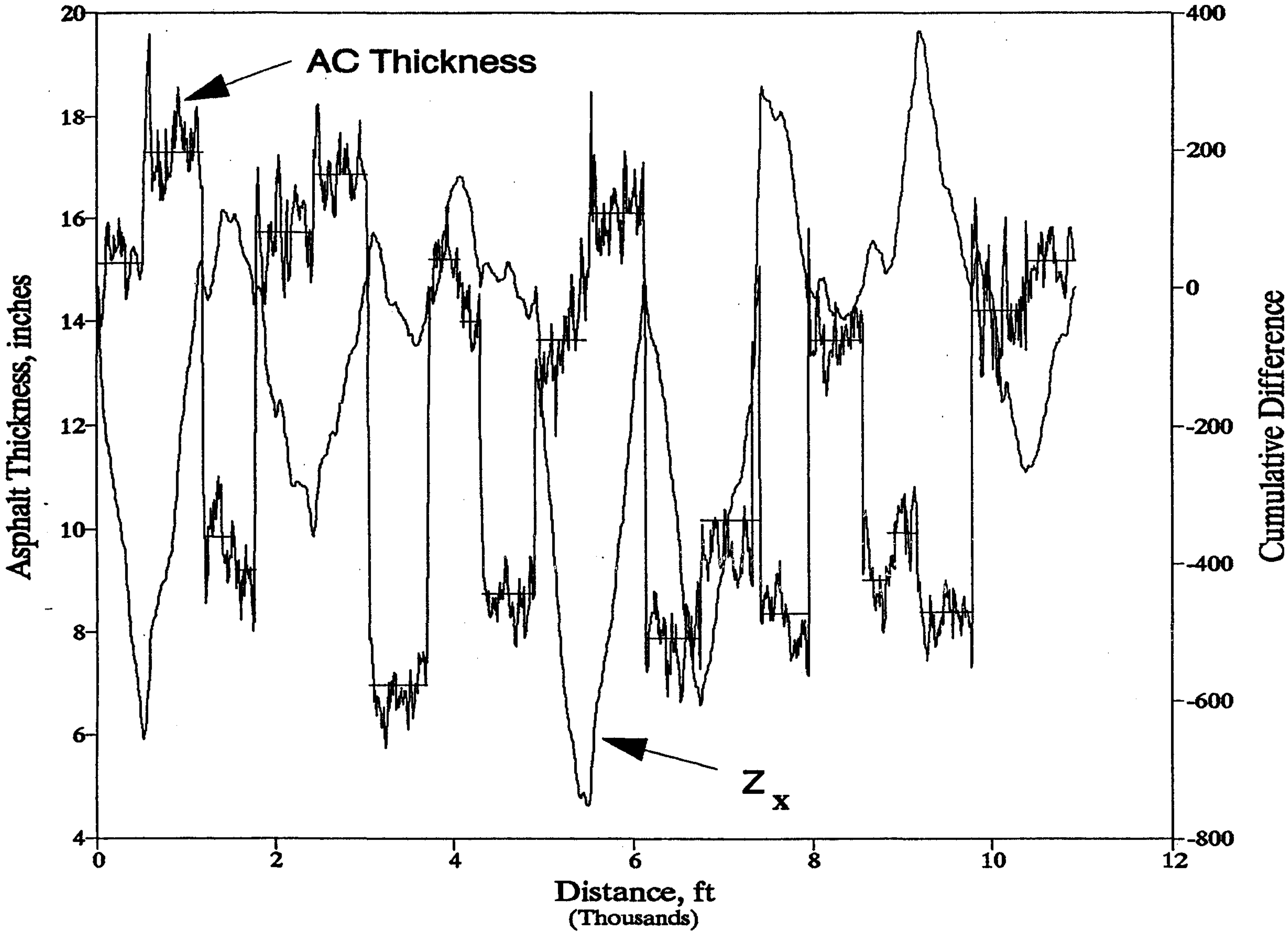


Figure 2-4. Results from second un of delineation program.

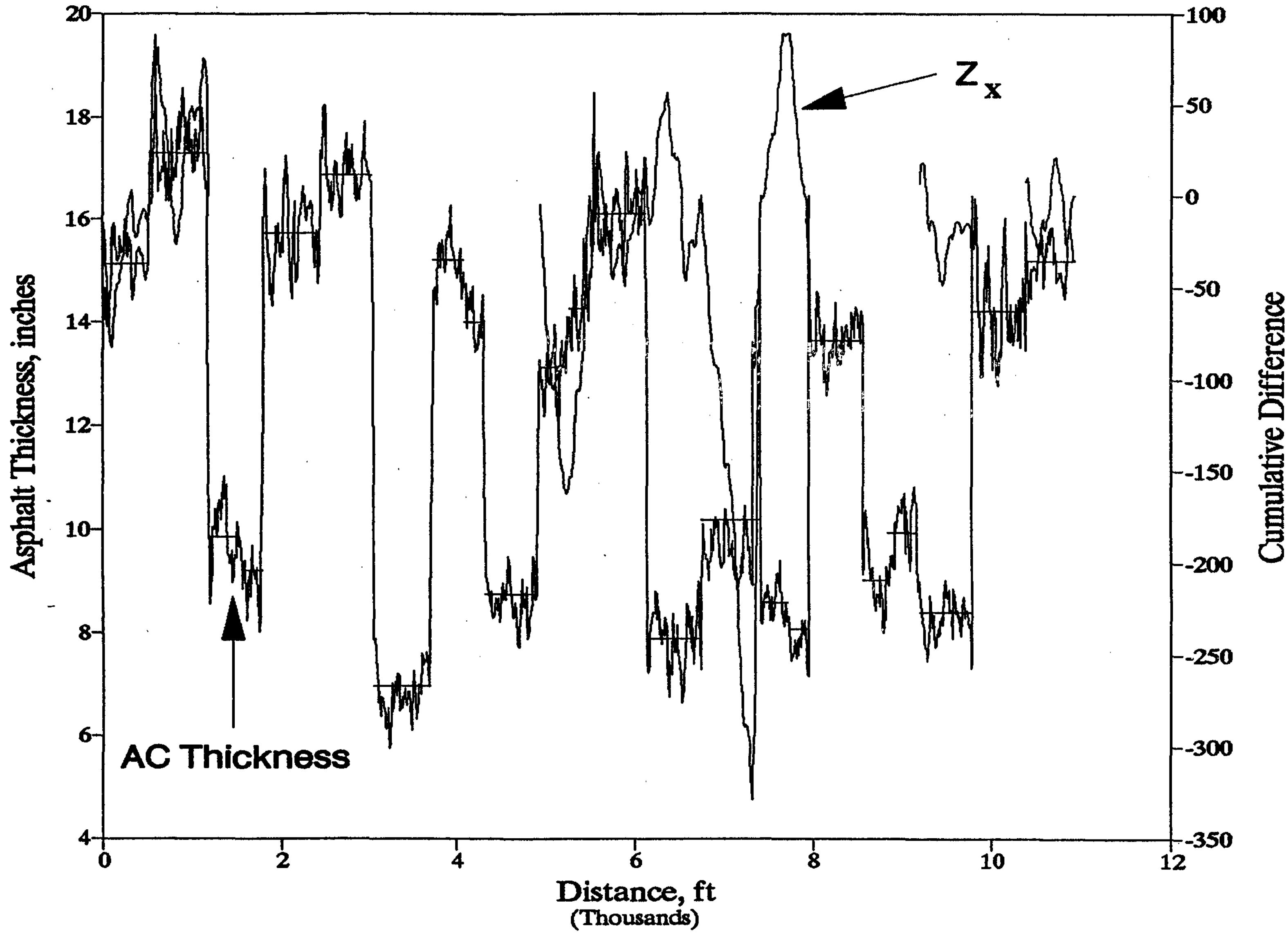


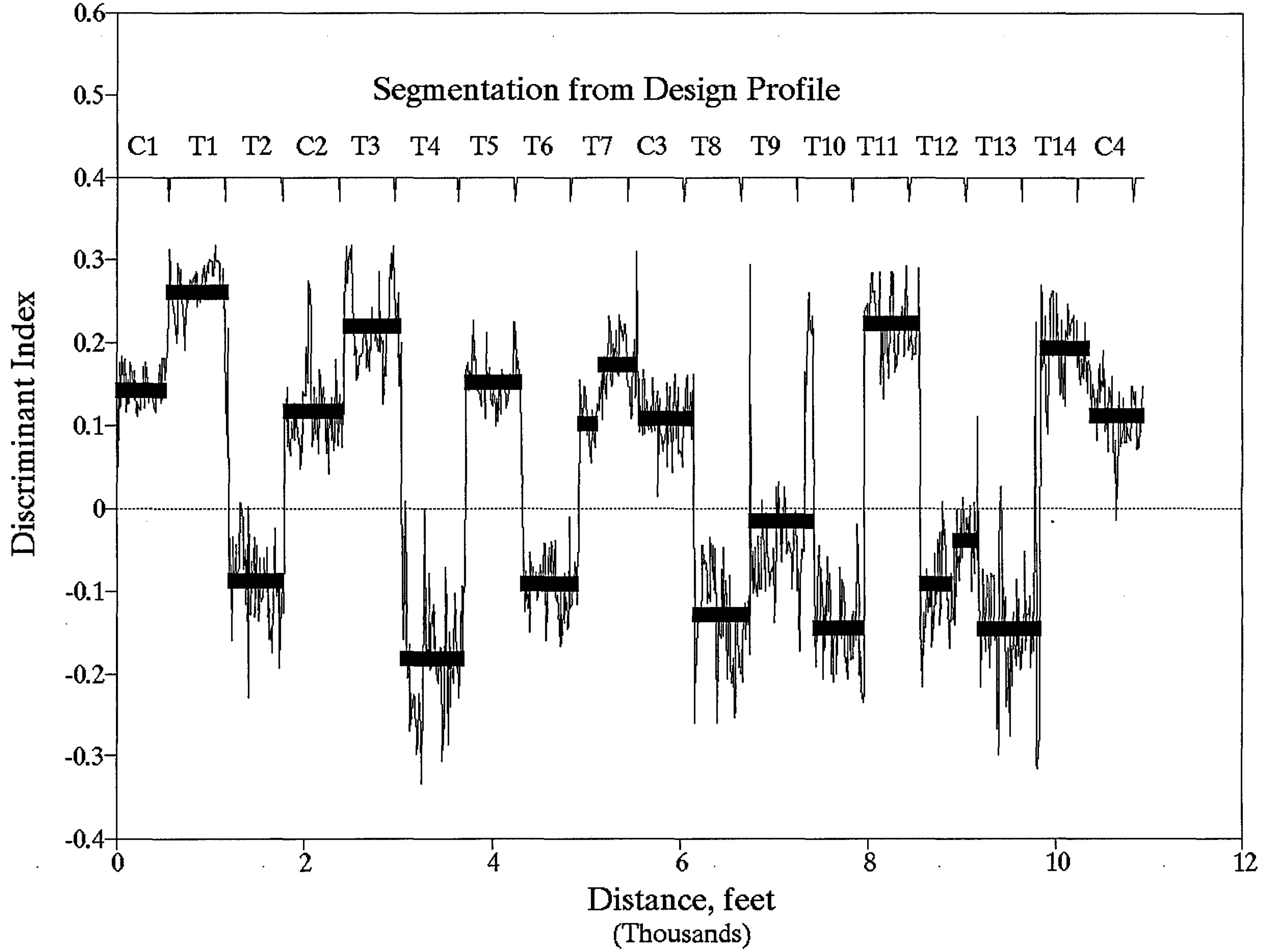
Figure 2-5. Results from third n of delineation program.

Table 2-1. Tabular Summary of Results From Delineation Program.

Section	Limits (ft.)		AC Thickness (in.)	
	From	To	Mean	Std. Deviation
1	12	530	15.1	0.55
2	540	1,195	17.3	1.09
3	1,206	1,551	9.9	0.59
4	1,561	1,795	9.2	0.98
5	1,805	2,427	15.7	0.70
6	2,437	3,019	16.9	0.65
7	3,029	3,713	7.0	0.84
8	3,723	4,073	15.2	0.52
9	4,083	4,306	14.0	0.58
10	4,316	4,921	8.7	0.71
11	4,931	5,244	13.1	0.49
12	5,254	5,492	14.3	0.56
13	5,502	6,133	16.1	0.75
14	6,143	6,749	7.9	0.56
15	6,759	7,422	10.2	1.60
16	7,432	7,729	8.6	0.33
17	7,738	7,964	8.1	1.67
18	7,974	8,556	13.6	0.42
19	8,566	8,824	9.0	0.59
20	8,834	9,180	9.9	0.60
21	9,190	9,791	8.4	1.04
22	9,801	10,380	14.2	0.84
23	10,390	10,926	15.2	0.42

unit. This table illustrates the kinds of output that may be generated from the post-processing of radar predictions.

Figure 2-6 compares the segmentation of the 2-mile project using predicted asphalt thicknesses with the actual segmentation. The horizontal bars in the figure denote the means of the predicted asphalt thicknesses for the various segments determined. It is observed that, in general, the results from application of the cumulative difference method are consistent with the actual segmentation. However, it is observed that test sections T2, T5, T7, T10, and T12, have been further subdivided into two subsections due to the variability in the predicted asphalt thicknesses in each of these sections. This result therefore illustrates the degree of detail with which a route can be segmented using the cumulative difference method with the radar predictions. The results are of course influenced by the criteria used for minimum section length and minimum difference between means of adjacent sections. Smaller values for these criteria would tend to result in a more detailed route segmentation. In addition, the segmentation will also be affected by the response variable used, e.g., base thickness, or base dielectric constant. Consequently, in practice, it is expected that separate delineations, based on a number of response variables, may need to be conducted. The final segmentation will then be based on an overall assessment of the different results.


Segmentation from Design Profile
C1 T1 T2 C2 T3 T4 T5 T6 T7 C3 T8 T9 T10 T11 T12 T13 T14 C4
Discriminant Index
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
2
4
6
8
10
12
Distance, feet
(Thousands)

CHAPTER 3. IMPROVEMENTS TO THE INITIAL SEGMENTATION PROCEDURE

In the previous chapter, the application of the cumulative difference method in delineating a project into homogeneous units, was introduced. The proposed procedure incorporates user-specified criteria on minimum section length and minimum difference between means of adjacent sections or segments. A test of the procedure was made using radar predictions on a 2-mile project where the actual segmentation was known, and the results obtained were generally found to be consistent with the known project segmentation. Nevertheless, it was observed that when the procedure was used to delineate other routes with higher variability in the predicted pavement responses, other considerations became necessary in order to arrive at more meaningful segmentation results. This is best explained by referring to Table 3-1 which shows intermediate results from application of the current procedure using predictions obtained from analysis of radar data taken along US 231, from the Bay County line to the I-10 east ramp, in District 3 in Florida. The segmentation was conducted using the predicted layer 2 thickness as the response variable. In addition, a minimum section length of 0.25 miles, and a minimum difference between adjacent section means of 0.50 inches were specified. Based on these criteria, the results shown in Table 3-1 were obtained.

A deficiency in the existing methodology comes to light when significance tests on the difference between adjacent section means are carried out. When these tests are conducted, it may be found that the means of certain adjacent sections are not statistically different from each other even though the difference between the means is at least equal to the prescribed minimum.

The test of significance of the difference between means is made using the 2-sample t-test described in Appendix A. In this test, a t-statistic is calculated from the means and standard deviations of the values of the predicted response variable for any 2 adjacent segments. This statistic is then compared with a critical t-value established on the basis of a user-specified confidence level. For a 2-sided t-test, the means are considered to be statistically different, at the specified

Table 3-1. Sample segmentation based on application of criteria on minimum section length and minimum difference between adjacent section means.

Section	Starting Milepost	Ending Milepost	Length (miles)	Layer 2 Thickness (in.)		Sample Size	t-statistic
				Mean	Standard Deviation		
A	0.000	1.230	1.230	8.66	2.48	124	8.571
B	1.230	2.071	0.841	11.81	2.58	75	2.346
C	2.071	3.111	1.040	12.65	2.20	104	5.221
D	3.111	3.721	0.610	14.95	3.45	61	4.631
E	3.721	4.031	0.310	11.81	2.14	31	3.642
F	4.031	5.241	1.210	13.90	3.01	121	10.078
G	5.241	6.461	1.220	10.90	1.33	122	6.034
H	6.461	6.961	0.500	12.49	2.04	50	25.710
I	6.961	8.749	1.788	7.65	0.79	180	10.599
J	8.749	9.609	0.860	8.83	0.93	83	33.616
K	9.609	12.712	3.103	4.07	1.20	309	26.695
L	12.712	13.030	0.318	10.21	1.27	30	N/A

confidence level, if the absolute value of the t-statistic is greater than or equal to the critical value.

Referring to Table 3-1, t-statistics for all adjacent segments (i.e., segments A and B, B and C, C and D,.....,K and L) were calculated and the results listed therein. At a confidence level of 99 percent and for the sample sizes of interest, the critical t-value is determined to be 2.576. It is observed from Table 3-1 that all of the t-statistics are greater than this critical value with the exception of that for segment B (t=2.346). This indicates that the means of the predicted layer 2 thicknesses for segments B and C are not significantly different at the specified confidence level even though the difference between the means satisfies the prescribed minimum of 0.50 inches. This result therefore shows the need for evaluating the significance of the difference between adjacent section means.

Consequently, an additional criterion was established for the segmentation algorithm, which is referred to herein as the test of significance criterion. This criterion is implemented in the modified algorithm as follows:

1. Sections are initially established based on the criteria specified for minimum section length and minimum difference between adjacent section means.
2. Starting with the first two segments, i.e., segments A and B, the t-statistic is calculated following the procedure given in Appendix A. This statistic is compared to the critical value to establish whether the means of the two segments are significantly different. The critical t-value is determined based on the user-specified confidence level and the sample sizes of the segments being compared.
3. If the means of two adjacent segments are significantly different based on the t-test, the segments are left as they are, and the t-statistic is then calculated for the next two adjacent segments, e.g., segments B and C, C and D, D and E, etc. Another t-test is subsequently conducted, and this process is continued until there are no more adjacent segments to compare, or when two adjacent segments fail the test of significance.
4. If the means of two adjacent segments are not significantly different based on the t-test, the two segments are combined to form a new

section with a different mean and standard deviation. The mean of this new section is then compared with the mean of the succeeding section (if one so exists), and the process goes back to step 3 above.

5. When segments are combined to form new sections, it will also be necessary to compare the mean of the new section with that of the immediately preceding segment. Consequently, the test of significance, as discussed above, is repeatedly conducted until no further changes in segmentation take place.

Application of the above procedure to the data shown in Table 3-1 results in the segmentation given in Table 3-2. In this latter table, a new segment, referred to as section B-C, was created by combining segments B and C of Table 3-1. As mentioned previously, the means of these segments are not significantly different for the level of confidence specified. Note from Table 3-2 that the endpoints of this new section correspond to the beginning and ending mileposts, respectively, of segments B and C in Table 3-1.

The mean pavement response for section B-C was also compared to the means of the adjacent sections (i.e., A and D), as reflected in the new t-statistics for sections A and B-C. Note from Table 3-2 that the new t-statistics of 12.837 and 6.617 both exceed the critical value of 2.576 indicating that the mean pavement response for section B-C is significantly different from the corresponding means of the adjacent sections.

It is realized that application of the test of significance described above may result in a new route segmentation with adjacent sections that do not meet the criterion on the minimum difference between means. Conversely, application of this minimum difference criterion may also result in adjacent segments that do not pass the test of significance. Consequently, in the modified segmentation algorithm, each criterion is successively applied until a segmentation is obtained that satisfies both criteria.

Table 3-2. Sample segmentation based on application of tests of significance on adjacent section means.

Section	Starting Milepost	Ending Milepost	Length (miles)	Layer 2 Thickness (in.)		Sample Size	t -statistic
				Mean	Standard Deviation		
A	0.000	1.230	1.230	8.66	2.48	124	12.837
B-C	1.230	3.111	1.881	12.30	2.40	179	6.617
D	3.111	3.721	0.610	14.95	3.45	61	4.631
E	3.721	4.031	0.310	11.81	2.14	31	3.642
F	4.031	5.241	1.210	13.90	3.01	121	10.078
G	5.241	6.461	1.220	10.90	1.33	122	6.034
H	6.461	6.961	0.500	12.49	2.04	50	25.710
I	6.961	8.749	1.788	7.65	0.79	180	10.599
J	8.749	9.609	0.860	8.83	0.93	83	33.616
K	9.609	12.712	3.103	4.07	1.20	309	26.695
L	12.712	13.030	0.318	10.21	1.27	30	N/A

CHAPTER 4. SAMPLE APPLICATION OF THE SEGMENTATION ALGORITHM

Radar measurements taken along a selected Florida roadway are used herein to illustrate the application of the segmentation algorithm presented previously. However, before this is done, it is first necessary to present some practical considerations that arise when the algorithm is used. These include:

1. specification of criteria;
2. choice of pavement response variable;
3. composite segmentation; and
4. discontinuities in the radar predictions.

The above considerations are discussed in the following sections.

SPECIFICATION OF CRITERIA

The criteria on minimum section length, and minimum difference between means of adjacent sections have significant influence on the results obtained from the segmentation procedure. With respect to the former criterion, it is important to take into perspective the intended applications of the radar data in deciding what minimum section length to use. Undoubtedly, there can be a great amount of variability in pavement structure along the length of a given highway, and, the lower the minimum section length, the better the chances of minimizing the variability within delineated segments, and of establishing more uniform sections. However, in practice, there is a limit to how short a section can get before it ceases to become a viable rehabilitation project. On a 10-mile stretch of highway, for example, it is unlikely that different overlays will be constructed for individual 0.1-mile sections. It is more likely that such short sections will be combined with other sections, or the highway divided into sections of much longer length, for the purposes of overlay design and construction. The important guideline to remember is that the segmentation should be consistent with the intended applications, and, in this regard, it is important to distinguish between project level, and network level applications. Current radar technology offers a viable means for conducting an inventory of layer thicknesses for an entire state roadway network. The appropriate minimum section length to specify will necessarily be different if one was interested in using the thickness information to evaluate pavement needs of the entire roadway network for budget appropriation, as compared to using the data to do an overlay design of a specific project.

With respect to the minimum difference between means of adjacent sections, the value to specify should be consistent with the observed variability of layer thicknesses within uniform pavement sections. Coring data taken from different Florida pavement sections where radar measurements were made indicate that the within-section variability of layer thicknesses varies over a significant range, with the base thickness showing more variability than the asphalt surface thickness. This is illustrated in Figure 4-1 which shows frequency distributions of the standard deviations of measured asphalt and base thicknesses from corings conducted on different pavement sections in District 3 in Florida. The pavement sections cover a wide range of asphalt mixtures and base material types. Measures of central tendency for the frequency distributions shown in Figure 4-1 are given in the following table:

Statistic	Asphalt Thickness (inches)	Base Thickness (inches)
Mode	0.29	1.21
Median	0.41	1.04
Mean	0.60	0.97

The above statistics can be used as guidelines when deciding on the value to specify for the minimum difference between section means. Because of the larger within-section variability associated with base thickness, a larger value for this criterion would be appropriate if base thickness is used as the response variable. In this particular instance, a value of 1.0 inch seems to be appropriate, based on the available core information. On the other hand, if asphalt thickness is used as the response variable, a criterion of 0.50 inches is recommended.

CHOICE OF PAVEMENT RESPONSE VARIABLE

In using the segmentation algorithm, the user must also specify the pavement response variable that will serve as the basis for the

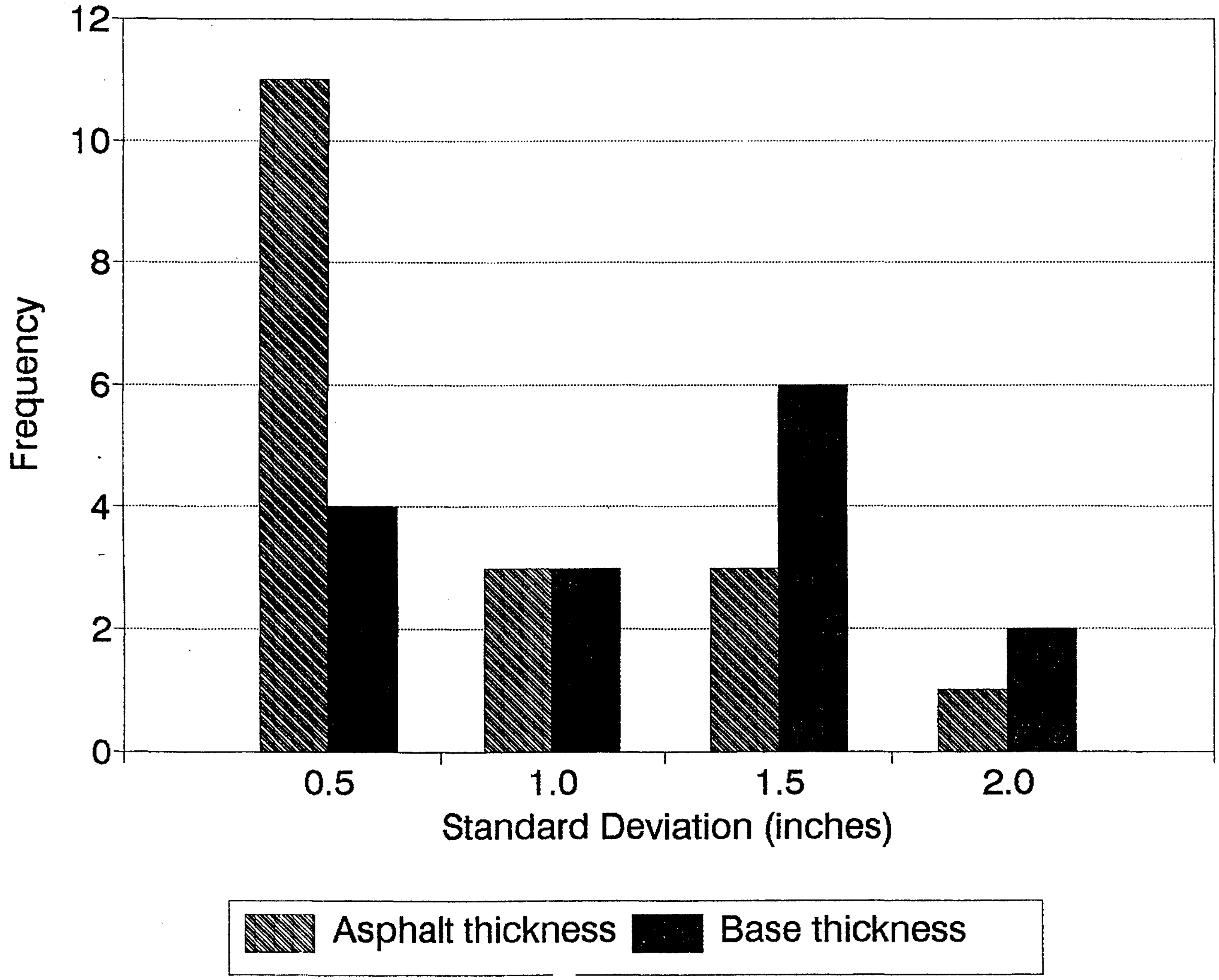


Figure 4-1. Frequency distributions of the standard deviations of measured asphalt and base thicknesses from different FDOT pavement sections.

segmentation. In general, there are two types of information that will be generated from the analysis of radar signals, i.e., layer thickness, and layer dielectric constant. Of these two, layer thickness is considered as the more important variable, insofar as pavement management applications are concerned. After all, surface and base thicknesses are important determinants of pavement performance. Consequently, it is expected that the segmentation will generally be accomplished based on the predicted layer thicknesses from the radar analysis, e.g., surface thickness, base thickness, or total pavement thickness. In addition, multiple runs of the computer program may be made, in practice, to evaluate different segmentations based on a number of pavement response variables such as those just mentioned. A capability has been included in the computer program to combine the results of separate analyses and establish a composite segmentation for the given route or network.

COMPOSITE SEGMENTATION

Given a set of segmentation results evaluated on the basis of different pavement response variables, the user may want to reconcile the differences in the segments established from the separate subsectionings that were conducted. A reasonable solution is to combine the endpoints of all of the different segments into a composite segmentation that reflects the results from the analyses made using different pavement response variables. This aggregation of segment endpoints will likely form new segments which need to be checked against the criteria established. For example, some segments in the composite segmentation may be shorter than the minimum section length previously defined. Consequently, such short segments are combined with the adjacent segments to satisfy the minimum section length requirement. In addition, tests are conducted to verify that adjacent segments satisfy at least one of the criteria specified for minimum difference between section means, and are significantly different based on at least one of the pavement response variables considered.

DISCONTINUITIES IN THE RADAR PREDICTIONS

Discontinuities in the radar predictions can arise due to the inability to detect layer interfaces below the pavement surface or because of the presence of bridges. The inability to detect layer interfaces is primarily attributed to a lack of dielectric contrast between two pavement layers, such as a concrete slab over a cement-treated base. In such cases, it will not be possible to predict layer thicknesses, and the corresponding predictions will have zero values. For the case of bridges, the measured radar data on these structures may not be processed at all leading to an absence of predictions for layer thicknesses or dielectric constants.

When discontinuities, such as those described, are present in the radar data, it is best to establish separate segments for the discontinuities, even if this action will result in segments that are less than the specified minimum section length. This recommendation is made since the combination of discontinuities with adjacent segments will strongly bias the computation of means and standard deviations of layer thicknesses and dielectric constants for the resulting segments. Consequently, such discontinuities are best set aside as separate segments, and a capability has been included in the computer program for accomplishing this.

SAMPLE PROGRAM APPLICATION

After the brief discussion on practical considerations, radar measurements taken along a selected Florida roadway are used to illustrate the application of the segmentation program. Route 46010 is chosen for this example as it is one of the longest in length and consists of some of the discontinuities previously discussed. The predicted layer thicknesses of Route 46010 are shown in Figure 4-2. From the figure, it is noted that the roadway surveyed is about 17 miles, and three pavement layers were detected from the radar data. Based on the radar predictions, layer 3 was judged to be the base layer, while layers 1 and 2 comprised the surface material. Figure 4-3 is a plot of the sum of predicted thicknesses for layers 1 and 2, and the predicted thicknesses for layer 3. These thicknesses were the two response variables used in the sample run of the segmentation algorithm presented herein.

Before proceeding with the segmentation, it was necessary to prepare the input file in a format suitable for the current version of the segmentation program. The format of the input file used is shown in Figure B-1 of Appendix B. This format may be changed to suit future development requirements of the segmentation program. In this sample application, the sums of the predicted thicknesses for layers 1 and 2 were placed in Column

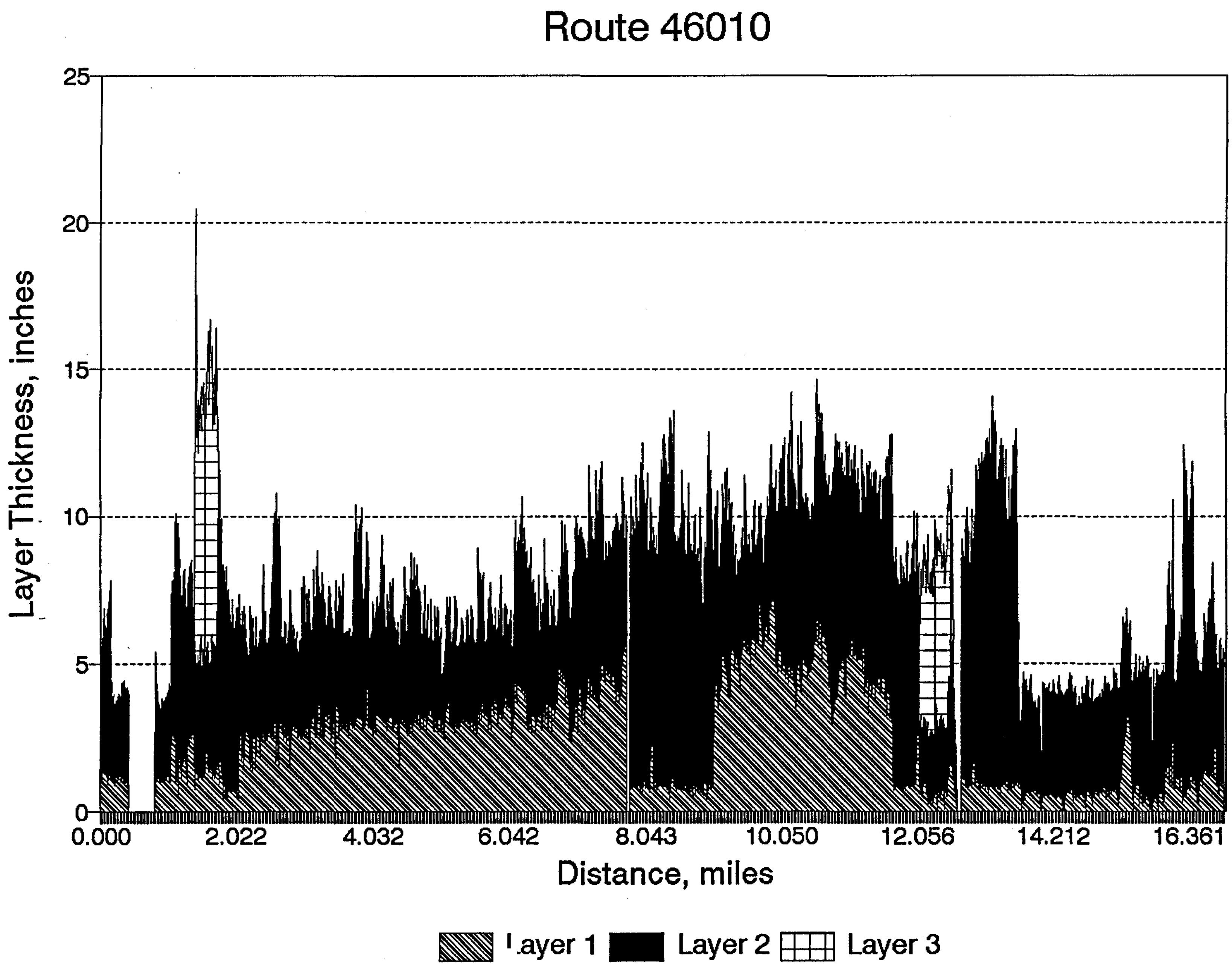


Figure 4-2. Thickness predictions of Layer 1, Layer 2, and Layer 3 of Route 46010.

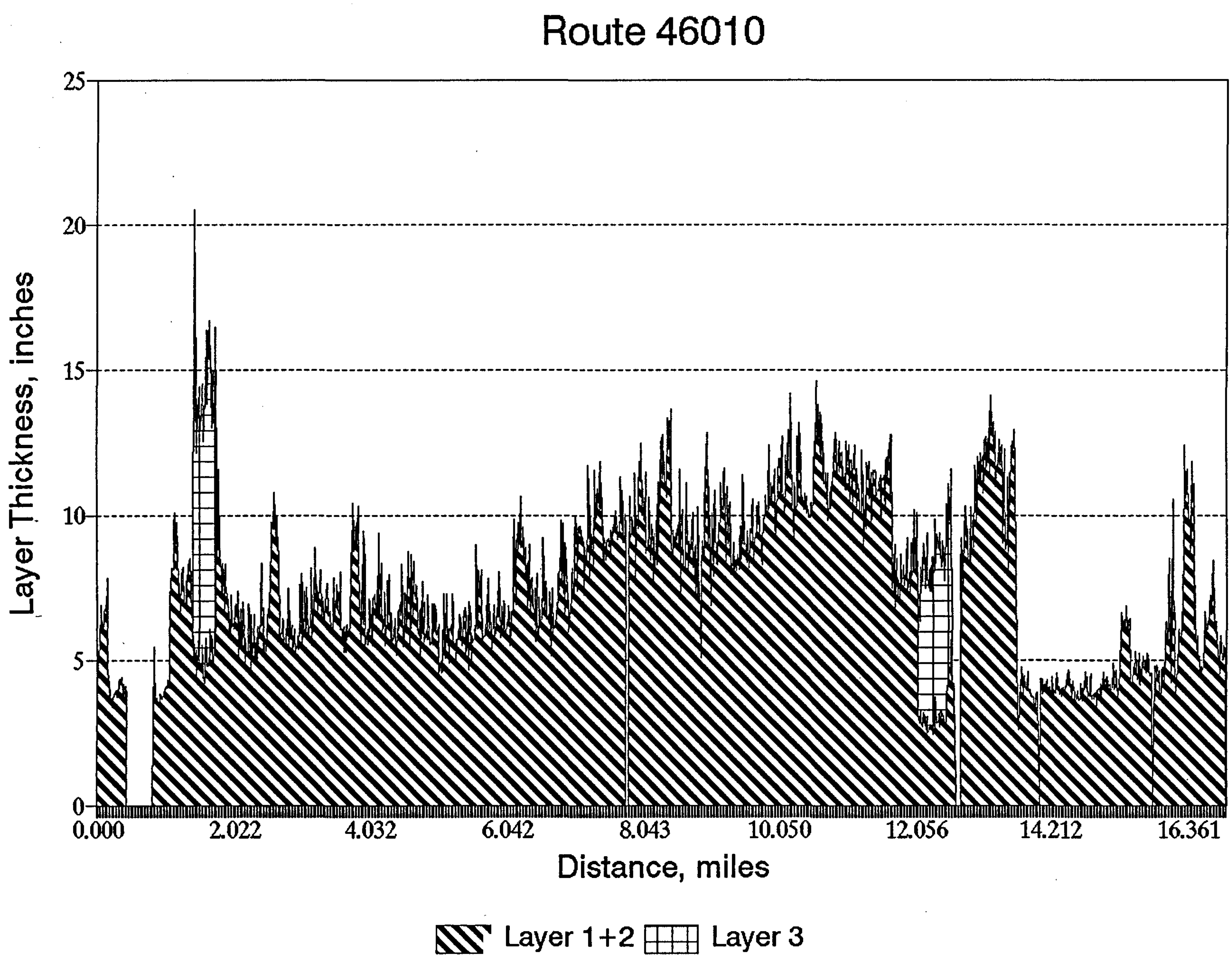


Figure 4-3. Thickness predictions of Layer 1+2 and Layer 3 of Route 46010.

4 of the input file. Note that the mile post reading in Column 0 is in thousandths of a mile.

Evaluation was carried out on the layer 1+2 thicknesses for the entire route. The segmentation criteria were set as follows:

Minimum Section Length= 0.25 miles; and

Minimum Difference between Section Means= 0.5 inches.

After pass 1 was completed, details of the resulting 17 segments, are illustrated in Figure 4-4, and summarized in Table 4-2. All the segments met the user-specified segmentation criteria with the exception of P1-17, the length of which is shorter than the prescribed minimum. However, in the procedure, exceptions to this rule have been established, and segments having lengths shorter than the minimum are left as is when one of the following conditions is met:

a. If the adjacent segments on both sides have zero means;
b. If the segment happens to be the last one, and the mean response of the previous segment is zero; and
c. If the segment is the last one, and the difference between its mean and the mean of the previous segment is greater than the user-specified minimum difference between means.

In the subsequent passes, finer delineations were made consistent with the user-specified criteria by applying the cumulative difference algorithm on selected segments from the preceding pass. Each of these segments fell into one of the following cases:

a. Segments with section lengths shorter than 0.5 miles (i.e. twice the minimum section length previously specified). In this instance, the segment was not further evaluated by the cumulative difference algorithm. Examples are segments P1-2, P1-3, P1-8, P1-16, and P1-17.
b. Segments which undergo further delineation for which the resulting subsections do not meet prescribed criteria so that the segmentation becomes invalid; and
c. Segments which undergo further delineation for which the resulting subsections meet prescribed criteria, or one of the exceptions noted earlier. New subsections are subsequently integrated into the results from the previous pass.

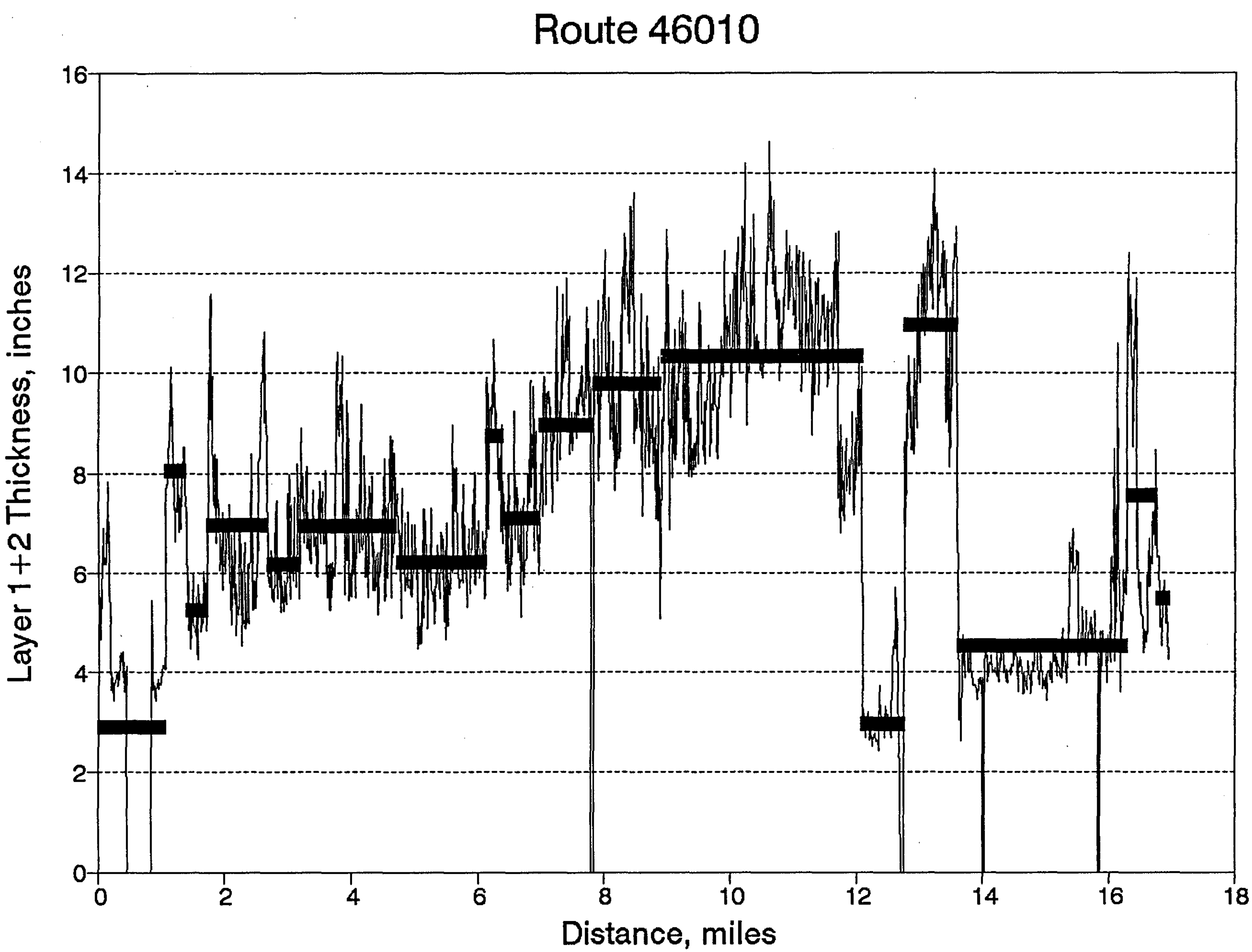


Figure 4-4. Segmentation of R ıte 46010 based on Layer 1+2 thickness after the initial pass of cumulative difference algorithm.

Table 4-2. Segmentation of Route 46010 based on layer 1+2 thickness after the initial pass of cumulative difference algorithm.

SECTION	STARTING MILEPOST	ENDING MILEPOST	LENGTH (miles)	LAYER 1+2 THKS (in.)		SAMPLE SIZE	*t*-STATISTIC
				MEAN	STD. DEV.		
P1-1*	.000	1.066	1.066	2.90	2.37	108	12.024
P1-2	1.066	1.384	.318	8.04	.87	32	15.525
P1-3	1.384	1.748	.364	5.28	.59	36	6.023
P1-4	1.748	2.692	.944	6.97	1.65	93	3.357
P1-5	2.692	3.202	.510	6.16	.72	51	4.727
P1-6	3.202	4.722	1.520	6.95	1.12	152	6.397
P1-7	4.722	6.122	1.400	6.22	.81	140	14.142
P1-8	6.122	6.382	.260	8.72	.96	26	6.965
P1-9	6.382	6.982	.600	7.12	.99	60	6.020
P1-10	6.982	7.832	.850	8.96	2.21	85	2.971
P1-11	7.832	8.913	1.081	9.77	1.60	109	3.278
P1-12	8.913	12.076	3.163	10.33	1.53	317	35.802
P1-13	12.076	12.760	.684	2.95	1.39	64	31.463
P1-14	12.760	13.604	.844	10.97	1.63	83	43.292
P1-15	13.604	16.284	2.680	4.51	.97	241	14.325
P1-16	16.284	16.754	.470	7.56	2.45	45	3.531
P1-17	16.754	16.944	.190	5.48	.69	18	N/A

* This segment labeling convention is used in the rest of this report. For example, segment P1-1 refers to the 1st segment that results after pass 1.

Segment P1-1 is used to illustrate the intermediate segmentation. In pass 2, segment P1-1 was subdivided into 3 smaller segments given in the table below. Note that, although the last subsection is shorter than the minimum section length, the subsection was still left as is based on the third exception noted previously.

Table 4-3. Sample intermediate segmentation results during pass 2.

SECTION	STARTING MILEPOST	ENDING MILEPOST	LENGTH (miles)	LAYER 1+2 THKS (in.)		SAMPLE SIZE	*t*-STATISTIC
				MEAN	STD. DEV.		
P1-1	.000	.440	.440	4.87	1.24	45	22.169
	.440	.840	.400	.10	.61	40	27.050
	.840	1.066	.226	3.95	.41	23	N/A

These newly formed subsections are then integrated into the segmentation results from the preceding pass to establish an updated segmentation. This updated segmentation is then checked against the user-specified segmentation criteria. In this way, the last subsection of P1-1 noted previously will actually get combined with an adjacent segment to satisfy the criterion on minimum section length.

The above process was repeated for another segment, until no segments could be further subdivided. At this stage, the user has the option of accepting the final results, or manually doing some changes to account for discontinuities in the radar data, such as would be caused by a bridge. As discussed previously, discontinuities should be set aside as separate sections to avoid biasing the calculation of mean thicknesses.

The results of the segmentation from the third and final pass are summarized in Table 4-4, and shown graphically in Figure 4-5. Note that section P3-2 in Table 4-4 represents a bridge. Consequently, because it represents a discontinuity, it was not combined with the adjacent segment, P3-3, even though the length of the segment is less than the prescribed minimum.

The same procedure was carried out to delineate Route 46010 based on the predicted thicknesses of layer 3. Since layer 3 was assumed to be a base layer, and considering the core statistics discussed earlier in this chapter, the following segmentation criteria were used.

Table 4-4. Final segmentation of Route 46010 based on layer 1+2 thickness.

SECTION	STARTING MILEPOST	ENDING MILEPOST	LENGTH (miles)	LAYER 1+2 THKS (in.)		SAMPLE SIZE	*t*-STATISTIC
				MEAN	STD. DEV.		
P3-1	.000	.440	.440	4.87	1.23	45	22.169
P3-2	.440	.840	.400	.10	.61	40	27.050
P3-3	.840	1.066	.226	3.95	.41	23	20.994
P3-4	1.066	1.384	.318	8.04	.87	32	15.525
P3-5	1.384	1.748	.364	5.28	.59	36	6.022
P3-6	1.748	2.692	.944	6.97	1.65	93	3.358
P3-7	2.692	3.202	.510	6.16	.72	51	4.727
P3-8	3.202	4.722	1.520	6.95	1.12	152	6.390
P3-9	4.722	6.122	1.400	6.22	.81	140	14.142
P3-10	6.122	6.382	.260	8.72	.96	26	6.965
P3-11	6.382	6.982	.600	7.12	.99	60	6.020
P3-12	6.982	7.832	.850	8.96	2.21	85	2.971
P3-13	7.832	8.473	.641	10.25	2.00	66	4.310
P3-14	8.473	8.913	.440	8.82	1.13	44	2.878
P3-15	8.913	9.890	.977	9.42	1.15	99	14.103
P3-16	9.890	11.700	1.810	11.27	1.00	181	18.655
P3-17	11.700	12.076	.376	8.09	.75	38	21.001
P3-18	12.076	12.760	.684	2.95	1.39	64	31.458
P3-19	12.760	13.604	.844	10.97	1.63	83	44.856
P3-20	13.604	15.342	1.738	4.10	.70	151	10.118
P3-21	15.342	16.284	.942	5.29	1.14	91	7.398
P3-22	16.284	16.754	.470	7.56	2.45	45	3.531
P3-23	16.754	16.944	.190	5.48	.69	18	N/A

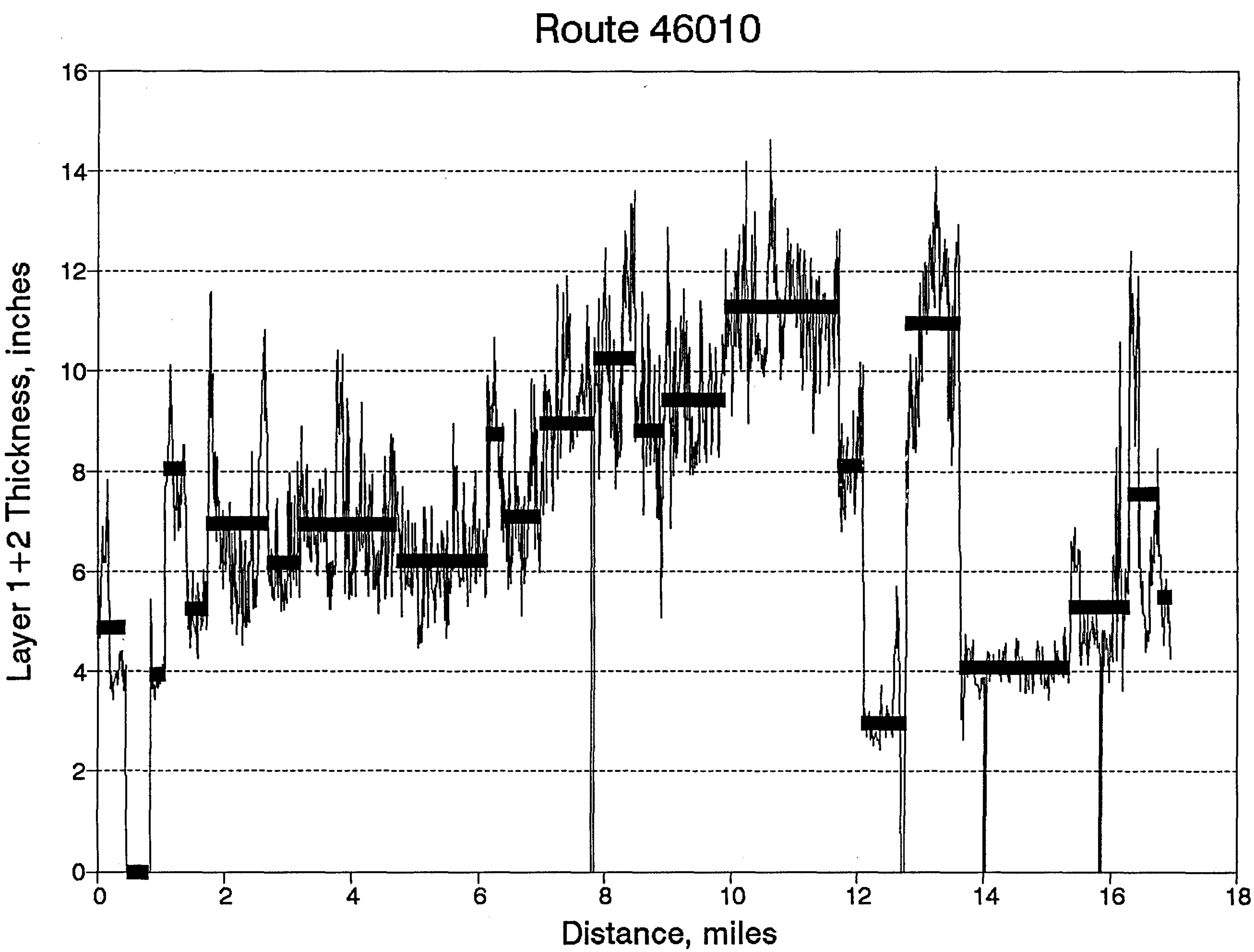


Figure 4-5. Final segmentatio of Route 46010 based on Layer 1+2 thickness.

Minimum Section Length = 0.25 miles; and

Minimum Difference between Section Means = 1 inch.

The final segmentation results are shown in Figure 4-6 and Table 4-5 below. As seen in Figures 4-2 and 4-3, thickness predictions were generally not possible for layer 3. Therefore, composite segmentation was not necessary as the segmentation based on the total surface thickness would obviously govern.

Table 4-5. Final segmentation of Route 46010 based on layer 3 thickness.

SECTION	STARTING MILEPOST	ENDING MILEPOST	LENGTH (miles)	LAYER 1+2 THKS (in.)		SAMPLE SIZE	*t*-STATISTIC
				MEAN	STD. DEV.		
P2-1	.000	1.404	1.404	.00	.00	142	49.941
P2-2	1.404	1.758	.354	9.18	2.21	35	135.273
P2-3	1.758	12.076	10.318	.00	.00	1032	168.451
P2-4	12.076	12.630	.554	5.36	1.03	51	104.737
P2-5	12.630	16.944	4.314	.00	.00	400	N/A

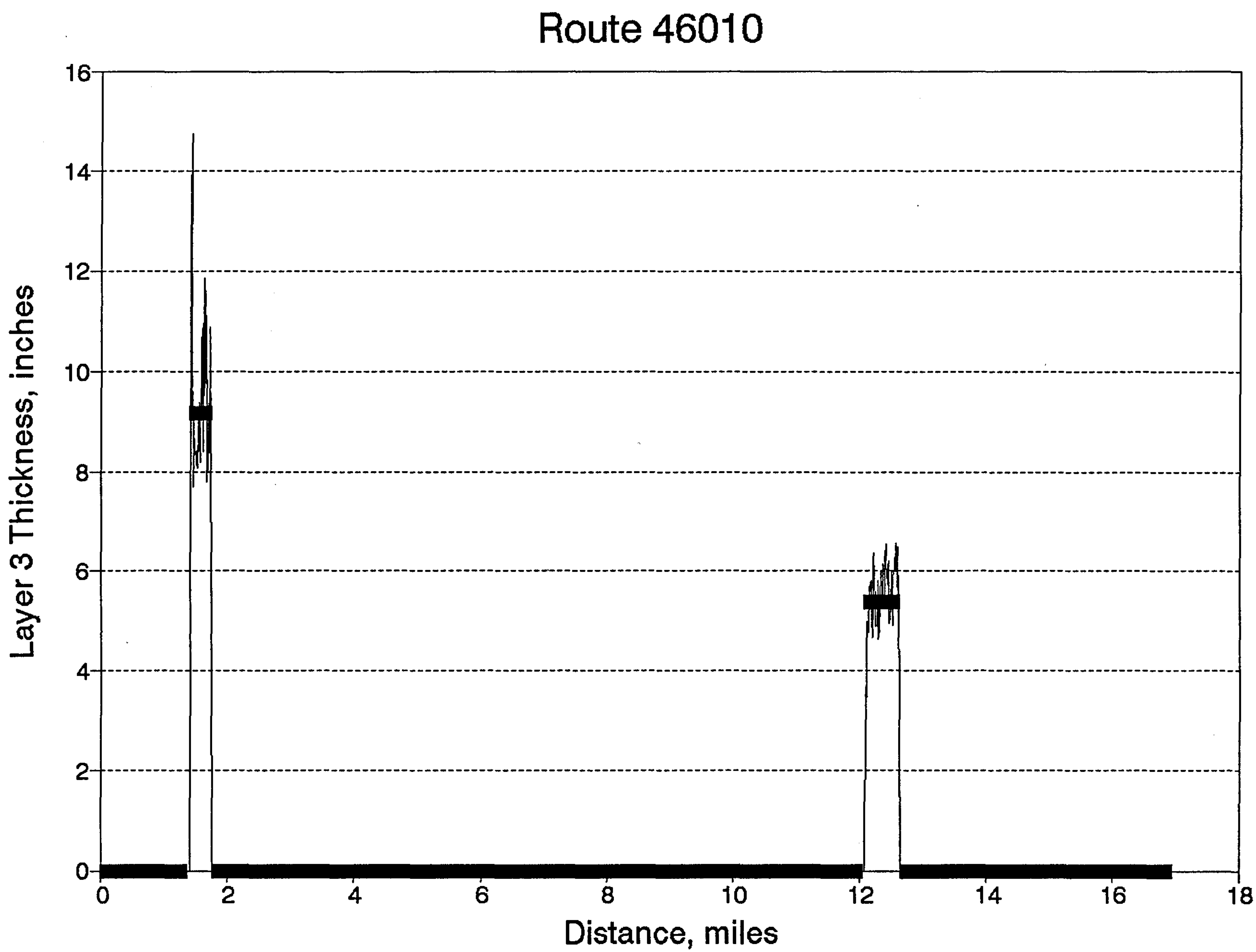


Figure 4-6. Final segmentatio.. of Route 46010 based on Layer 3 thickness.

CHAPTER 5. SUMMARY AND CONCLUSION

The preceding chapters have presented the segmentation program developed as part of this Florida study. This program can be used to assist the Florida DOT in dividing a roadway into several homogeneous segments based on the radar predictions. The essential features of the algorithm are summarized as follows:

1. The cumulative difference method is used to divide a user-specified segment into several smaller segments. Minimum section length and minimum difference between section means are the criteria used to combine small segments to the adjacent segments. Each of the newly formed segments is further subdivided using the same procedure, until no further delineations are possible based on the criteria specified. This procedure was used to delineate an in-service pavement section where the actual segmentation was known, and the results were found to be consistent with the design profile specification.

2. An additional criterion, involving a test of significance of the difference between adjacent means, is incorporated to fine tune the segmentation program. In the procedure developed, adjacent segments are combined when the respective means are not significantly different from one another. This feature was illustrated in Chapter 3 using Florida pre-production radar data on Route 5303R.

3. Delineations based on different pavement parameters may be combined to establish a composite segmentation for the given route that meets the criteria specified.

The segmentation program has been tested with various sets of pre-production radar data with satisfactory results. It is believed that this program for delineating highway networks or projects into sections based on radar predictions will be useful in a variety of pavement management applications, from network level determination of rehabilitation and maintenance needs, to overlay design of specific projects.

APPENDIX A. TWO-SAMPLE t-TEST

SAMPLE AND POPULATION

Statistics concerns itself mainly with conclusions and predictions resulting from chance outcomes that occur in carefully planned experiments or investigations. In the finite case, these chance outcomes constitute a subset, or **sample**, of measurements or observations from a larger set of values called the **population**. For example, a set of measurements of the asphaltic surface layer thicknesses from a radar survey of selected sites along a particular roadway, at a certain day and time, constitutes a sample. Another set of measurements taken at the same sites at a different day or time will constitute a new sample. And the set of all the physically possible yet practically impossible measurements on all sites along the same roadway constitutes a population. Most of the time, knowledge of a population is needed to have better a understanding of the subject of study, and to provide for better decision making. However, for practical reasons, sample data are used instead to make inferences regarding the population. For example, it may be of interest to establish whether the average surface layer thicknesses of two sites along a given roadway are significantly different for the purpose of delineating homogeneous pavement sections. This types of problem is best handled through statistical hypotheses testing.

STATISTICAL HYPOTHESES

A statistical hypothesis is an assertion or conjecture about the distribution of one or more random variables, or about the value of a given parameter. In these tests, there are always defined, two possible states of the universe, which are both exhaustive and exclusive. That is, for a given test, only these two, and no other can exist. The first state, given by the null hypothesis, H_0, usually assumes that there is no significant difference between the value of the universe parameter being tested and the value of a statistic computed from a sample drawn from that universe. For example, one may be interested in testing the null hypothesis that the average surface thickness of a given pavement section is 6.0 inches, i.e., H_0: $\mu = 6.0$ inches, where μ is the population mean of surface layer thicknesses.

The other state of the world is given by the alternate hypothesis, H_a, which will be accepted if statistical testing leads to rejection of H_0.

In the above example, the alternative hypothesis may be, H_a: $\mu \neq 6.0$ inches, although the highway engineer may also be interested in evaluating whether $\mu > 6.0$ inches or $\mu < 6.0$ inches.

ONE-TAILED AND TWO-TAILED HYPOTHESES TESTING

In testing the null hypothesis, H_0: $\theta = \theta_0$, against the two-sided alternate hypothesis, H_a: $\theta \neq \theta_0$, it seems reasonable to accept the null hypothesis when the point estimate, $\hat{\theta}$, of θ is close to θ_0, and to reject it when $\hat{\theta}$ is much smaller or much larger than θ_0. Thus, it would be logical to let the critical region consist of both tails of the sampling distribution of the test statistic, $\hat{\boldsymbol{\theta}}$. Such a test is referred to as a **two-tailed test.**

On the other hand, in testing the null hypothesis, H_0: $\theta = \theta_0$, against the one-sided alternative hypothesis, H_a: $\theta < \theta_0$, it would seem reasonable to reject H_0 only when $\hat{\theta}$ is much smaller than θ_0. Therefore, it would be reasonable to let the critical region consist only of the left tail of the sampling distribution of $\hat{\boldsymbol{\theta}}$. This test is referred to as a **one-tailed test.**

TESTS CONCERNING DIFFERENCES BETWEEN MEANS

In many cases, it is important to know whether there is a difference between the means of two populations. Suppose that the problem is to find out if average surface layer thicknesses of two adjacent roadway segments are statistically the same. Further, assume that the thickness measurements are random and independent with sample sizes, n_1 and n_2, and that the samples are obtained from two normal populations (i.e., the sets of all asphaltic layer thicknesses of the two segments) having the means, μ_1 and μ_2, with known variances, σ_1^2 and σ_2^2. The test hypotheses are set up as follows:

$$H_0:\ \mu_1 - \mu_2 = \delta \qquad \text{(A-1)}$$

$$\begin{aligned} H_a:\ &\mu_1 - \mu_2 \neq \delta, \quad \text{or} \\ &\mu_1 - \mu_2 > \delta, \quad \text{or} \\ &\mu_1 - \mu_2 < \delta \end{aligned} \qquad \text{(A-2)}$$

where δ is a given constant. The respective critical regions are:

$$|z| \geq z_{\alpha/2}, \quad \text{or}$$
$$z \geq z_{\alpha}, \quad \text{or} \qquad \text{(A-3)}$$
$$z \leq -z_{\alpha}$$

where,

$$z = \frac{\bar{X}_1 - \bar{X}_2 - \delta}{\sqrt{\dfrac{\sigma_1^2}{n_1} + \dfrac{\sigma_2^2}{n_2}}} \qquad \text{(A-4)}$$

When dealing with independent random samples from populations with unknown variances which may not be normal, the above test can still be used by substituting sample variances, s_1 and s_2, for σ_1 and σ_2 in Equation A-4 as long as both the samples are large enough (i.e., $n \geq 30$) for the central limit theorem to be invoked.

When n_1 and n_2 are small, and σ_1 and σ_2 are unknown, the above test cannot be used. In this instance, the theoretical sampling distribution of the differences is assumed to be a t-distribution, and the following ***t*-test** is used:

$$t = \frac{\bar{X}_1 - \bar{X}_2 - \delta}{s_p \sqrt{\dfrac{1}{n_1} + \dfrac{1}{n_2}}} \qquad \text{(A-5)}$$

where,

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \qquad \text{(A-6)}$$

and,

$\bar{X}$ = sample mean

n = sample size

s = sample standard deviation

s_p^2 = weighted average of the sample variances, s_1^2 and s_2^2

δ = a given constant

With the same null and alternate hypotheses given in Equations A-1 and A-2, the respective critical regions are as follows:

$$\begin{aligned} |t| &\geq t_{\alpha/2,\ n_1+n_2-2} \\ t &\geq t_{\alpha,\ n_1+n_2-2} \\ t &\leq -t_{\alpha,\ n_1+n_2-2} \end{aligned} \tag{A-7}$$

One of the segmentation criteria described in Chapter 3 is used to establish whether the mean responses of two adjacent segments are statistically different. In this particular instance, δ is set to zero, so that the appropriate hypotheses for the test are as follows:

$$H_0: \quad \mu_1 - \mu_2 = 0 \tag{A-8}$$

$$H_a: \quad \mu_1 - \mu_2 \neq 0 \tag{A-9}$$

This means that H_0 cannot be rejected if the two means are not statistically different, and H_0 must be rejected if the two means are statistically different. For a confidence coefficient of 99% (i.e., $1-\alpha$, where α=0.01), with degrees of freedom (i.e., n_1+n_2-2) greater or equal than 30, the two-tailed rejection region is defined by:

$$|t| \geq t_{\alpha/2,\ n_1+n_2-2} = 2.576 \tag{A-10}$$

Thus, H_0 cannot be rejected if the absolute value of the t-statistic computed using Equation A-5 is less than 2.576. This implies that the mean responses of the two adjacent segments are not statistically different, so that the two segments should therefore be combined.

APPENDIX B. SEGMENTATION PROGRAM USER'S GUIDE

SPECIFICATIONS

1. Software

   Developed in FORTRAN 77 language.

   Compiled by MicroSoft® FORTRAN Optimizing Compiler Version 5.00.

   Executable program is approximately 270 kilobytes.

2. Hardware

   An IBM® PC or PC-compatible computer that runs DOS Version 3.0 or later.

   A minimum of 320 kilobytes of available user memory.

3. Features

   The segmentation program allows user to

   - select or change a radar data file.
   - select or change a pavement parameter.
   - define end-points of evaluation.
   - define minimum section length.
   - define minimum difference between section means.
   - name output file for segmentation results.
   - perform segmentation based on one parameter.
   - perform composite segmentation.

4. Input File

   The format of the input file is shown in Figure B-1.

Column 0	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
dist	h1	h2	h3	h4	e'1	e'2	e'3	e'4
0	2.24	3.77	0	6.01	4.50	3.58	2.87	2.87
10	2.31	3.19	0	5.50	4.87	3.30	1.96	1.96
20	1.84	3.97	0	5.81	4.21	3.06	1.84	1.84
30	2.46	2.21	0	4.67	4.49	3.47	2.73	2.73
40	2.25	2.93	0	5.18	4.40	3.39	2.29	2.29
50	1.04	4.35	0	5.39	4.00	3.32	2.25	2.25
60	1.37	4.21	0	5.58	4.08	3.04	2.06	2.06
70	1.40	5.52	0	6.92	4.06	3.19	2.10	2.10
80	1.33	5.12	0	6.45	4.07	3.24	2.33	2.33
90	1.36	4.80	0	6.16	4.30	3.53	2.63	2.63
100	1.37	4.90	0	6.27	4.24	3.50	2.52	2.52
110	1.17	4.99	0	6.16	4.11	3.27	2.32	2.32
120	1.32	5.42	0	6.74	3.97	3.02	2.13	2.13
...								
...								
16894	0.82	4.16	0	4.98	3.49	4.44	6.40	6.40
16904	0.93	4.06	0	4.99	3.48	4.36	6.02	6.02
16914	0.96	4.08	0	5.04	3.45	4.06	6.42	6.42
16924	1.42	4.10	0	5.52	3.69	4.03	5.31	5.31
16934	2.07	3.19	0	5.26	3.47	3.82	5.78	5.78
16944	2.40	1.86	0	4.26	4.19	6.39	9.92	9.92

Figure B-1. Sample input file for segmentation program.

Notes:

Heading: First line of input file. Presence of heading is necessary, both for the segmentation program and for record.
Column 0: Mile post reading, 0.001 miles. Example, the distance at last trace 16944 denotes 16.944 miles.
Column 1: Layer 1 thicknesses, inches.
Column 2: Layer 2 thicknesses, inches.
Column 3: Layer 3 thicknesses, inches.
Column 4: Layer 4 thicknesses, inches. (In this example, Column 4 is the sum of Column 1 and Column 2).
Column 5: Layer 1 dielectric constant (real part).
Column 6: Layer 2 dielectric constant (real part).
Column 7: Layer 3 dielectric constant (real part).
Column 8: Layer 4 dielectric constant (real part).

STRUCTURE OF PROGRAM

The program is organized in modular fashion. A calling routine calls subroutines. Each subroutine performs a specific task and/or calls other subroutines. After each task, a subroutine returns control over to its calling routine. When a task is completed, the program will prompt to request user's input for the next task.

RUNNING THE PROGRAM

1. **START:** To start running the program, type 'CUD' at the DOS prompt and hit the ENTER key. (Note that in this User's Guide, all underscored characters indicate user's entry.) In the following, it is assumed that the program files are in subdiectory 'SEG' of the 'C' drive.

```
C:>CD SEG

C:\SEG>CUD
```

2. **MAIN MENU:** The Main Menu will appear on the monitor displaying various options. The input file name and parameter currently selected will also be displayed. However, if no selection has been made, a '?' will be displayed instead.

```
              SEGMENTATION PROGRAM
                   MAIN MENU

  1. Select infile: ?
  2. Select parameter: ?
  3. Single parameter segmentation.
  4. View segmentation results.
  5. Composite segmentation.
  9. Exit.
Enter selection:
```

3. **SELECT INPUT FILE:** To select a new input file, type '1' at the Main Menu.

```
                   MAIN MENU

  1. Select infile: ?
  2. Select parameter: ?
  3. Single parameter segmentation.
  4. View segmentation results.
  5. Composite segmentation.
  9. Exit.
Enter selection: 1
```

The name of the current input file will be displayed. The user will then be asked to enter the name of the input file, and the multiplying factor for the DMI readings. This factor is used to tranform the DMI readings into the desired unit of measurement.

```
Current Infile= ?
New Infile= R4601.D04
Multiplier applied on Dist in Infile= 1000.00
```

4. **SELECT PAVEMENT PARAMETER:** To specifiy the parameter on which the segmentation will be based, type '2' at the Main Menu. The available parameters will be displayed, followed by the current selection, and finally a prompt for the user to enter his or her selection. This option will also be evoked automatically after 'SELECT INPUT FILE' (i.e. option '1' of the Main Menu) is completed.

   In the example shown below, the user may choose 'H1' (or 'h1') to select surface layer thickness or enter 'H2' to select base layer thickness. There are four parameters to choose from (H1 to H4), and there is no current selection as indicated by the '?' on the 'Current Parameter=' field. For demonstration purpose, 'H4' is the parameter desired.

```
H1:THK1   H2:THK2   H3:THK3   H4:THK4
Current Parameter= ?
New Parameter= H4
```

   Once a parameter has been specified, the program will proceed to read the selected parameter data from the input file. Subsequently, the user will be prompted to name an output file, referred to herein as the parameter response file. This file, which will contain records of trace numbers, DMI readings, and corresponding data for the selected pavement parameter, will be saved for future use. The format of this file is as shown in Figure B-2. In the example below, the file name 'H4.P' has been entered as the pavement response file.

```
Pvmt Resp File= H4.P
```

5. **SEGMENTATION BASED ON ONE PARAMETER:** To perform segmentation on the selected parameter, type '3' at the Main Menu as shown below.

Column 0	Column 1	Column 2
trace	dist	response
0	.000	6.0100
1	.010	5.5000
2	.020	5.8100
3	.030	4.6700
4	.040	5.1800
5	.050	5.3900
6	.060	5.5800
7	.070	6.9200
8	.080	6.4500
9	.090	6.1600
10	.100	6.2700
11	.110	6.1600
12	.120	6.7400
...		
...		
1654	16.894	4.9800
1655	16.904	4.9900
1656	16.914	5.0400
1657	16.924	5.5200
1658	16.934	5.2600
1659	16.944	4.2600

Figure B-2. Sample pavement response file.

Notes:

Column 0: Trace number
Column 1: Distance, miles
Column 2: Pavement response (in this example, layer 1+2 thicknesses)

```
                MAIN MENU

    1. Select infile: R4601.D04
    2. Select parameter: H4
    3. Single parameter segmentation.
    4. View segmentation results.
    5. Composite segmentation.
    9. Exit.
Enter selection: 3
```

The program will display the serial numbers of the first trace and the last trace. (Note that the first trace will always be numbered as '0', instead of '1'; so if there are 1000 total traces in the input file, the last trace will be numbered as '999'.) Next, the user will be prompted to enter the range of trace numbers on which the cumulative difference evaluation will be conducted. In the example given below, all traces will be included in the evaluation.

```
Trace: First=    0, Last= 1659
Evaluation Start at Trace= 0
Evaluation Stop  at Trace= 1659
```

The program will then proceed to calculate the cumulative difference and its gradient. Then, the user will be asked to name an output file, herein referred to as the cumulative difference file. This file, which will contain records of trace nmumbers, cumulative differences, and signs of the corresponding gradients, will be saved for future use. In the example below, the cumulative difference file has been given the name 'H4.C'.

```
Cumu Diff File= H4.C
```

SEGMENTATION CRITERIA: After the evaluation of cumulative differences and gradients, the user will be prompted to enter the segmentation criteria on minimum section length, and the minimum difference between means of adjacent segments.

```
Min sect length (mi)= .25
Min diff of sect mean= .5
```

The program then proceeds with the segmentation based on the user-specified criteria.

SECTION FILE: During the segmentation, intermediate steps will be displayed on the monitor. Upon completion, the user will then be asked to name an output section file, as shown below.

```
Segmentation by Minimum Section Length                          |
Cyclic Segmentation                                             | Display of
  Segmentation by Minimum Difference Between Means              } intermediate
  ...                                                           | steps
  ...                                                           |
  Segmentation by Statistical Significance of Section Means     |
Name of section file to be printed= H4.S
```

In the above example, the section file has been given the name 'H4.S'. This file will contain trace numbers and mile post readings corresponding to the beginning and ending of each segment, the segment length, and statistics on the selected pavemeter parameter, i.e. mean, standard deviation, sample size, and *t*-statistic.

6. **SUBSEQUENT PASS:** The user has the option to make another run of the segmentation algorithm on any of the segments established during a previous run. This will allow finer delineations to be made consistent with the user-specific criteria.

```
Current pass= 1.  Next pass (Y/N)=
```

If a subsequent pass is declined, the Main Menu will again be displayed, and the user will be asked to select the next operation. If a subsequent pass is to be made, the user will be asked to supply the following information for the next pass.

```
Trace: First=    0, Last= 1659
Evaluation Start at Trace= aaaa
Evaluation Stop  at Trace= bbbb

Cumu Diff File= H4.C

Min sect length (mi)= .25
Min diff of sect mean= .5
```

The program will then further subdivide the specific segment defined by the range of trace numbers specified above. The new segmentation results will then be printed to a new output file to be specified by the user. In the example below, this new output file has been called 'H4NEW.S'.

```
Segmentation by Minimum Section Length                          |
Cyclic Segmentation                                             | Display
  Segmentation by Minimum Difference Between Means              } intermediate
  ...                                                           | steps
  ...                                                           |
  Segmentation by Statistical Significance of Section Means     |
Name of section file to be printed= H4NEW.S
```

UPDATING NEW SEGMENTATION: Next, the program will proceed to update the first section file (i.e. 'H4.S') with the segmentation data from the new section file (i.e. 'H4NEW.S'). The resultant segmentation will again be subject to verification, so that each segment is consistent with the segmentation criteria.

```
Update To Section File 1= H4.S
Segmentation by Minimum Section Length                          |
Cyclic Segmentation                                             | Display of
  Segmentation by Minimum Difference Between Means              } intermediate
  ...                                                           | steps
  ...                                                           |
  Segmentation by Statistical Significance of Section Means     |
```

EVALUATING ANOTHER SECTION: If the user wishes to evaluate other pavement sections in the current pass, Step 6 will be repeated. Otherwise, user will be asked to decide if a subsequent pass is desired.

```
Current pass= 2.  Finish evaluating this pass (Y/N)=
Current pass= 2.  Next pass (Y/N)=
```

If the subsequent pass is declined, the Main Menu will then be displayed, and the user will be asked to select the next operation.

7. **VIEW SEGMENTATION RESULTS:** When option '4' is selected in the Main Menu, the view segmentation results procedure will be evoked.

```
                    MAIN MENU

      1. Select infile: R4601.D04
      2. Select parameter: H3
      3. Single parameter segmentation.
      4. View segmentation results.
      5. Composite segmentation.
      9. Exit.
    Enter selection: 4
```

The predicted values for the pavement parameter selected, and the segmentation results from the most recent pass will be displayed.

8. **COMPOSITE SEGMENTATION:** When option '5' is selected in the Main Menu, the composite segmentation procedure will be evoked. The user will be asked to enter one at a time, the names of the section files on which the composite segmentation will be performed.

```
                    MAIN MENU

      1. Select infile: R4601.D04
      2. Select parameter: H3
      3. Single parameter segmentation.
      4. View segmentation results.
      5. Composite segmentation.
      9. Exit.
    Enter selection: 5

    Composite Segmentation: Section file= H4.S
    Select another section file (Y /N)= Y
    Composite Segmentation: Section file= H3.S
    Select another section file (Y /N)= N
    Segmentation by Minimum Section Length
    Name of compsite segmentation file= R4601.SEG
```

In the example given above, there are altogether two section files (namely 'H4.S' and 'H3.S') to be combined. These files may have been generated from seperate runs of the computer program using layer 3 and layer 4 thickness predictions as the parameters of the segmentation. The composite segmentation will combine the different segments in the section files specified and will verify that each of the final sections is consistent with the minimum section length criterion. Shorter sections will be combined with the adjacent sections, when necessary.