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16. Abstract

The Falling Weight Deflectometer is commonly used in Texas for pavement evaluation and design purposes. Typically, measurements are made at a given date so that the data reflect the environmental conditions prevailing during the time of measurement. For pavement applications, the backcalculated asphalt concrete modulus needs to be adjusted or corrected to reference or standard conditions of temperature and loading frequency. The **M**odulus **T**emperature **C**orrection **P**rogram (**MTCP**) incorporates procedures for adjusting backcalculated asphalt concrete (AC) moduli to user-prescribed reference pavement temperatures. In this way, seasonal variations in AC modulus may be predicted for pavement evaluation and design purposes. Instructions in using MTCP are given in this user's manual.

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USER'S GUIDE FOR THE MODULUS TEMPERATURE CORRECTION PROGRAM (MTCP)

by

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and

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Emmanuel G. Fernando, P.E. # 69614.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

BACKGROUND AND SCOPE OF REPORT

The Texas Department of Transportation uses the Falling Weight Deflectometer (FWD) for pavement evaluation. A common application is the backcalculation of pavement layer moduli by deflection basin fitting. In Texas, pavement engineers use the MODULUS program (Michalak and Scullion, 1995) to provide estimates of pavement layer moduli from measured FWD deflections. These estimates are subsequently used in other applications, such as the FPS-19 flexible pavement design procedure, the Program for Analyzing Loads Superheavy (Jooste and Fernando, 1995 and Fernando, 1997), and the Program for Load Zoning Analysis (PLZA) developed by Fernando and Liu (1999).

For pavement applications, the results obtained from the FWD need to be adjusted or corrected to reference or standard conditions of temperature, moisture, and loading frequency. The **M**odulus **T**emperature **C**orrection **P**rogram (**MTCP**) described in this user's guide incorporates procedures for adjusting asphalt concrete moduli to user-prescribed reference pavement temperatures. To provide compatibility with the MODULUS program which is currently implemented within TxDOT, the output from MODULUS is used as an input to the modulus temperature correction program. This approach is expected to facilitate the implementation of MTCP within TxDOT.

To provide for implementation, researchers prepared this user's guide to explain how MTCP is used. The guide is organized into three chapters and an appendix:

1. Chapter I identifies the system requirements for running MTCP;
2. Chapter II provides instructions on using the program to estimate pavement temperatures, adjust backcalculated asphalt concrete (AC) moduli to a specified reference temperature, and predict the monthly variation of AC moduli at a given site;
3. Chapter III illustrates program output; and
4. the appendix provides a flow chart that may serve as a map of the analysis functions for practical applications.

Users of the program must have a working knowledge of MODULUS. The temperature corrections depend, to a considerable degree, on the layer moduli backcalculated from the FWD data. Thus, having a good working knowledge of MODULUS (and backcalculation, in general) will aid in understanding the results from the temperature corrections. In practice, it may be necessary to run MODULUS and MTCP a number of times to achieve realistic and reasonable results, particularly when the initial backcalculation indicates the need to divide the FWD data into two or more segments to better model the variations in pavement deflections, backcalculated moduli, or pavement layering.

SYSTEM REQUIREMENTS

MTCP requires a microcomputer with the Windows (9*x*, NT, 2000, ME) operating system and Microsoft Excel, version 97 or later. A Pentium microprocessor or its equivalent and a minimum of 32 Mb of memory are recommended. Users must have a good working knowledge of the Windows operating system and Microsoft Excel. To install the program, simply copy the files in the program disk onto a subdirectory of your computer's hard drive. For example, you may want to create a subdirectory called *C:\MTCP* and copy the program files into this subdirectory. Once you copy the files, you may run the program by first going into Excel and loading the spreadsheet called *MTCP.XLS* in the program subdirectory using Excel's *File/Open* command. You will then be asked if you want to disable or enable the macros that are in the MTCP spreadsheet. Click on the ***Enable Macros*** button of the dialog box to use the program for temperature correction of backcalculated AC moduli. The title screen in Figure 1 is then displayed. If the MTCP title screen is bigger or smaller than your computer display, you may resize the screen using the zoom box at the top toolbar of the Excel spreadsheet. In the example shown in Figure 1, the zoom box is currently set at 100%. Click the size you want in the zoom box or enter a number between 10 and 400 to resize the screen.

To start using MTCP, click anywhere on the MTCP title screen to get to the main program menu illustrated in Figure 2. From this menu, you may access the available program functions. The available functions are described in the remainder of this user's guide.
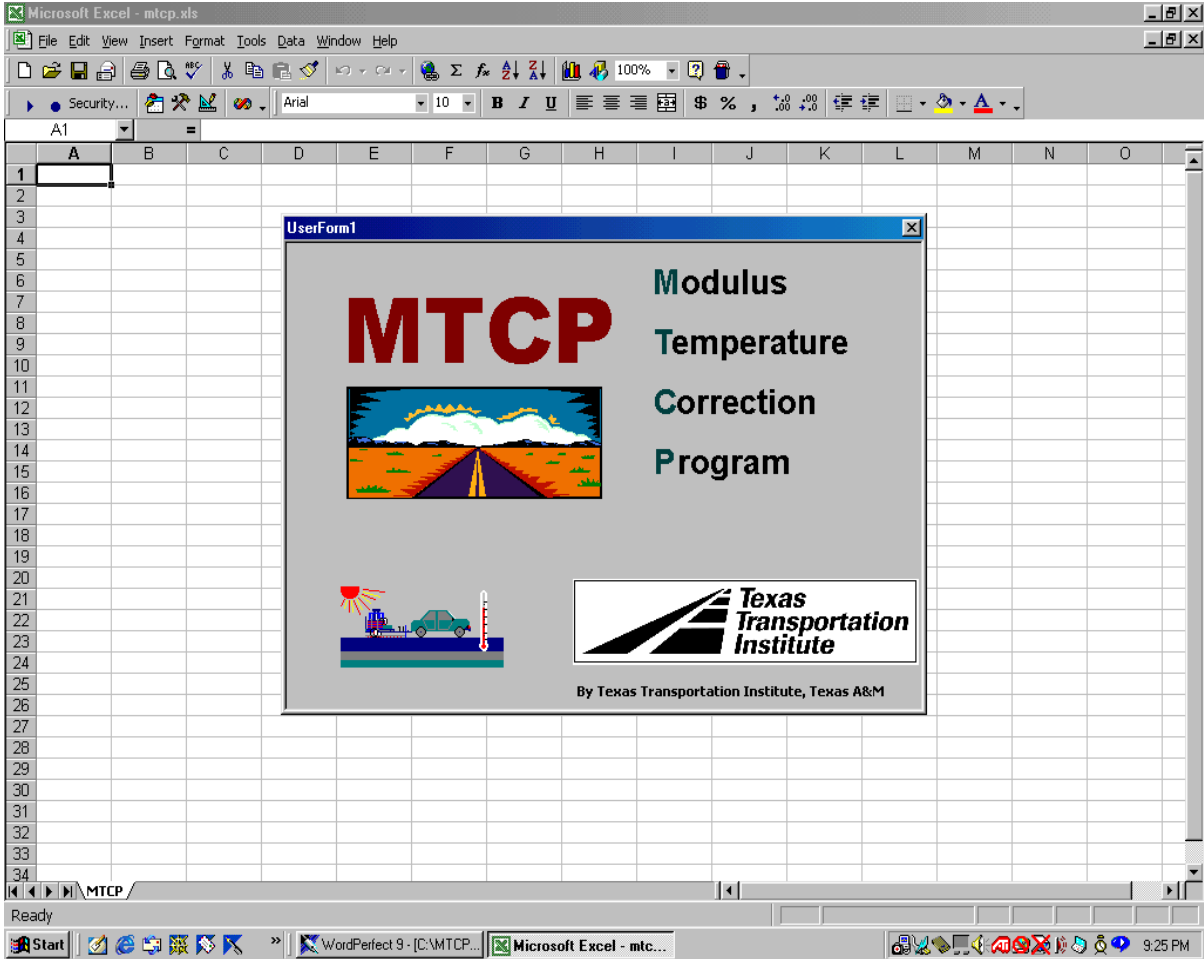
Figure 1. MTCP Title Screen.
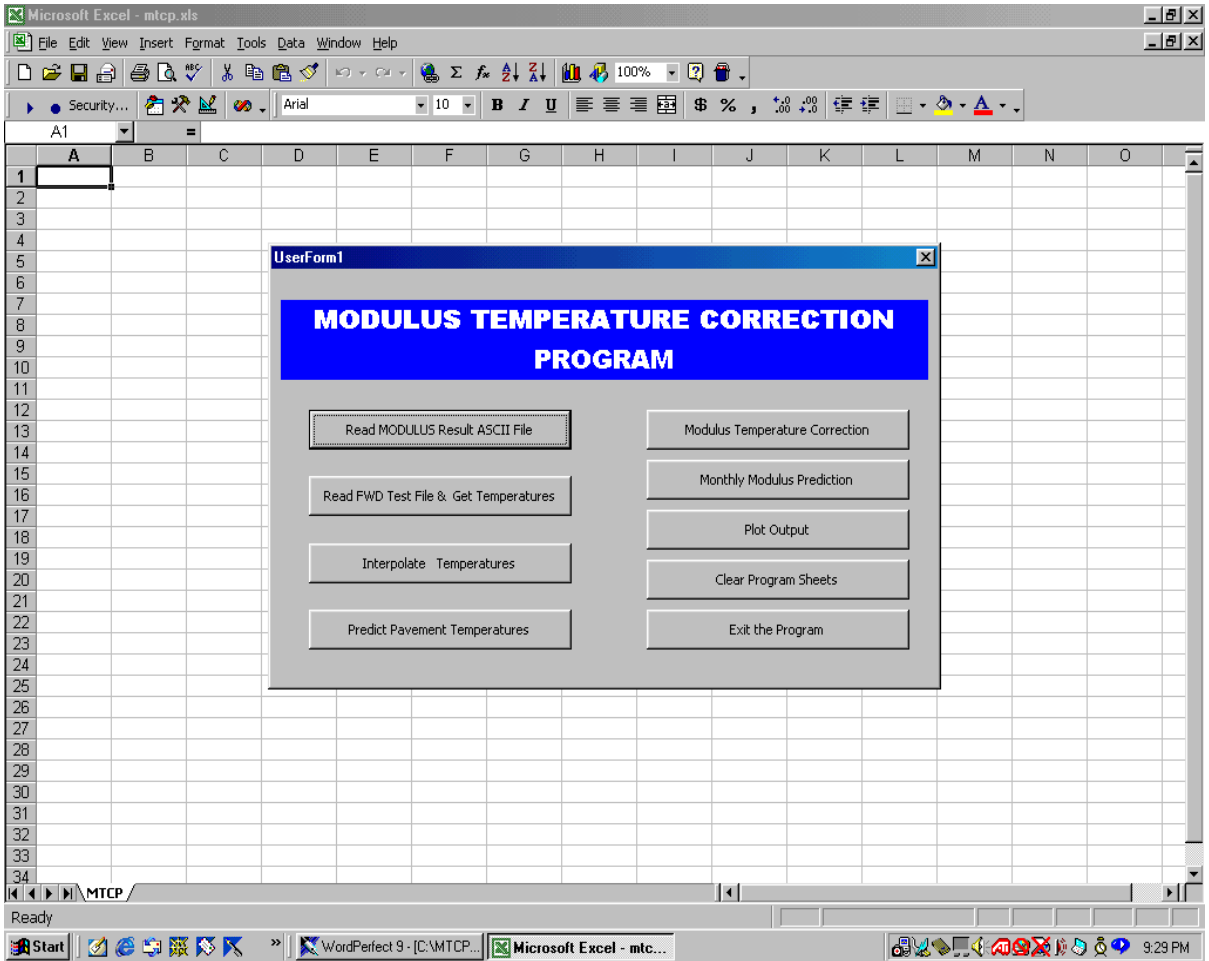
Figure 2. MTCP Main Menu.

CHAPTER II
USING THE MODULUS TEMPERATURE
CORRECTION PROGRAM

The FWD is commonly used in Texas for pavement evaluation and design purposes. Typically, pavement engineers make measurements at a given date so that the data reflect the environmental conditions prevailing during the time of measurement. MTCP has been developed to give TxDOT pavement engineers a tool for adjusting backcalculated AC moduli to account for temperature effects. Through this program, seasonal variations in AC moduli may be predicted for pavement evaluation and design purposes. Instructions for using MTCP are given in this chapter.

SPECIFYING MTCP INPUT FILES

Within TxDOT, pavement engineers use MODULUS for backcalculating layer moduli from FWD measurements. Consequently, researchers developed MTCP to use the output from MODULUS directly. This is done by clicking on the *Read MODULUS Result ASCII File* button of the main menu given in Figure 2. Specifying the MODULUS summary output file is the first step in using the program for temperature correction of backcalculated AC moduli. Clicking on *Read MODULUS Result ASCII File* brings up the dialog box shown in Figure 3. From this menu, the user can specify the MODULUS summary output file to use in the analysis. Simply highlight the file by clicking on the file name in the dialog box. Then click on the *Open* button at the lower right corner of the dialog box to confirm your selection. From this menu, you may also search the different drives and subdirectories on your computer for the particular file you want to process.

The MODULUS output file is read, and the contents of the file are imported into the *output* worksheet shown in Figure 4. To view the information, click on *Exit the Program* to close the main menu as illustrated in Figure 5. You may go back to this menu at any time by pressing the *Ctrl*, *Shift*, and *M* keys in combination (*Ctrl+Shift+M*). The information displayed in Figure 5 is the same as that given in the MODULUS summary output and consists of the:
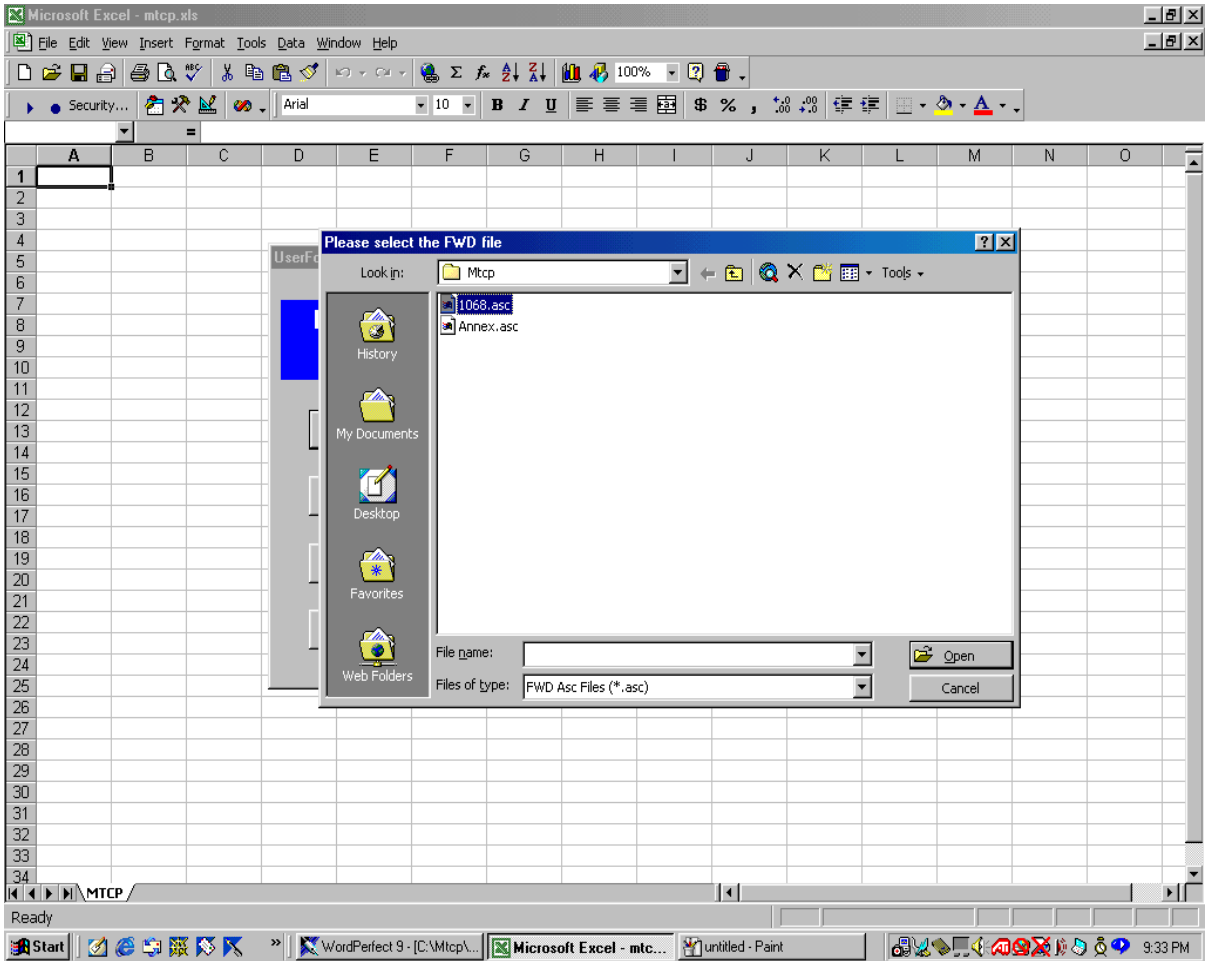
Figure 3. Dialog Box for Specifying MODULUS Output File to Analyze.

Microsoft Excel - 1068.xls

File Edit View Insert Format Tools Data Window Help

A1 = TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District	1		Modulus Range (ksi)																
County	139			Thick (in) Min	Max	Poisson													
			Surface	10.9	30	1500	0.4												
			Base	6	15	200	0.35												

TEMPERATURE (F)

Station	Load	R1														Limit Air	Surface Paveme	Test tin
75.100	9375	6.76																
75.200	9279	6.84																
75.300	9263	7.06																
75.400	9167	7.14																
75.500	9807	6.46																
75.600	9879	6.71																
75.700	9671	7.10																
75.800	9471	7.87																
75.900	9375	8.47																
76.000	9391	9.88																
76.100	9383	10.39																
76.200	9407	12.10																
76.300	9279	14.20																
76.400	9390	12.13																
76.500	9342	12.69																
76.600	9283	14.88																
76.700	9271	16.48																
76.800	9168	17.17	12.07	9.90	7.90	6.13	3.72	1.73	119.0	23.0	0.0	13.0	0.5	123.7				
76.900	9513	11.79	9.26	8.16	6.79	5.53	3.60	1.70	291.0	20.0	0.0	14.5	0.3	123.8				
77.000	9561	11.94	9.48	8.37	6.95	5.68	3.66	1.72	302.0	15.0	0.0	14.5	0.3	123.6				
77.100	9418	12.90	9.99	8.76	7.23	5.79	3.63	1.74	248.0	15.3	0.0	14.3	0.6	131.9				
77.200	9338	14.55	10.81	9.17	7.43	5.85	3.60	1.63	180.0	17.7	0.0	14.1	0.4	115.4				
77.300	9597	12.28	9.50	8.26	6.89	5.57	3.68	1.69	250.0	31.7	0.0	14.0	0.3	114.9				
77.400	9609	12.23	9.63	8.38	6.95	5.60	3.60	1.68	275.0	17.1	0.0	14.8	0.3	120.7				

output

Ready

UserForm1

MODULUS TEMPERATURE CORRECTION PROGRAM

Read MODULUS Result ASCII File

Read FWD Test File & Get Temperatures

Interpolate Temperatures

Predict Pavement Temperatures

Modulus Temperature Correction

Monthly Modulus Prediction

Plot Output

Clear Program Sheets

Exit the Program

Start | WordPerfect 9 - [C:\Mtcp\... | Microsoft Excel - 106... | untitled - Paint | 9:52 PM

Figure 4. MODULUS Output File Imported into MTCP.

7
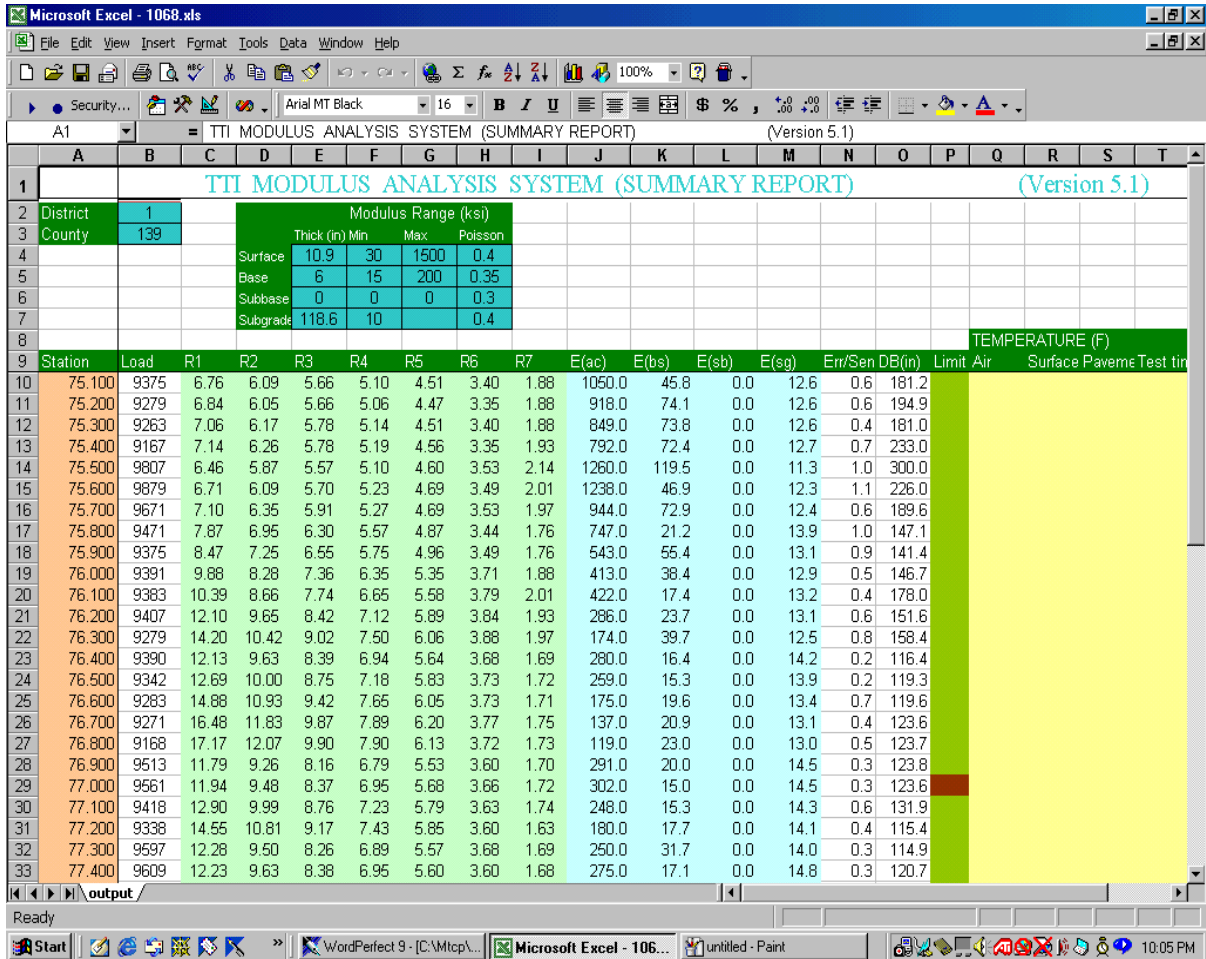
Figure 5. Viewing the MODULUS Summary Output File.

1. district and county where FWD measurements were taken;

2. pavement layer thicknesses;

3. allowable range of the backcalculated modulus for each layer;

4. FWD load, sensor deflections, and backcalculated layer moduli at each test location along with the absolute error per sensor between the predicted and measured deflections;

2. depth to bedrock estimated from the measured deflections at each station; and

3. computed means, standard deviations, and coefficients of variation for the measured deflections, backcalculated moduli, depths to bedrock, and absolute errors per sensor.

In addition, the column labeled *Limit* in the worksheet gives an indication of whether any of the backcalculated moduli reached the limits set by the user during the backcalculation. If moduli reach any limit, the program shades the cell for that particular station red under the *Limit* column. Otherwise, the cell is shaded green. To the right of the *Limit* column are blank cells where temperature data taken during FWD testing are entered. Air and surface temperatures are normally measured from sensors built into the FWD and are recorded at each test location. These measurements are written in the same data file where the deflections are saved. For the purpose of predicting pavement temperatures using the methods built into the program, surface temperatures taken with an infrared sensor are required. Consequently, researchers recommend that infrared sensors be installed in TxDOT's FWDs to implement the computer program developed from this project. In practice, attention must be given to maintaining the infrared sensor in good operating condition and checking the sensor calibration to ensure the validity of the temperature measurements.

In addition, the operator collects pavement temperatures at specific locations using a temperature probe. For this purpose, researchers recommend that temperatures be measured at half the depth of the surface layer if the thickness is known at the time of FWD testing, or at a depth of 1.6 inches (4 cm) from the surface if the thickness is not known. These recommendations are based on the findings from this study (Fernando and Liu, 2001).

Since layer thicknesses are needed to analyze the FWD deflections using MODULUS, users may obtain this information beforehand and use it in planning the FWD testing. For this purpose, researchers strongly suggest a Ground Penetrating Radar (GPR) survey on the route to establish the variations in layer thicknesses from the profiles obtained. Specifically, the GPR survey should be conducted to:

1. detect changes in pavement layer thicknesses and divide the project into analysis segments,

2. establish the locations of FWD measurements consistent with pavement thickness variations identified from the radar data, and

3. establish the need for cores or Dynamic Cone Penetrometer (DCP) data to supplement the radar survey and identify locations where coring and DCP measurements should be made.
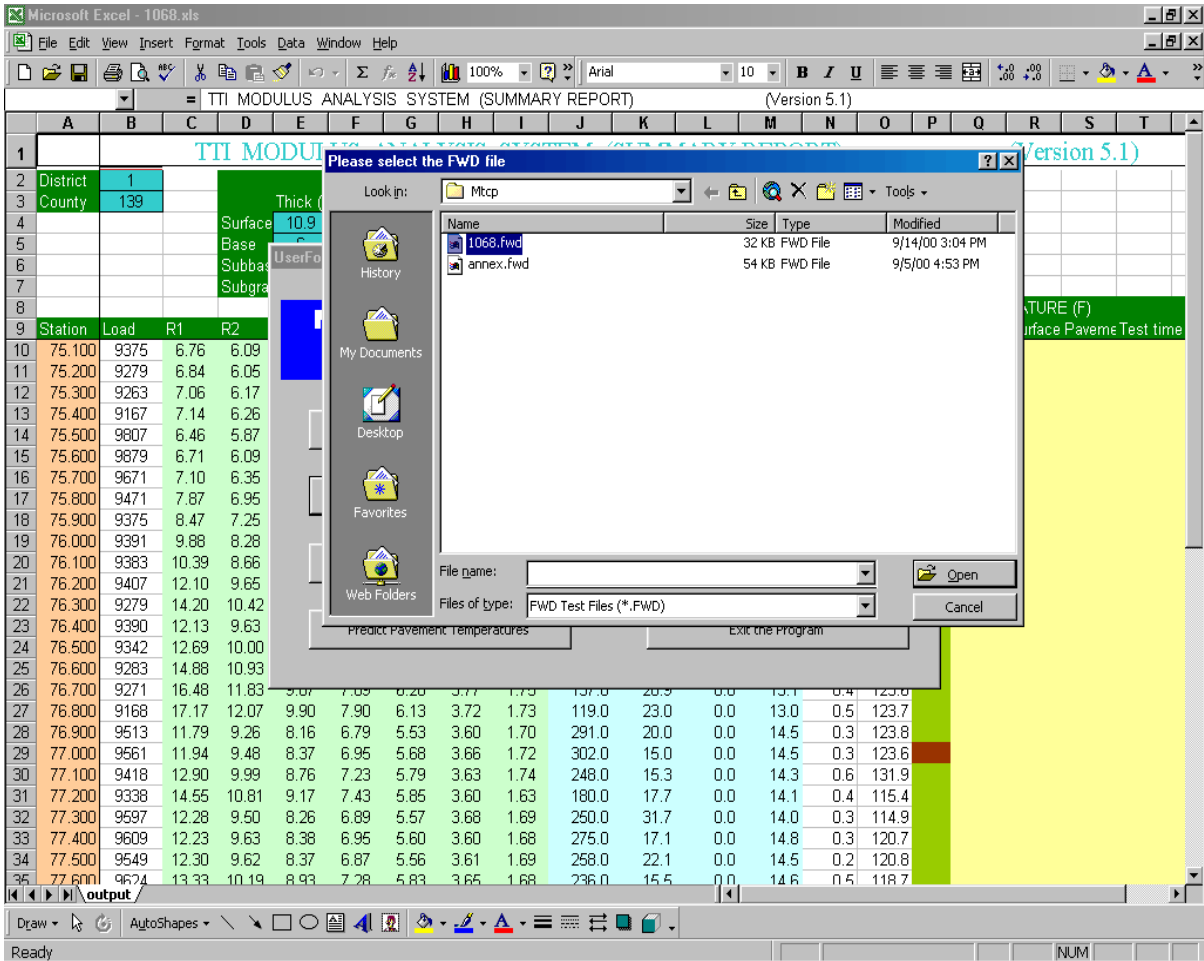
Figure 6. Dialog Box for Specifying the FWD Data File.

Pavement temperatures measured during the FWD survey should be properly recorded into the data file consistent with the FWD operator's manual (TxDOT, 1996). In this way, all temperature data may be read from the file and imported directly into the MTCP spreadsheet without having to manually key in the pavement temperatures. The air, surface, and pavement temperatures taken during the survey may be imported into the spreadsheet by clicking on the ***Read FWD Test File & Get Temperatures*** button of the main menu given in Figure 2. The dialog box in Figure 6 is then displayed for you to specify the name of the FWD data file. After selecting the FWD file, click on the ***Open*** button of the dialog box to import the temperature data into the spreadsheet as illustrated in Figure 7.

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= TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)   (Version 5.1)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S	T
2	District	1				Modulus Range (ksi)													
3	County	139				Thick (in) Min	Max	Poisson											
4				Surfa													TEMPERATURE (F)		
9	Station	Load	R1	R2												imit Air	Surface	Paveme	Test tin
10	75.100	9375	6.76	6.0												48.0	53.0	51.0	10:24
11	75.200	9279	6.84	6.0												49.0	56.0	53.0	12:19
12	75.300	9263	7.06	6.1												52.0	62.0	55.0	14:04
13	75.400	9167	7.14	6.2												55.0	66.0	57.0	15:33
14	75.500	9807	6.46	5.8												31.0	40.0	37.0	8:25
15	75.600	9879	6.71	6.0												41.0	59.0	44.0	10:26
16	75.700	9671	7.10	6.3												54.0	62.0	51.0	9:30
17	75.800	9471	7.87	6.9												51.0	58.0	64.0	7:37
18	75.900	9375	8.47	7.2												68.0	81.0	69.0	10:18
19	76.000	9391	9.88	8.2												65.0	75.0	83.0	6:46
20	76.100	9383	10.39	8.6												75.0	93.0	82.0	8:59
21	76.200	9407	12.10	9.6												83.0	104.0	91.0	11:54
22	76.300	9279	14.20	10.4												87.0	128.0	100.0	14:36
23	76.400	9390	12.13	9.6												81.0	79.0	95.0	7:31
24	76.500	9342	12.69	10.0												85.0	84.0	97.0	9:19
25	76.600	9283	14.88	10.93	9.42	7.65	6.05	3.73	1.71	175.0	19.6	0.0	13.4	0.7	119.6	91.0	96.0	105.0	12:01
26	76.700	9271	16.48	11.83	9.87	7.89	6.20	3.77	1.75	137.0	20.9	0.0	13.1	0.4	123.6	96.0	104.0	111.0	14:20
27	76.800	9168	17.17	12.07	9.90	7.90	6.13	3.72	1.73	119.0	23.0	0.0	13.7	0.5	123.7	97.0	108.0	114.0	16:24
28	76.900	9513	11.79	9.26	8.16	6.79	5.53	3.60	1.70	291.0	20.0	0.0	14.5	0.3	123.8	78.0	75.0	92.0	6:40
29	77.000	9561	11.94	9.48	8.37	6.95	5.68	3.66	1.72	302.0	15.0	0.0	14.5	0.3	123.6	82.0	80.0	91.0	8:45
30	77.100	9418	12.90	9.99	8.76	7.23	5.79	3.63	1.74	248.0	15.3	0.0	14.3	0.6	131.9	88.0	89.0	95.0	10:57
31	77.200	9338	14.55	10.81	9.17	7.43	5.85	3.60	1.63	180.0	17.7	0.0	14.1	0.4	115.4	91.0	99.0	103.0	13:03
32	77.300	9597	12.28	9.50	8.26	6.89	5.57	3.68	1.69	250.0	31.7	0.0	14.0	0.3	114.9	77.0	80.0	96.0	6:54
33	77.400	9609	12.23	9.63	8.38	6.95	5.60	3.60	1.68	275.0	17.1	0.0	14.8	0.3	120.7	80.0	81.0	95.0	8:58

MODULUS TEMPERATURE CORRECTION PROGRAM

- Read MODULUS Result ASCII File
- Read FWD Test File & Get Temperatures
- Interpolate Temperatures
- Predict Pavement Temperatures
- Modulus Temperature Correction
- Monthly Modulus Prediction
- Plot Output
- Clear Program Sheets
- Exit the Program

Ready

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Figure 7. Temperature Data Imported from the FWD Data File.

PERFORMING THE TEMPERATURE CORRECTION

Before corrections to a reference temperature may be made, the pavement temperatures you are correcting from must first be established. These pavement temperatures are referred to herein as the base temperatures for the modulus correction and refer to the pavement temperatures at which the FWD deflections were taken. There are two functions available in MTCP to establish the base temperatures. One allows you to estimate the pavement temperature at a given FWD station by interpolating between pavement temperatures measured at two neighboring stations that bound it.

In practice, pavement temperatures will not normally be measured at each test location. By clicking on the *Interpolate Temperatures* button in the main menu, you can fill in the missing information by interpolation from the available pavement temperature measurements. As a minimum, pavement temperatures should be measured at the beginning

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and end of the FWD survey for a given project. The program uses a linear interpolation based on the time of the FWD measurement. This is given in the *Test Time* column of the spreadsheet illustrated in Figure 7. No extrapolation is done for locations that are outside the range of stations where pavement temperatures were measured. Stations preceding the first temperature measurement are assigned that pavement temperature while stations following the last measurement are assigned the last value.

If you did not enter the pavement temperatures at the time of the FWD survey, you may manually key in the data along the *Pavement* column of the spreadsheet inside the cells corresponding to stations where pavement temperatures were taken. After manually entering the data, you may then click on **Interpolate Temperatures** to fill in the rest of the cells along the *Pavement* column with interpolated pavement temperatures.

Alternatively, if pavement temperatures were not measured during the survey, the base temperatures for the correction may be established using one of three options available within MTCP for predicting pavement temperature. All three options require the infrared surface temperatures taken with the FWD and the average of the previous day's minimum and maximum air temperatures at the vicinity of the project. The first two options are the BELLS2 and BELLS3 equations which were developed using data from Seasonal Monitoring Program (SMP) sites located in North America. The development of these equations are documented in a report by Lukanen, Stubstad, and Briggs (1998) and in a paper by Stubstad et al. (1998). BELLS2 is the equation for the FWD testing protocol used in the Long-Term Pavement Performance (LTPP) program. On the other hand, BELLS3 is intended for routine testing and was developed from efforts made to consider the effects of shading on the infrared surface temperatures measured on the SMP sites. The functional form of the BELLS2 and BELLS3 equations is given by:

$$T_d = \beta_0 + \beta_1\, IR + [\log_{10}(d) - 1.25]\, [\, \beta_2\, IR + \beta_3\, T_{(1\text{-day})} + \beta_4\, \sin(hr_{18} - 15.5)\,] +$$
$$\beta_5\, IR\, \sin(hr_{18} - 13.5) \tag{1}$$

where,

T_d = pavement temperature at depth, d, within the asphalt layer, °C

IR = surface temperature measured with the FWD infrared temperature gauge, °C

d = depth at which the temperature is to be predicted, mm

Table 1. Coefficients of the BELLS2 and BELLS3 Equations.

Coefficient	BELLS2	BELLS3
$\$_0$	+2.780	+0.950
$\$_1$	+0.912	+0.892
$\$_2$	-0.428	-0.448
$\$_3$	+0.553	+0.621
$\$_4$	+2.630	+1.830
$\$_5$	+0.027	+0.042
R^2	0.977	0.975
SEE	1.8 °C	1.9 °C
N_{obs}	10,304	10,304

$T_{(1\text{-day})}$ = the average of the previous day's high and low air temperatures, °C

hr_{18} = time of day in the 24-hour system but calculated using an 18-hour asphalt temperature rise and fall time as explained by Stubstad et al. (1998)

The coefficients of Eq.(1) are given in Table 1 for both the BELLS2 and BELLS3 equations. Also shown are the R^2, standard error of the estimate (SEE) and the number of observations (N_{obs}) used to develop each equation. Note that the average of the previous day's high and low air temperatures is the only variable not collected during routine FWD testing that the user needs to provide to predict pavement temperatures with BELLS2 or BELLS3. Researchers recommend that pavement temperatures be predicted at half the depth of the surface layer.

The third option available within MTCP to predict pavement temperature uses the same variables as BELLS2 and BELLS3 but has the functional form given by Eq.(2) below:

$$
\begin{aligned}
T_d = \ & \$_0 + \$_1\,(IR + 2)^{1.5} + \log_{10}(d)\,\big(\,\{\,\$_2\,(IR + 2)^{1.5} + \$_3\,\sin^2(hr_{18} - 15.5) + \\
& \$_4\,\sin^2(hr_{18} - 13.5) + \$_5\,[T_{(1\text{-day})} + 6]^{1.5}\,\} + \\
& \$_6\,\sin^2(hr_{18} - 15.5)\,\sin^2(hr_{18} - 13.5)
\end{aligned}
\tag{2}
$$

where the terms are as defined previously and the coefficients are:

$$\beta_0 = 6.460 \qquad \beta_1 = 0.199 \qquad \beta_2 = -0.083 \qquad \beta_3 = -0.692$$

$$\beta_4 = 1.874 \qquad \beta_5 = 0.059 \qquad \beta_6 = -6.783$$

Equation (2) has an R^2 of 0.931 and a standard error of the estimate of 3.1 °C with 1575 observations. It was developed using data collected from SMP sites in Texas, New Mexico, and Oklahoma and from two flexible pavement sections located at the Texas A&M Riverside Campus. If the pavement temperatures at these sites are predicted using the original BELLS2 and BELLS3 equations, standard errors of the estimate of 4.1 °C and 4.9 °C are obtained, respectively (Fernando and Liu, 2001). To improve the predictive accuracy, researchers undertook to calibrate the BELLS2 and BELLS3 equations using data that are representative of conditions within Texas. These efforts led to the development of Eq.(2) which is referred to as the Texas-LTPP equation.

You may access the available options for predicting pavement temperature by clicking on the ***Predict Pavement Temperatures*** button of the main menu. This will display the dialog box illustrated in Figure 8 where you will specify:

1. the depth, in inches, at which the temperature is to be predicted;
2. the average of the previous day's high and low air temperatures in °F; and
3. the method for predicting pavement temperature, i.e., BELLS2, BELLS3, or the Texas-LTPP equation given by Eq.(2).

You may select the equation to use by clicking on the down arrow in the *Select Equation* field of the dialog box to display the list of available options (see Figure 9). Select the equation by clicking on it. Note that the surface thickness from the MODULUS output file is displayed in the dialog box for your reference when you specify the depth at which pavement temperatures are to be predicted. It is also important that you specify the depth in inches and the average of the previous day's high and low air temperatures in °F as noted in the dialog box. The program automatically converts these inputs to the corresponding metric units used in the equations.

After entering the required data in Figure 8, click on the ***OK*** button of the dialog box to proceed with the temperature prediction. The results are written into the spreadsheet immediately to the right of the *Test time* column as shown in Figure 10. This column is labeled *Predicted Temperature*. If you bring the pointer inside the cell for this label, a comment box is displayed (Figure 10) which gives information on the equation selected for predicting pavement temperatures, the depth at which the temperatures were predicted, and
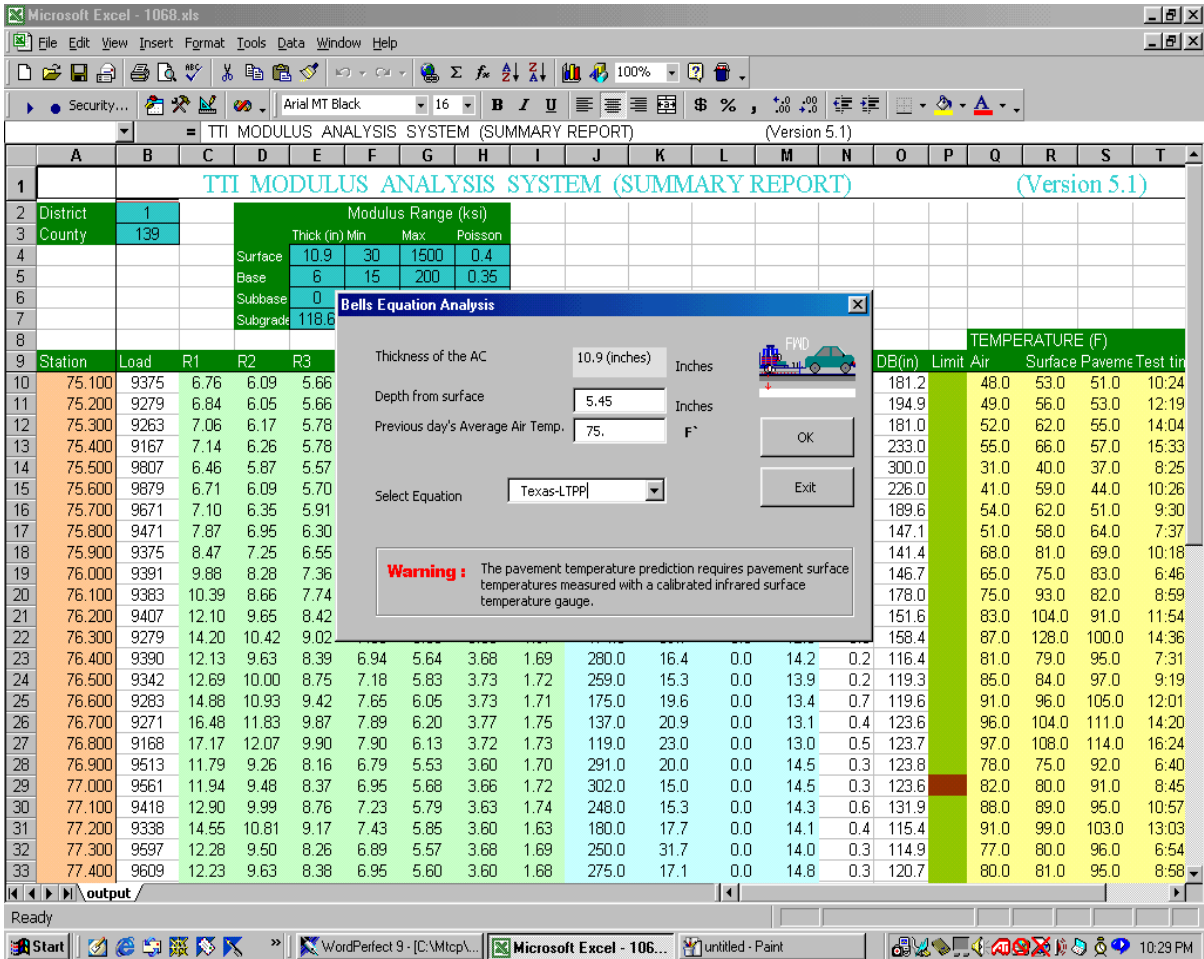
TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

Microsoft Excel - 1068.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
2	District	1					Modulus Range (ksi)													
3	County	139			Thick (in)	Min	Max	Poisson												
4				Surface	10.9	30	1500	0.4												
5				Base	6	15	200	0.35												
6				Subbase	0															
7				Subgrade	118.6															
8																	TEMPERATURE (F)			
9	Station	Load	R1	R2	R3										DB(in)	Limit	Air	Surface	Pavement	Test time

Station	Load	R1	R2	R3											DB(in)		Air	Surface	Pavement	Test time
75.100	9375	6.76	6.09	5.66											181.2		48.0	53.0	51.0	10:24
75.200	9279	6.84	6.05	5.66											194.9		49.0	56.0	53.0	12:19
75.300	9263	7.06	6.17	5.78											181.0		52.0	62.0	55.0	14:04
75.400	9167	7.14	6.26	5.78											233.0		55.0	66.0	57.0	15:33
75.500	9807	6.46	5.87	5.57											300.0		31.0	40.0	37.0	8:25
75.600	9879	6.71	6.09	5.70											226.0		41.0	59.0	44.0	10:26
75.700	9671	7.10	6.35	5.91											189.6		54.0	62.0	51.0	9:30
75.800	9471	7.87	6.95	6.30											147.1		51.0	58.0	64.0	7:37
75.900	9375	8.47	7.25	6.55											141.4		68.0	81.0	69.0	10:18
76.000	9391	9.88	8.28	7.36											146.7		65.0	75.0	83.0	6:46
76.100	9383	10.39	8.66	7.74											178.0		75.0	93.0	82.0	8:59
76.200	9407	12.10	9.65	8.42											151.6		83.0	104.0	91.0	11:54
76.300	9279	14.20	10.42	9.02											158.4		87.0	128.0	100.0	14:36
76.400	9390	12.13	9.63	8.39	6.94	5.64	3.68	1.69	280.0	16.4	0.0	14.2	0.2	116.4		81.0	79.0	95.0	7:31
76.500	9342	12.69	10.00	8.75	7.18	5.83	3.73	1.72	259.0	15.3	0.0	13.9	0.2	119.3		85.0	84.0	97.0	9:19
76.600	9283	14.88	10.93	9.42	7.65	6.05	3.73	1.71	175.0	19.6	0.0	13.4	0.7	119.6		91.0	96.0	105.0	12:01
76.700	9271	16.48	11.83	9.87	7.89	6.20	3.77	1.75	137.0	20.9	0.0	13.1	0.4	123.6		96.0	104.0	111.0	14:20
76.800	9168	17.17	12.07	9.90	7.90	6.13	3.72	1.73	119.0	23.0	0.0	13.0	0.5	123.7		97.0	108.0	114.0	16:24
76.900	9513	11.79	9.26	8.16	6.79	5.53	3.60	1.70	291.0	20.0	0.0	14.5	0.3	123.8		78.0	75.0	92.0	6:40
77.000	9561	11.94	9.48	8.37	6.95	5.68	3.66	1.72	302.0	15.0	0.0	14.5	0.3	123.6		82.0	80.0	91.0	8:45
77.100	9418	12.90	9.99	8.76	7.23	5.79	3.63	1.74	248.0	15.3	0.0	14.3	0.6	131.9		88.0	89.0	95.0	10:57
77.200	9338	14.55	10.81	9.17	7.43	5.85	3.60	1.63	180.0	17.7	0.0	14.1	0.4	115.4		91.0	99.0	103.0	13:03
77.300	9597	12.28	9.50	8.26	6.89	5.57	3.68	1.69	250.0	31.7	0.0	14.0	0.3	114.9		77.0	80.0	96.0	6:54
77.400	9609	12.23	9.63	8.38	6.95	5.60	3.60	1.68	275.0	17.1	0.0	14.8	0.3	120.7		80.0	81.0	95.0	8:58

Bells Equation Analysis

Thickness of the AC — 10.9 (inches) Inches

Depth from surface — 5.45 Inches

Previous day's Average Air Temp. — 75. F`

Select Equation — Texas-LTPP

OK   Exit

Warning : The pavement temperature prediction requires pavement surface temperatures measured with a calibrated infrared surface temperature gauge.

Figure 8. Dialog Box to Specify Input Data for Pavement Temperature Prediction.

Bells Equation Analysis

Thickness of the AC — 10.9 (inches) Inches

Depth from surface — 5.45 Inches

Previous day's Average Air Temp. — 75. F`

OK   Exit

Select Equation — Texas-LTPP
- Bells2
- Bells3
- Texas-LTPP

Warning : The pavement temperature prediction requires pavement surface temperatures measured with a calibrated infrared surface temperature gauge.
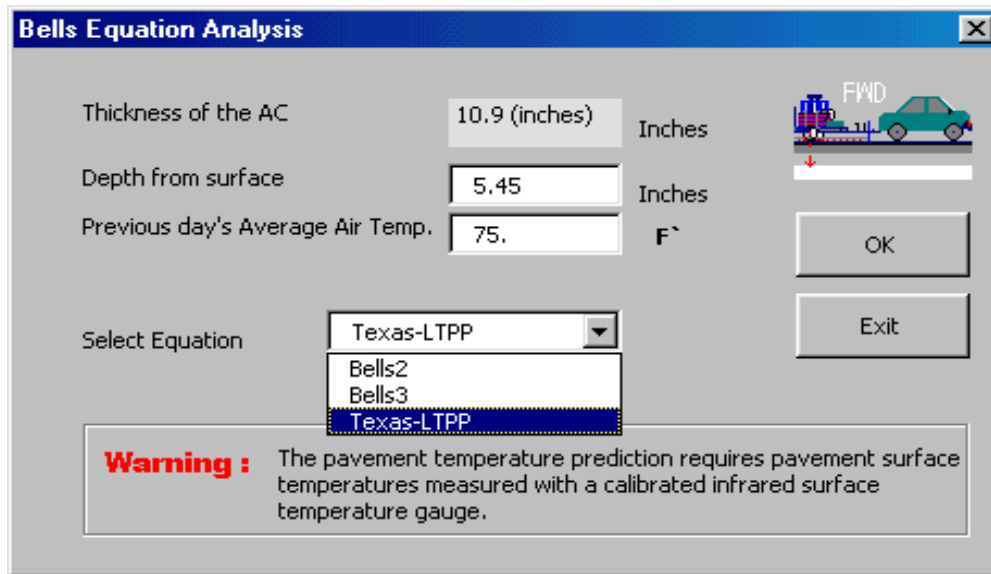
Figure 9. Equations Available for Predicting Pavement Temperatures.
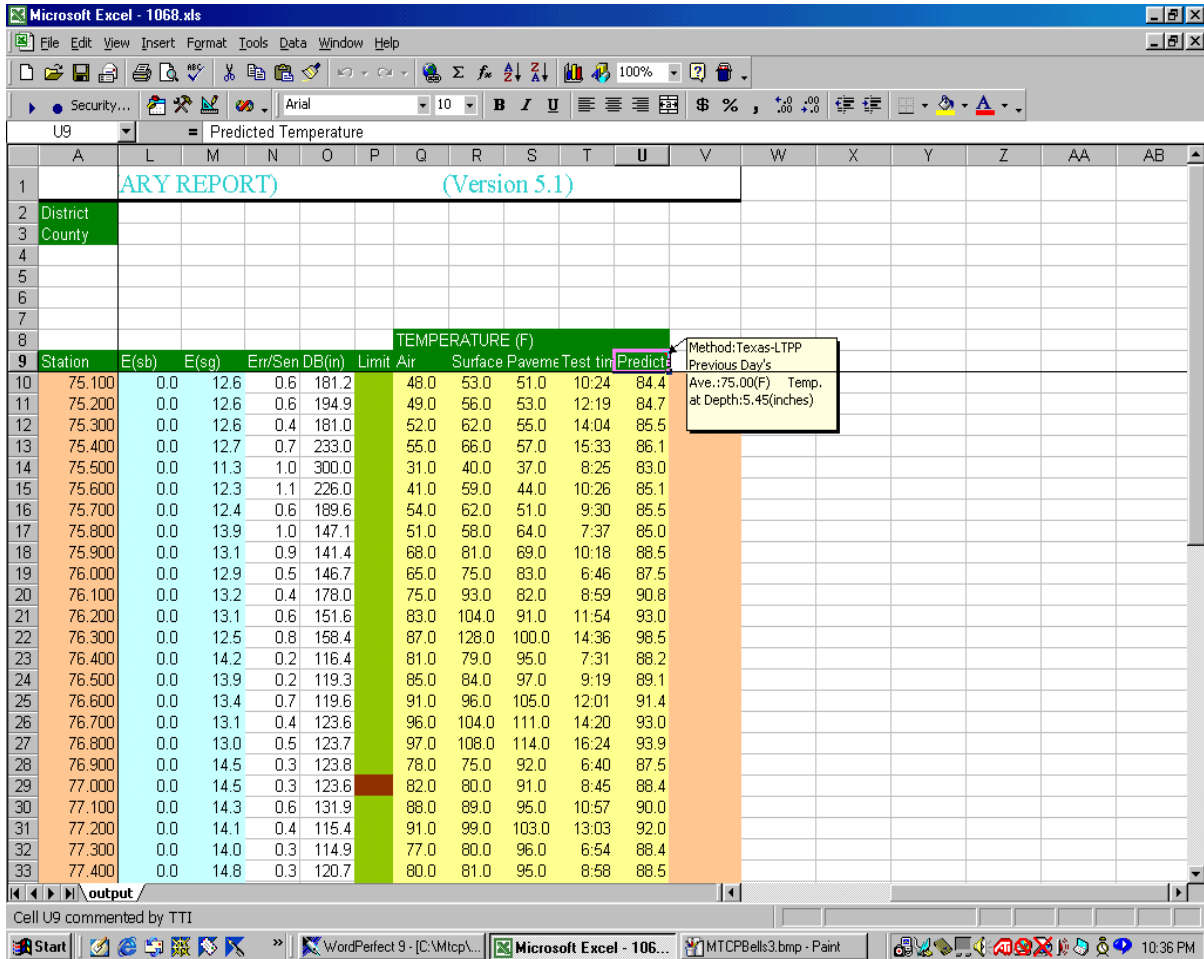
15

Figure 10. Predicted Pavement Temperatures from MTCP.

the average of the previous day's high and low air temperatures. A red triangular spot at the upper right corner identifies cells with comment boxes. Sometimes there may be more information than can be displayed inside the comment box. In this case, you may resize the box by right clicking on the cell and selecting the *Edit Comment* function (Figure 11) to view all of the information inside the box.

After the base temperatures are established, you can proceed with the modulus correction by clicking on the **Modulus Temperature Correction** button of the main menu illustrated in Figure 2. This will display the dialog box shown in Figure 12 which provides the following three options for temperature correction of backcalculated AC moduli:

1. the existing TxDOT equation used in the Flexible Pavement System (FPS) and load zoning analysis programs,
2. the Chen equation (Chen at al., 2000), and
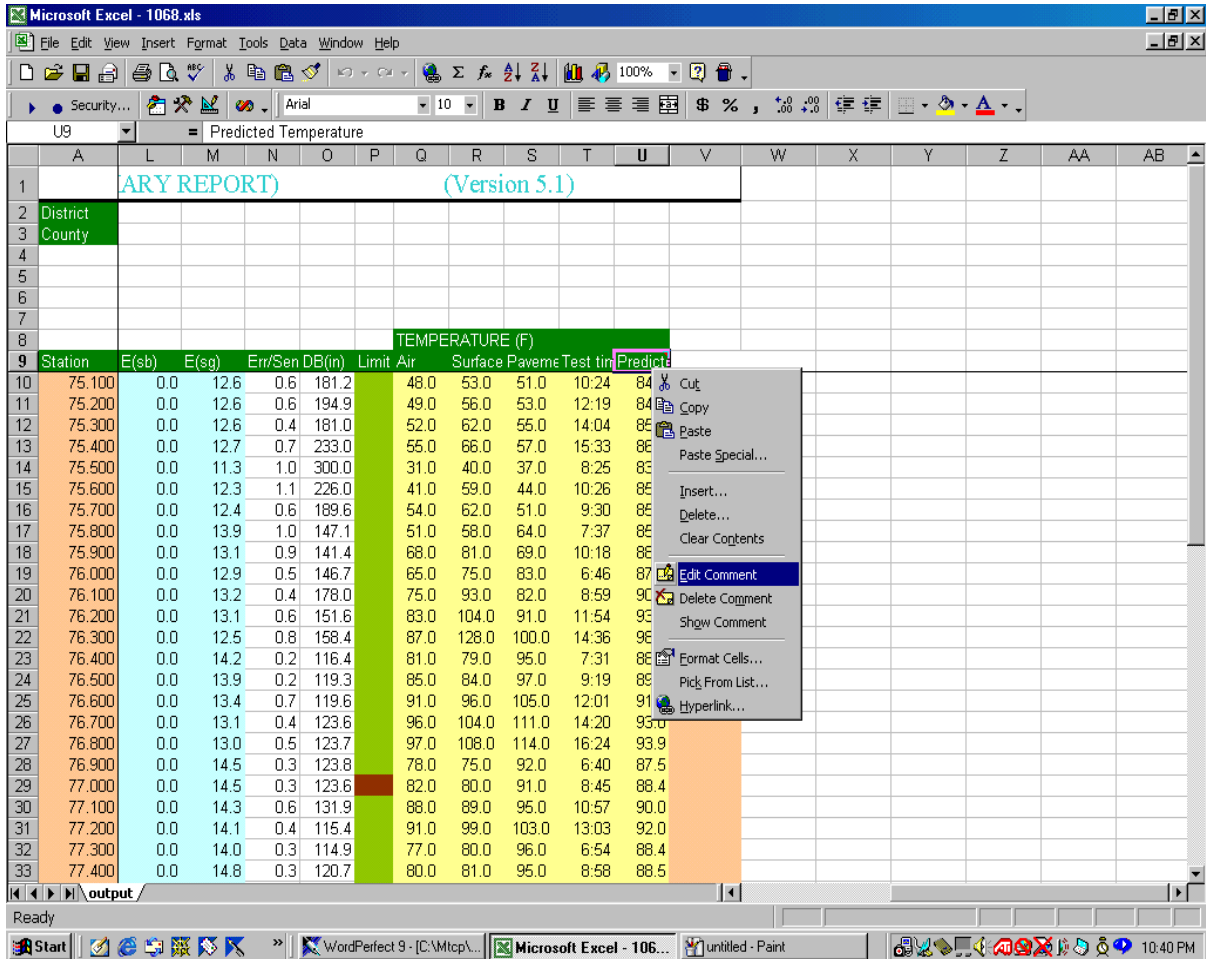3. Witczak's dynamic modulus equation.

16

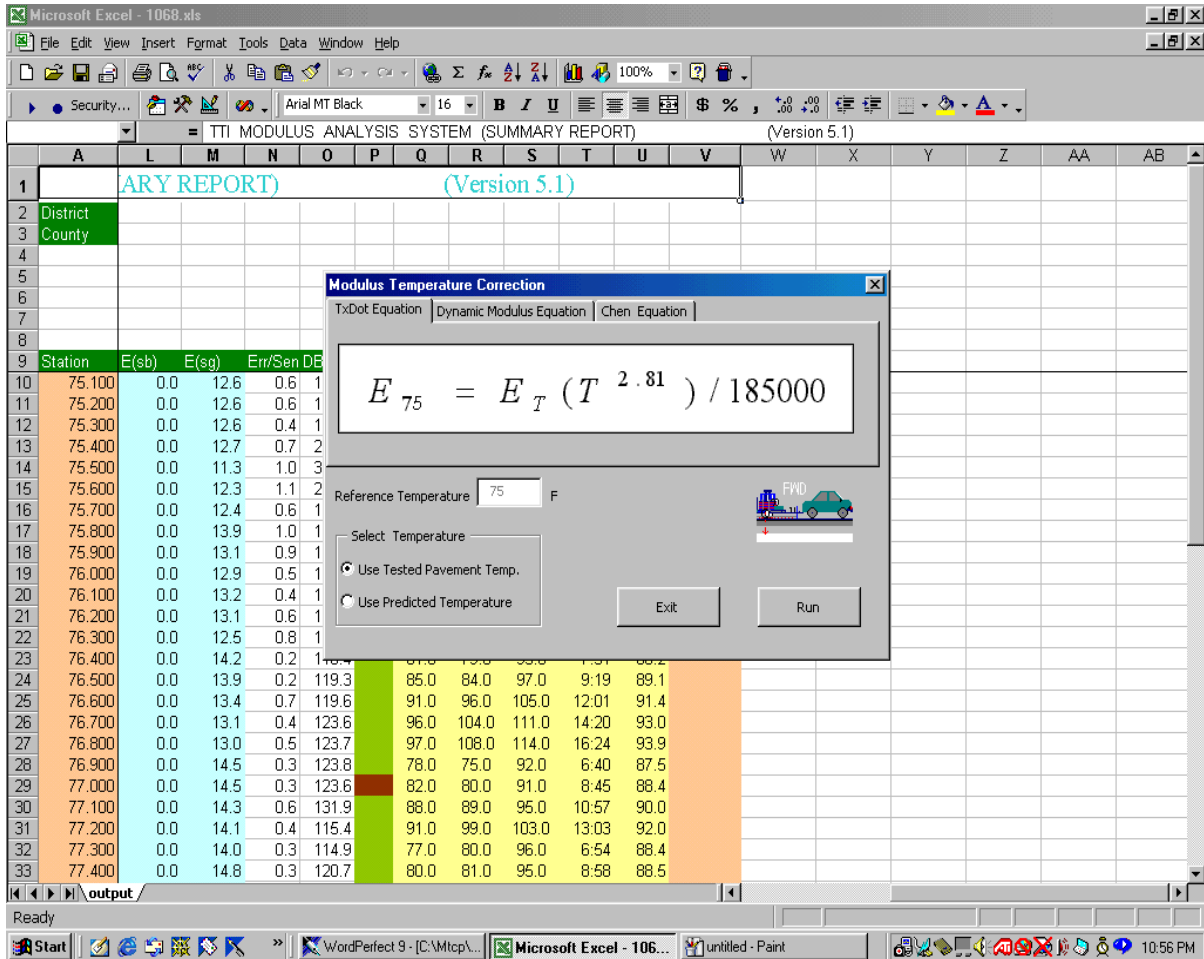**Figure 11. Resizing the Comment Box Using the *Edit Comment* Function in Excel.**

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= TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)   (Version 5.1)

Modulus Temperature Correction

TxDot Equation | Dynamic Modulus Equation | Chen Equation

$$E_{75} = E_T (T^{2.81}) / 185000$$

Reference Temperature [75] F

Select Temperature
- ⦿ Use Tested Pavement Temp.
- ◯ Use Predicted Temperature

Exit   Run

	Station	E(sb)	E(sg)	Err/Sen DB
10	75.100	0.0	12.6	0.6
11	75.200	0.0	12.6	0.6
12	75.300	0.0	12.6	0.4
13	75.400	0.0	12.7	0.7
14	75.500	0.0	11.3	1.0
15	75.600	0.0	12.3	1.1
16	75.700	0.0	12.4	0.6
17	75.800	0.0	13.9	1.0
18	75.900	0.0	13.1	0.9
19	76.000	0.0	12.9	0.5
20	76.100	0.0	13.2	0.4
21	76.200	0.0	13.1	0.6
22	76.300	0.0	12.5	0.8
23	76.400	0.0	14.2	0.2
24	76.500	0.0	13.9	0.2
25	76.600	0.0	13.4	0.7
26	76.700	0.0	13.1	0.4
27	76.800	0.0	13.0	0.5
28	76.900	0.0	14.5	0.3
29	77.000	0.0	14.5	0.3
30	77.100	0.0	14.3	0.6
31	77.200	0.0	14.1	0.4
32	77.300	0.0	14.0	0.3
33	77.400	0.0	14.8	0.3

Figure 12. Dialog Box Showing TxDOT's Equation for Modulus Temperature Correction.

You can select the equation to use for temperature correction by clicking on the appropriate folder tab of the dialog box in Figure 12, where TxDOT's equation for modulus temperature correction is shown. This equation is based on a reference temperature of 75 °F. The independent variables of the equation are the FWD test temperature T in °F and the backcalculated asphalt concrete modulus E_T that is read from the MODULUS summary output file. The FWD test temperatures correspond to the base pavement temperatures established in the previous step. As shown in Figure 12, you have two options for specifying the base pavement temperatures. If pavement temperatures were measured during the FWD survey, you can use the measured temperatures at specific stations and the interpolated values at the other stations by clicking on the *Use Tested Pavement Temp.* option in the dialog box. If no pavement temperatures were measured during the survey, you can use the predicted temperatures from BELLS2, BELLS3, or the Texas-LTPP equation presented previously.
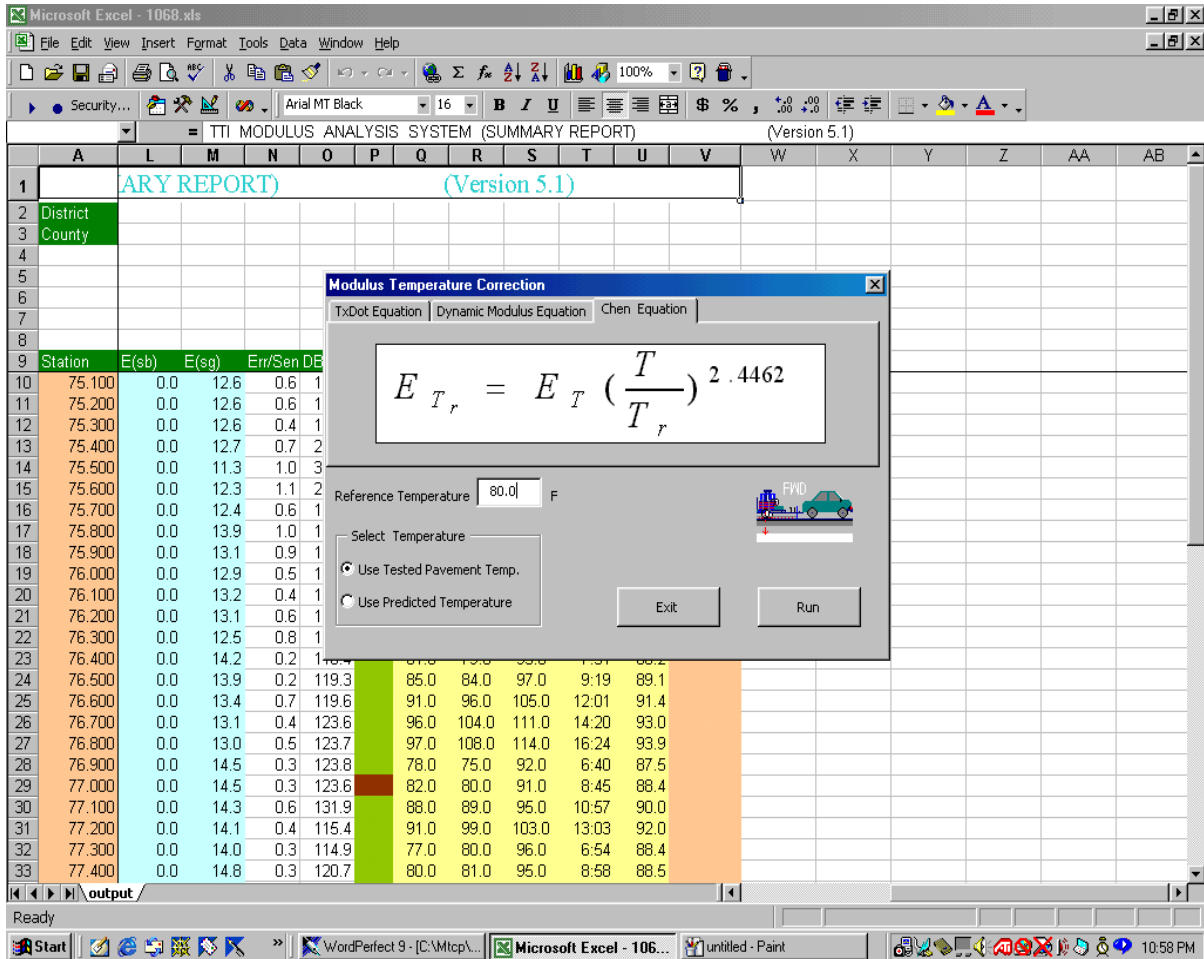
18

Figure 13. Chen Equation for Modulus Temperature Correction.

You may then perform the modulus temperature correction by clicking the ***Run*** button of the dialog box. Alternatively, you may click the ***Exit*** button to go back to the main menu without performing the temperature corrections.

Figure 13 shows the Chen equation. This equation was developed using FWD and pavement temperature data taken from three test sections established as part of TxDOT's Mobile Load Simulator (MLS) project (Chen et al., 2000). The equation is therefore applicable for pavements that are similar to the sections tested. Nevertheless, modulus temperature correction factors from this equation were found to agree reasonably well with corresponding factors from TxDOT's equation even though the two were developed from different studies.

The Chen equation permits the correction to be made for any user-specified reference temperature T_r. The reference temperature (in °F) is specified in the dialog box of Figure 13. Note that both the Chen and existing TxDOT equations do not require AC mixture properties

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for modulus temperature correction and are thus easy to use in practice. These equations were developed for the typical mixtures used in the state. However, there may be occasions where the user may want to evaluate the temperature dependency for the specific asphalt mix used in a given project. Consequently, a third option (Figure 14) was incorporated into MTCP that is based on the prediction equation for dynamic modulus developed by Witczak and Fonseca (1996). This option requires data on the aggregate gradation and the binder viscosity-temperature relationship for the asphalt concrete mixture. The equation for modulus temperature correction is given by:

$$\log_{10} E_R \;=\; \log_{10} E_T \;+\; A \left[\frac{1}{1+e^{-(B_R+0.7425\log_{10} h_R)}} - \frac{1}{1+e^{-(B_T+0.7425\log_{10} h_T)}} \right] \tag{3}$$

$$R^2 = 0.93 \qquad SEE = 0.12 \quad \text{(log scale)}$$

where,

$$A \;=\; 1.87 + 0.003\,p_4 + 0.00004\,p_{3/8} - 0.00018\,(p_{3/8})^2 + 0.0164\,p_{3/4} \tag{4}$$

$$B_R \;=\; 0.716\log_{10} f_R \tag{5}$$

$$B_T \;=\; 0.716\log_{10} f_T \tag{6}$$

E_R = AC modulus corrected for the selected reference temperature, 10^5 psi

E_T = backcalculated asphalt concrete modulus, 10^5 psi

O_R = binder viscosity corresponding to the reference temperature, 10^6 Poises

O_T = binder viscosity corresponding to the FWD test temperature, 10^6 Poises

p_4 = cumulative percent retained on #4 sieve by total aggregate weight

$p_{3/8}$ = cumulative percent retained on 3/8-inch sieve by total aggregate weight

$p_{3/4}$ = cumulative percent retained on 3/4-inch sieve by total aggregate weight

f_R = reference loading frequency, Hz

f_T = test frequency, Hz

For the impulse loading of the FWD, the test frequency may be approximated from the following relationship proposed by Lytton et al. (1990):
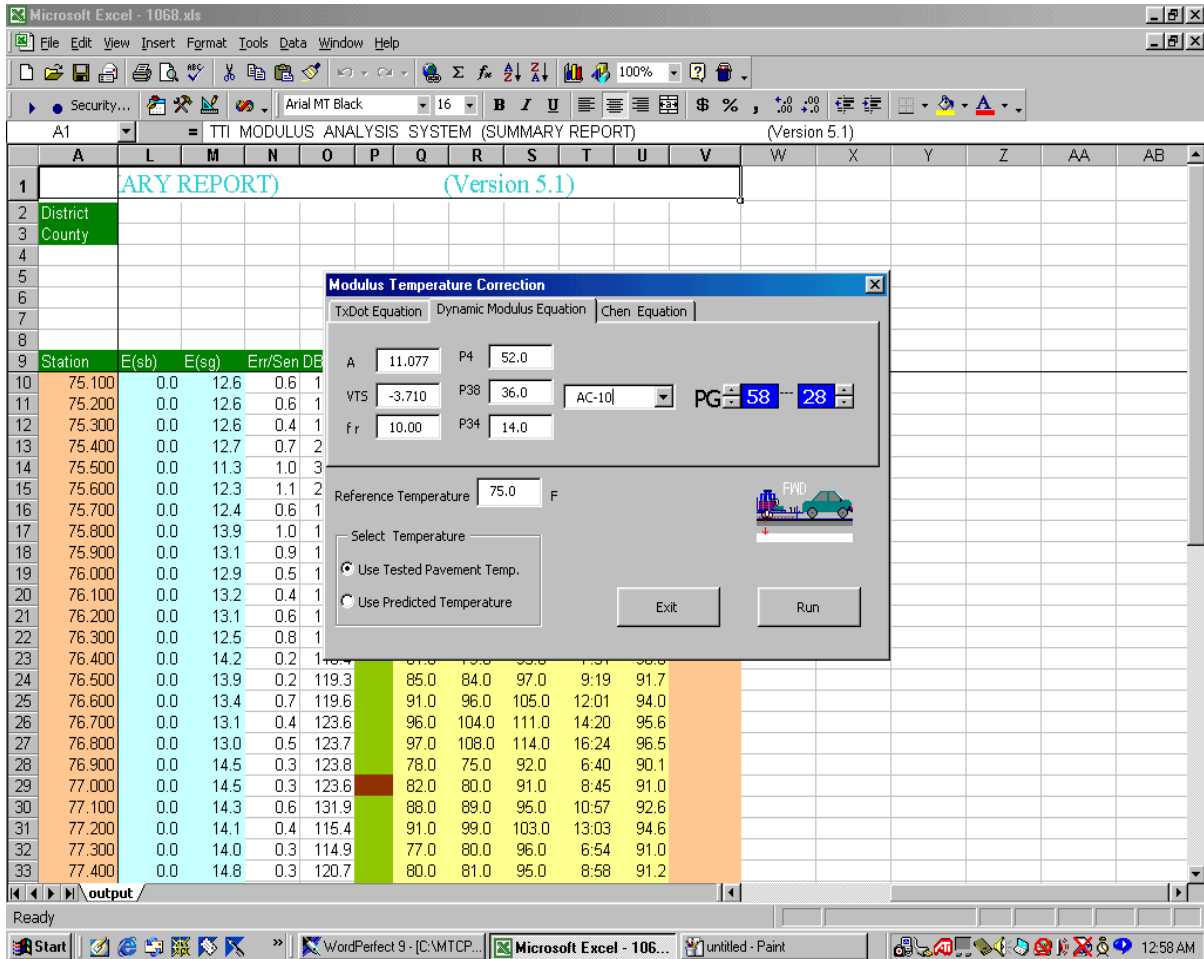
$$f_T \;=\; \frac{1}{2t} \tag{7}$$

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A1   =   TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)   (Version 5.1)

	A	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	ARY REPORT)					(Version 5.1)												
2	District																	
3	County																	
4																		
5																		
6																		
7																		
8																		
9	Station	E(sb)	E(sg)	Err/Sen DB														
10	75.100	0.0	12.6	0.6	1													
11	75.200	0.0	12.6	0.6	1													
12	75.300	0.0	12.6	0.4	1													
13	75.400	0.0	12.7	0.7	2													
14	75.500	0.0	11.3	1.0	3													
15	75.600	0.0	12.3	1.1	2													
16	75.700	0.0	12.4	0.6	1													
17	75.800	0.0	13.9	1.0	1													
18	75.900	0.0	13.1	0.9	1													
19	76.000	0.0	12.9	0.5	1													
20	76.100	0.0	13.2	0.4	1													
21	76.200	0.0	13.1	0.6	1													
22	76.300	0.0	12.5	0.8	1													
23	76.400	0.0	14.2	0.2	1													
24	76.500	0.0	13.9	0.2	119.3	85.0	84.0	97.0	9:19	91.7								
25	76.600	0.0	13.4	0.7	119.6	91.0	96.0	105.0	12:01	94.0								
26	76.700	0.0	13.1	0.4	123.6	96.0	104.0	111.0	14:20	95.6								
27	76.800	0.0	13.0	0.5	123.7	97.0	108.0	114.0	16:24	96.5								
28	76.900	0.0	14.5	0.3	123.8	78.0	75.0	92.0	6:40	90.1								
29	77.000	0.0	14.5	0.3	123.6	82.0	80.0	91.0	8:45	91.0								
30	77.100	0.0	14.3	0.6	131.9	88.0	89.0	95.0	10:57	92.6								
31	77.200	0.0	14.1	0.4	115.4	91.0	99.0	103.0	13:03	94.6								
32	77.300	0.0	14.0	0.3	114.9	77.0	80.0	96.0	6:54	91.0								
33	77.400	0.0	14.8	0.3	120.7	80.0	81.0	95.0	8:58	91.2								

output

Ready

Modulus Temperature Correction

TxDot Equation | Dynamic Modulus Equation | Chen Equation

A 11.077   P4 52.0

VTS -3.710   P38 36.0   AC-10   PG 58 - 28

f r 10.00   P34 14.0

Reference Temperature 75.0 F

Select Temperature
- ● Use Tested Pavement Temp.
- ○ Use Predicted Temperature

Exit   Run

Start   WordPerfect 9 - [C:\MTCP...   Microsoft Excel - 106...   untitled - Paint   12:58 AM

Figure 14. Dialog Box for Temperature Correction Based on Witczak's Dynamic Modulus Equation.

where t is the duration of the impulse load in seconds. The duration of the impulse load for the FWD is about 30 msecs which gives a test frequency of about 16.7 Hz, the value used in MTCP for modulus correction On the other hand, f_R should correspond to the frequency of loading used in pavement design. This typically ranges from 8 to 10 Hz for the standard 18-kip single axle load traveling at typical highway speeds. The reference frequency is entered in the f_r field of the dialog box shown in Figure 14. Note that if you enter a value equal to the FWD load frequency (16.7 Hz), no correction for the effect of load duration on the AC modulus will be made.

The gradation information for the mix is entered in the fields labeled *P4*, *P38*, and *P34* corresponding, respectively, to p_4, $p_{3/8}$, and $p_{3/4}$. The binder viscosity corresponding to the reference and base pavement temperatures are determined using the ASTM D-2493 viscosity-temperature relationship given by:

$$\log_{10} \log_{10} h \quad = \quad A + VTS \log_{10} T_{\circ R} \tag{8}$$

where $\mho$ is the binder viscosity, $T_{\circ R}$ is the temperature in degrees Rankine, and A and VTS are model coefficients determined from testing. In practice, A and VTS may be determined by conducting dynamic shear rheometer (DSR) tests at a range of temperatures on the binder extracted from a core taken at the project site. This extraction will also provide the gradation data needed to use the dynamic modulus equation for temperature correction.

DSR tests may be conducted at an angular frequency of 10 rad/sec and for a temperature range of 40 to 130 °F. From the binder complex shear modulus G^* and phase angle * determined at a given temperature, the corresponding binder viscosity may be estimated from the equation:

$$h \quad = \quad \frac{G^*}{10} \left(\frac{1}{\sin d} \right)^{4.8628} \tag{9}$$

The binder viscosities determined at the different test temperatures may be used in a regression analysis to get the A and VTS coefficients of Eq.(8). These coefficients are then entered in the corresponding fields of the dialog box given in Figure 14.

In the absence of actual test data to determine the coefficients, researchers have incorporated default values into MTCP to permit you to conduct an approximate analysis. The default coefficients are based on the asphalt grade and are applicable for unmodified binders. Table 2 shows the coefficients for AC-graded binders while Table 3 shows the coefficients for performance-graded (PG) asphalts. The coefficients in Table 2 are based on research conducted by Mirza (1993) and are representative of asphalts that have undergone field aging. Those in Table 3 are from unpublished data taken from the AASHTO 2002 development work. The predicted binder viscosities from these coefficients are representative of mix/laydown conditions.

If the binder on the project is AC-graded, you may specify the asphalt type by clicking on the down arrow in Figure 14 to display the list of asphalt grades for which default coefficients are available (see Figure 15). From this list, you may click on the applicable binder type to select it. The coefficients corresponding to this binder are then displayed in the A and VTS fields of the dialog box.

Table 2. Default *A* and *VTS* Coefficients for AC-Graded Asphalts[1].

Viscosity Grade (Original Conditions)	Viscosity Range at 140 °F (Poises)	A	VTS
AC - 2.5	100 - 350	11.8408	-3.9974
AC - 5	350 - 700	11.4711	-3.8557
AC - 10	700 - 1400	11.0770	-3.7097
AC - 20	1400 - 2800	10.9168	-3.6469
AC - 40	2800 - 5200	10.6528	-3.5477

[1] Representative of asphalts that have undergone field aging.

Table 3. Default *A* and *VTS* Coefficients for PG-Graded Asphalts[1].

High Temp. Grade	Low Temperature Grade													
	-10		-16		-22		-28		-34		-40		-46	
	A	*VTS*	*A*	*VTS*	*A*	*VTS*	*A*	*VTS*	*A*	*VTS*	*A*	*VTS*	*A*	*VTS*
46									11.504	-3.901	10.101	-3.393	8.755	-2.905
52	13.386	-4.570	13.305	-4.541	12.755	-4.342	11.840	-4.012	10.707	-3.602	9.496	-3.164	8.310	-2.736
58	12.316	-4.172	12.248	-4.147	11.787	-3.981	11.010	-3.701	10.035	-3.350	8.976	-2.968		
64	11.432	-3.842	11.375	-3.822	10.980	-3.680	10.312	-3.440	9.461	-3.134	8.524	-2.798		
70	10.690	-3.566	10.641	-3.548	10.299	-3.426	9.715	-3.217	8.965	-2.948	8.129	-2.648		
76	10.059	-3.331	10.015	-3.315	9.715	-3.208	9.200	-3.024	8.532	-2.785				
82	9.514	-3.128	9.475	-3.114	9.209	-3.019	8.750	-2.856	8.151	-2.642				

[1] Coefficients representative of mix/laydown conditions (unpublished data from AASHTO 2002 development work).
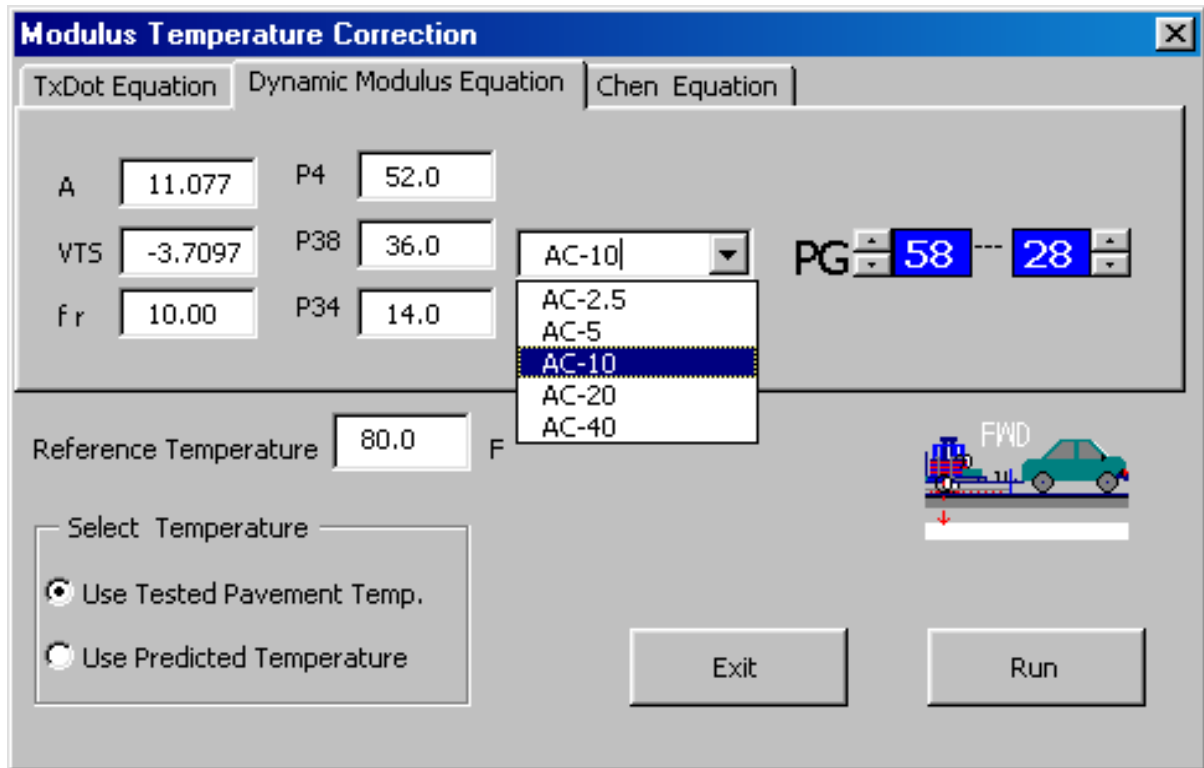
Figure 15. Drop-Down List of AC-Graded Asphalts with Default Coefficients.

If the binder on the project is PG-graded, you simply click on the up and down arrows of the PG fields in the dialog box until you get the number designations you want. The *A* and *VTS* coefficients for that PG grade are then displayed. Note that coefficients are only available for the PG grades shown in Table 3. It is also noted that the *A* and *VTS* coefficients displayed in the dialog box always correspond to those specified for the last run made. Default values for these coefficients may have been used, or alternatively, coefficients from laboratory test data may have been entered in the *A* and *VTS* fields of the dialog box shown in Figure 15. Thus, these fields will not necessarily display coefficients that correspond to the current AC and/or PG grades displayed in the dialog box.

The results from the temperature corrections are written into the worksheet along the column labeled *Corrected Modulus*. As shown in Figure 16, the column label has a comment box which gives information about the method used to perform the temperature correction. Specifically, the comment box identifies the method, as well as the reference and base pavement temperatures used for the corrections. In addition, if the dynamic modulus equation is selected, the *A* and *VTS* coefficients, reference loading frequency, and aggregate gradation are displayed in the comment box.

Station	E(sb)	E(sg)	Err/Sen	DB(in)	Limit	Air	Surface	Paveme	Test tim	Predict	Corrected Modulus
75.100	0.0	12.6	0.6	181.2		48.0	53.0	51.0	10:24	87.0	481.9
75.200	0.0	12.6	0.6	194.9		49.0	56.0	53.0	12:19	87.3	433.1
75.300	0.0	12.6	0.4	181.0		52.0	62.0	55.0	14:04	88.2	412.8
75.400	0.0	12.7	0.7	233.0		55.0	66.0	57.0	15:33	88.7	397.8
75.500	0.0	11.3	1.0	300.0		31.0	40.0	37.0	8:25	85.6	504.3
75.600	0.0	12.3	1.1	226.0		41.0	59.0	44.0	10:26	87.7	524.6
75.700	0.0	12.4	0.6	189.6		54.0	62.0	51.0	9:30	88.1	433.2
75.800	0.0	13.9	1.0	147.1		51.0	58.0	64.0	7:37	87.6	429.1
75.900	0.0	13.1	0.9	141.4		68.0	81.0	69.0	10:18	91.2	350.4
76.000	0.0	12.9	0.5	146.7		65.0	75.0	83.0	6:46	90.1	404.2
76.100	0.0	13.2	0.4	178.0		75.0	93.0	82.0	8:59	93.4	399.3
76.200	0.0	13.1	0.6	151.6		83.0	104.0	91.0	11:54	95.6	373.4
76.300	0.0	12.5	0.8	158.4		87.0	128.0	100.0	14:36	101.1	322.6
76.400	0.0	14.2	0.2	116.4		81.0	79.0	95.0	7:31	90.8	426.2
76.500	0.0	13.9	0.2	119.3		85.0	84.0	97.0	9:19	91.7	426.4
76.600	0.0	13.4	0.7	119.6		91.0	96.0	105.0	12:01	94.0	396.3
76.700	0.0	13.1	0.4	123.6		96.0	104.0	111.0	14:20	95.6	393.8
76.800	0.0	13.0	0.5	123.7		97.0	108.0	114.0	16:24	96.5	384.6
76.900	0.0	14.5	0.3	123.8		78.0	75.0	92.0	6:40	90.1	394.6
77.000	0.0	14.5	0.3	123.6		82.0	80.0	91.0	8:45	91.0	394.3
77.100	0.0	14.3	0.6	131.9		88.0	89.0	95.0	10:57	92.6	377.5
77.200	0.0	14.1	0.4	115.4		91.0	99.0	103.0	13:03	94.6	376.2
77.300	0.0	14.0	0.3	114.9		77.0	80.0	96.0	6:54	91.0	395.7
77.400	0.0	14.8	0.3	120.7		80.0	81.0	95.0	8:58	91.2	418.6
77.500	0.0	14.5	0.2	120.8		80.0	81.0	97.5	10:47	91.2	432.3
77.600	0.0	14.6	0.5	118.7		88.0	91.0	100.2	12:47	93.0	441.1

Comment box:
Use: Dynamic Modulus Equation
Corrected to 80.0'F
A---=11.077
VTS-=-3.710
fr--=10.0
P.4-=52.0%
P.38=36.0%
P.34=14.0%
You use the pavement temperature in S column

Figure 16. Temperature Corrected Moduli from the Analysis.

MONTHLY MODULUS PREDICTION

In certain instances, it may be necessary to model the seasonal variation in material properties. MTCP permits the user to estimate the monthly variation in asphalt concrete modulus given the mean monthly pavement temperatures for a given project. In the program, the mean monthly pavement temperatures are estimated from the mean monthly air temperatures using the following equation (Asphalt Institute, 1982):

$$MMPT \;=\; MMAT\left[1 + \frac{1}{(z+4)}\right] - \frac{34}{(z+4)} + 6 \tag{10}$$

where,

$MMPT$ = mean monthly pavement temperature, °F

$MMAT$ = mean monthly air temperature, °F

z = depth at which pavement temperature is to be predicted, inches

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As an aid in using this feature, a database of mean monthly air temperatures has been compiled that covers all counties in the state. This database is built in to MTCP and is used to estimate the mean monthly pavement temperatures. The reference modulus corresponding to the reference temperature is then adjusted to the predicted mean monthly pavement temperatures.

By default, the reference modulus is taken as the average of the corrected moduli for the different stations. Thus, in performing the temperature correction for the backcalculated asphalt concrete moduli, the user may specify a reference temperature that he or she considers representative of the year-round pavement temperatures at the project surveyed. In this instance, the corrected moduli will correspond to average yearly conditions at the site. To evaluate monthly variations, the average of the corrected moduli is adjusted to the predicted mean monthly pavement temperatures in MTCP.

Alternatively, the user may correct the backcalculated moduli to a reference temperature that he or she considers to be representative of the pavement temperatures at the time of the FWD survey. In this instance, the program will predict how the reference modulus, corresponding to conditions at the date of testing, varies with the predicted monthly changes in pavement temperatures at the site surveyed.

While the program uses the average of the corrected moduli as the default reference for evaluating monthly variations, the user may specify an alternative reference value for the analysis. This option is described later. At this point, a few guidelines about the selection of the reference modulus are in order.

The user should examine the variation in the corrected moduli for the different stations tested. If the coefficient of variation exceeds 15 percent, the user should ask whether the variability suggests possible differences in pavement materials and layer thicknesses along the route surveyed. He or she should check the measured deflections, backcalculated moduli, predicted depths to bedrock, the average absolute errors per sensor, and whether any of the prescribed limits were reached in the backcalculation. Depending on the results, there may be a need to subsection the FWD data to create homogeneous segments for the MODULUS backcalculation. For this purpose, the MODULUS program may be used to delineate segments of a specified minimum length based on the cumulative difference method. Michalak and Scullion (1995) describe how this option is used in MODULUS.

The user may have to collect additional information on the route to better characterize the pavements for the segments identified. The MODULUS and temperature correction programs are then run on each segment. Results from these runs should be reviewed to establish the need for further analyses.

To predict how the asphalt concrete modulus at the site will vary with temperature changes over the year, click on the ***Monthly Modulus Prediction*** button of the MTCP main menu. The dialog box shown in Figure 17 is then displayed. This dialog box shows the averages of the daily minimum and daily maximum air temperatures for each month, as determined from the weather station in the county where the project surveyed is located. The average monthly air temperatures are also shown as well as the name, elevation, and location of the weather station. The county ID displayed in the dialog box is read directly from the FWD data file. If for some reason, the county ID in the file is wrong, you may simply type the correct ID in the dialog box or use the up and down buttons beside the *County ID* field to scroll through the weather data for the different counties in Texas. A list of the counties is given in Figure 18 for your reference.

After establishing the county ID for the project, click on the folder tab labeled *Input* in the dialog box. The screen shown in Figure 19 is then displayed where you may specify:

1.   the depth at which the mean monthly pavement temperatures will be predicted,
2.   the reference temperature, and
3.   the reference modulus.

For consistency, the depth and the reference temperature are the same as that specified in the correction of the backcalculated asphalt concrete moduli. For your reference, the thickness of the surface layer is also provided. The reference modulus shown is the average of the corrected moduli, as explained earlier. You may change any of these default values, but you need to make sure that the values you input are consistent with each other.

When you are through specifying the input parameters for this dialog box, click on the ***Next*** button to continue. The screen shown in Figure 20 is then displayed. You will notice that the mean monthly pavement temperatures are calculated and written into a new worksheet labeled *Month*. In addition, the average monthly air temperatures and the reference modulus are reported in the worksheet. There is also a dialog box where you can specify the equation you want to use for correcting the reference modulus to the predicted mean monthly pavement temperatures. The two choices available are the dynamic modulus and Chen equations. To
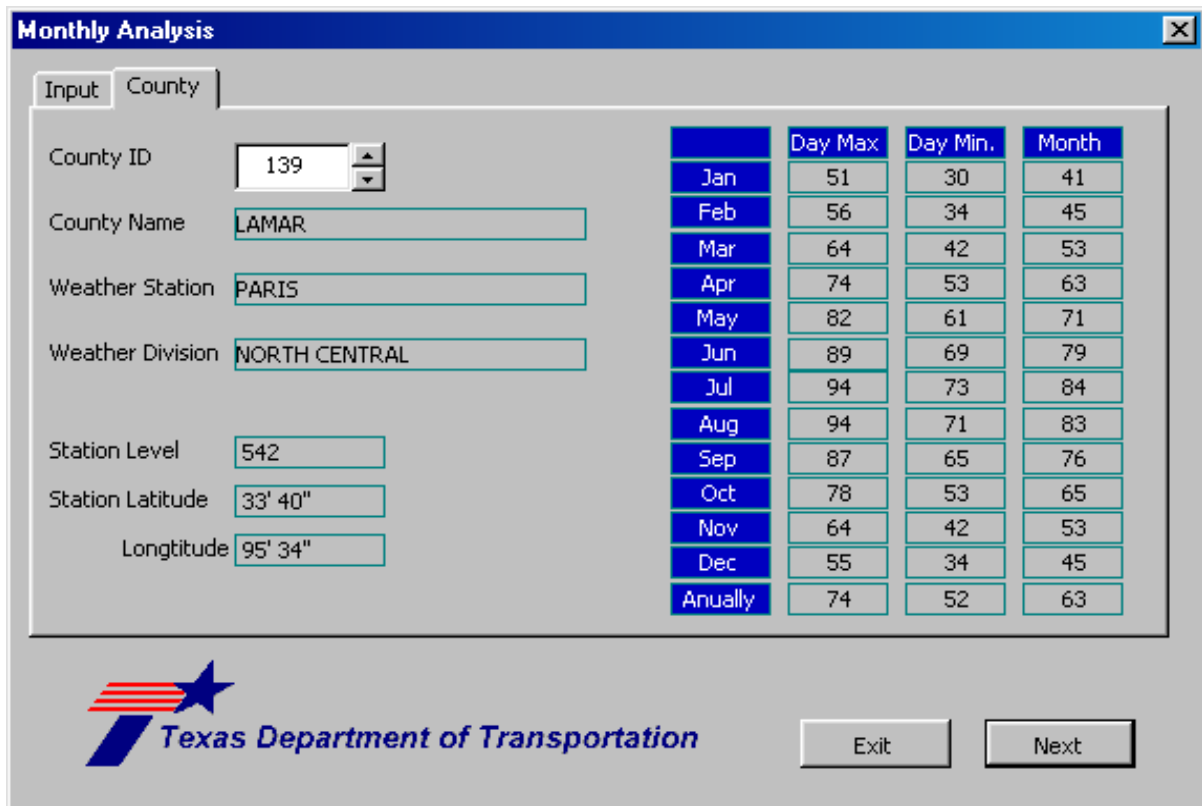
Figure 17. Dialog Box of Monthly Air Temperatures for Specified County.

DISTRICT 1
(Paris)
60	Delta
75	Fannin
81	Franklin
92	Grayson
113	Hopkins
117	Hunt
139	Lamar
190	Rains
194	Red River

DISTRICT 2
(Fort Worth)
73	Erath
112	Hood
120	Jack
127	Johnson
182	Palo Pinto
184	Parker
213	Somervell
220	Tarrant
249	Wise

DISTRICT 3
(Wichita Falls)
5	Archer
12	Baylor
39	Clay
49	Cook
169	Montague
224	Throckmorton
243	Wichita
244	Wilbarger
252	Young

DISTRICT 4
(Amarillo)
6	Armstrong
33	Carson
56	Dallam
59	Deaf Smith
91	Gray
99	Hansford
104	Hartley
107	Hemphill
118	Hutchinson
148	Lipscomb
171	Moore
179	Ochiltree
180	Oldham
188	Potter
191	Randall
197	Roberts
211	Sherman

DISTRICT 5
(Lubbock)
9	Bailey
35	Castro
40	Cochran
54	Crosby
58	Dawson
78	Floyd
84	Gaines
86	Garza
96	Hale
111	Hockley
140	Lamb
152	Lubbock
153	Lynn
185	Parmer
219	Swisher
223	Terry
251	Yoakum

DISTRICT 6
(Odessa)
2	Andrews
52	Crane
69	Ector
151	Loving
156	Martin
165	Midland
186	Pecos
195	Reeves
222	Terrell
231	Upton
238	Ward
248	Winkler

DISTRICT 7
(San Angelo)
41	Coke
48	Concho
53	Crockett
70	Edwards
88	Glasscock
119	Irion
134	Kimble
164	Menard
192	Reagan
193	Real
200	Runnels
207	Schleicher
216	Sterling
218	Sutton
226	Tom Green

DISTRICT 8
(Abilene)
17	Borden
30	Callahan
77	Fisher
105	Haskell
115	Howard
128	Jones
132	Kent
168	Mitchell
177	Nolan
208	Scurry
209	Shackelford
217	Stonewall
221	Taylor

DISTRICT 9
(Waco)
14	Bell
18	Bosque
50	Coryell
74	Falls
98	Hamilton
110	Hill
147	Limestone
161	McLennan

DISTRICT 10
(Tyler)
1	Anderson
37	Cherokee
93	Gregg
108	Henderson
201	Rusk
212	Smith
234	Van Zandt
250	Wood

DISTRICT 11
(Lufkin)
3	Angelina
114	Houston
174	Nacogdoches
187	Polk
202	Sabine
203	San Augustine
204	San Jacinto
210	Shelby
228	Trinity

DISTRICT 12
(Houston)
20	Brazoria
80	Fort Bend
85	Galveston
102	Harris
170	Montgomery
237	Waller

DISTRICT 13
(Yoakum)
8	Austin
29	Calhoun
45	Colorado
62	DeWitt
76	Fayette
90	Gonzales
121	Jackson
143	Lavaca
158	Matagorda
235	Victoria
241	Wharton

DISTRICT 14
(Austin)
11	Bastrop
16	Blanco
27	Burnett
28	Caldwell
87	Gillespie
106	Hays
144	Lee
150	Llano
157	Mason
227	Travis
246	Williamson

DISTRICT 15
(San Antonio)
7	Atascosa
10	Bandera
15	Bexar
46	Comal
83	Frio
95	Guadalupe
131	Kendall
133	Kerr
162	McMullen
163	Medina
232	Uvalde
247	Wilson

DISTRICT 16
(Corpus Christi)
4	Aransas
13	Bee
89	Goliad
126	Jim Wells
129	Karnes
137	Kleberg
149	Live Oak
178	Nueces
196	Refugio
205	San Patricio

DISTRICT 17
(Bryan)
21	Brazos
26	Burleson
82	Freestone
94	Grimes
145	Leon
154	Madison
166	Milam
198	Robertson
236	Walker
239	Washington

DISTRICT 18
(Dallas)
43	Collin
57	Dallas
61	Denton
71	Ellis
130	Kaufman
175	Navarro
199	Rockwall

DISTRICT 19
(Atlanta)
19	Bowie
32	Camp
34	Cass
103	Harrison
155	Marion
172	Morris
183	Panola
225	Titus
230	Upshur

DISTRICT 20
(Beaumont)
36	Chambers
101	Hardin
122	Jasper
124	Jefferson
146	Liberty
176	Newton
181	Orange
229	Tyler

DISTRICT 21
(Pharr)
24	Brooks
31	Cameron
109	Hildago
125	Jim Hogg
66	Kenedy
214	Starr
245	Willacy
253	Zapata

DISTRICT 22
(Laredo)
64	Dimmit
67	Duval
136	Kinney
142	La Salle
159	Maverick
233	Val Verde
240	Webb
254	Zavala

DISTRICT 23
(Brownwood)
25	Brown
42	Coleman
47	Comanche
68	Eastland
141	Lampasas
160	McCulloch
167	Mills
206	San Saba
215	Stephens

DISTRICT 24
(El Paso)
22	Brewster
55	Culberson
72	El Paso
116	Hudspeth
123	Jeff Davis
189	Presidio

DISTRICT 25
(Childress)
23	Briscoe
38	Childress
44	Collingsworth
51	Cottle
63	Dickens
65	Donley
79	Foard
97	Hall
100	Hardeman
135	King
138	Knox
173	Motley
242	Wheeler

Figure 18. List of Texas Counties by District (TxDOT, 1998).
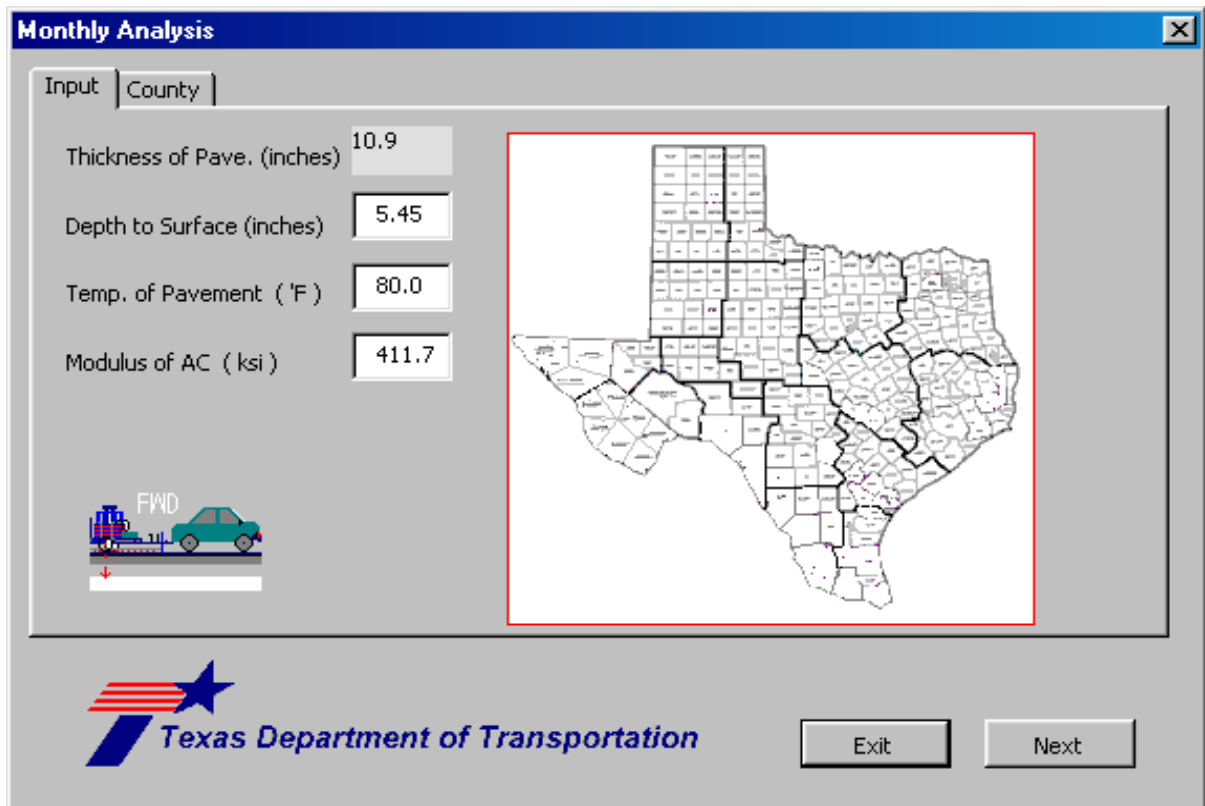
Figure 19. Dialog Box of Input Parameters for the Monthly Modulus Prediction.
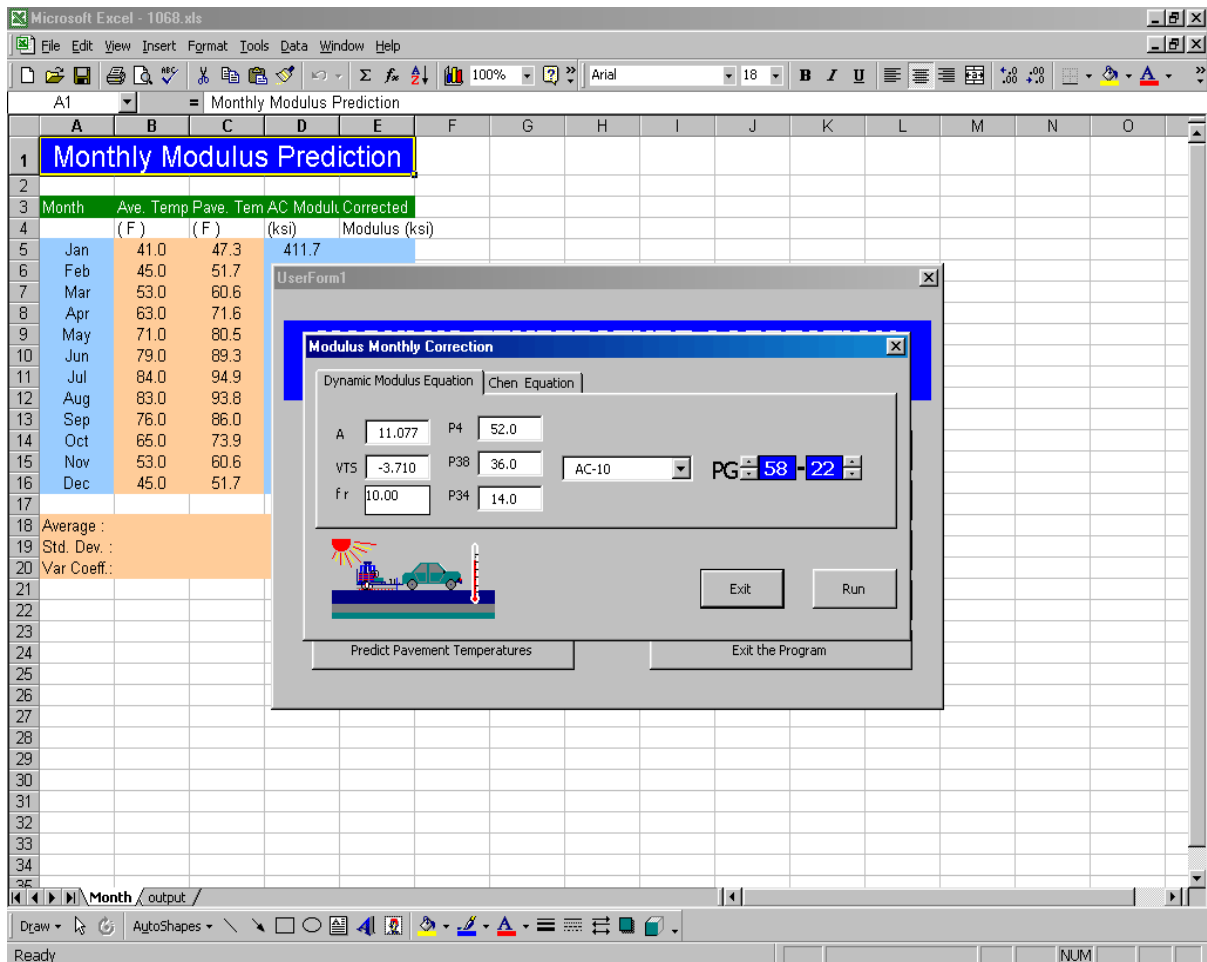
Figure 20. Dialog Box to Specify Equation for Monthly Modulus Prediction.

specify which equation to use, simply click on its folder tab. Note that if you used the dynamic

modulus equation to correct the backcalculated AC moduli, the *A* and *VTS* coefficients you

previously specified are displayed in the dialog box as well as the reference loading frequency

and the gradation of the asphalt mix. While you may change these variables in the dialog box, it

is important that the values you enter are consistent with the method employed to correct the

backcalculated AC moduli. In most applications, it is likely that you would only have to click

on the ***Run*** button of the dialog box to perform the monthly modulus predictions based on the

dynamic modulus equation without having to change any of the data shown. To select the Chen

equation, click on its folder tab and then on the ***Run*** button of the dialog box to perform the

analysis.

Figure 21 illustrates the output from the evaluation of monthly modulus variation. The

predicted modulus for each month is written in the last column of the worksheet. The label for

this column also has a comment box that reports the parameters used in correcting the reference
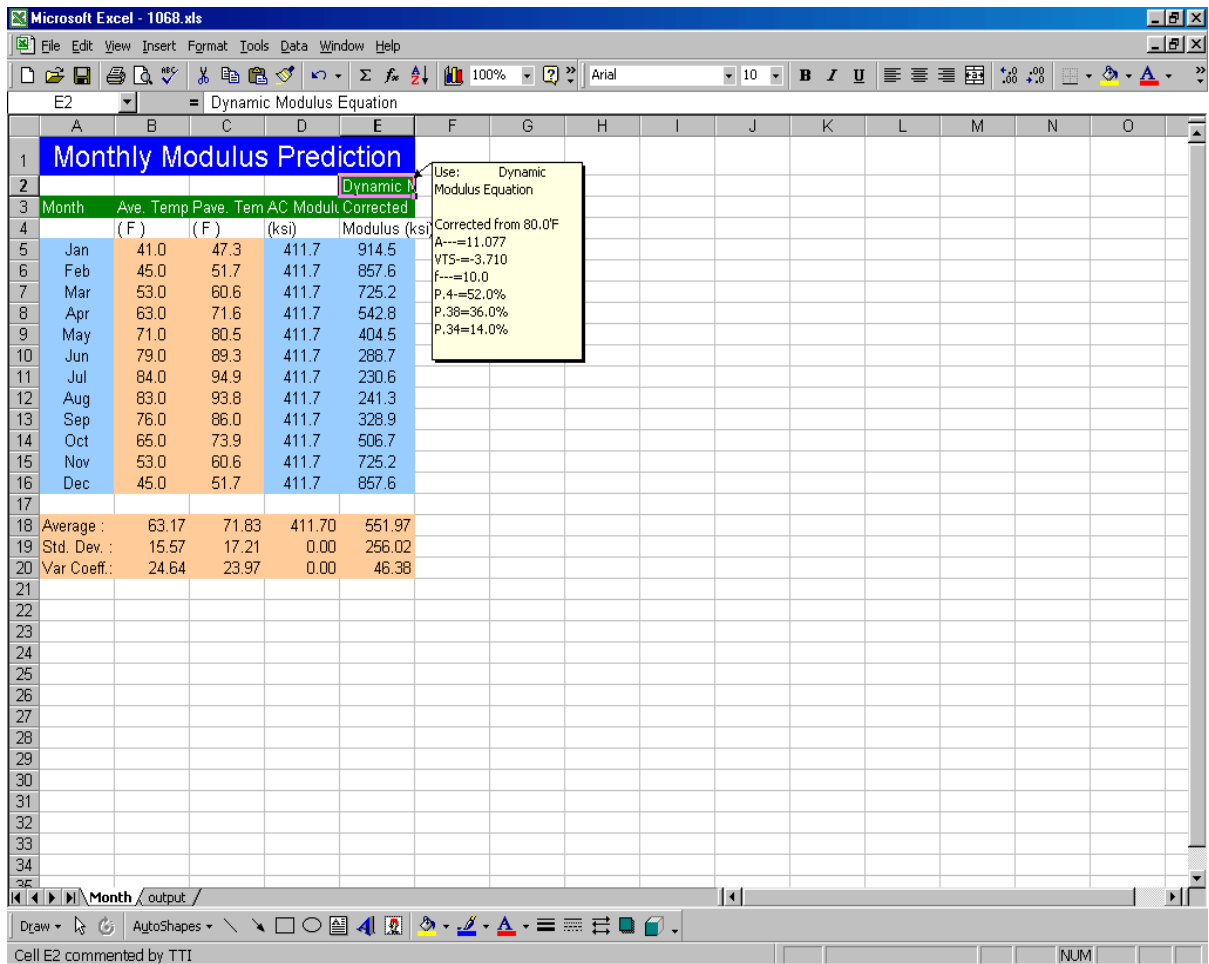
Figure 21. Illustration of Output from Monthly Modulus Prediction.

modulus to the predicted mean monthly pavement temperatures. You may resize the box as necessary using Excel's *Edit Comment* function to view the information.

CHAPTER III

MTCP OUTPUT

GETTING OUTPUT OF ANALYSIS RESULTS

As presented in Chapter II, there are two worksheets created by MTCP which have the input data used in the analyses as well as the results. The *output* worksheet contains the summary output from the MODULUS backcalculation; the measured air, surface, and pavement temperatures from the FWD survey; the predicted pavement temperatures; and the corrected asphalt concrete moduli. The other worksheet, labeled *Month*, has the monthly average air temperatures, the predicted mean monthly pavement temperatures, and the predicted monthly variation in asphalt concrete modulus for the material tested. You may print each of these worksheets using the *Print* function available in Excel. You may also produce charts of the results by clicking the ***Plot Output*** button of the MTCP main menu. This will bring up the chart selection menu illustrated in Figure 22.

Table 4 describes the chart options available from the menu. The default worksheet names shown in the table are reserved for program use. You may not use any of these names to label worksheets that you manually create in the Excel spreadsheet. Note that the charts which may be produced depend on the main menu functions that have already been executed. For example, neither the FWD nor MODULUS summary output data may be plotted until the data files have been read by MTCP. Similarly, the corrected asphalt concrete moduli and the predicted monthly variations in the AC modulus cannot be plotted until the temperature corrections and the monthly modulus predictions have been made.

To select a chart from the menu, simply click on its checkbox. You may select all charts at once by clicking on the ***Select All*** button of the menu. If you wish to undo any selection, click again on the chart's checkbox. To undo all selections at once, click the ***Clear*** button of the menu. The button labeled ***Reverse Select*** will undo previous selections you have made while at the same time checking the boxes of charts not previously selected. Thus, ***Reverse Select*** has the same effect as ***Clear*** if all of the available charts were previously selected.
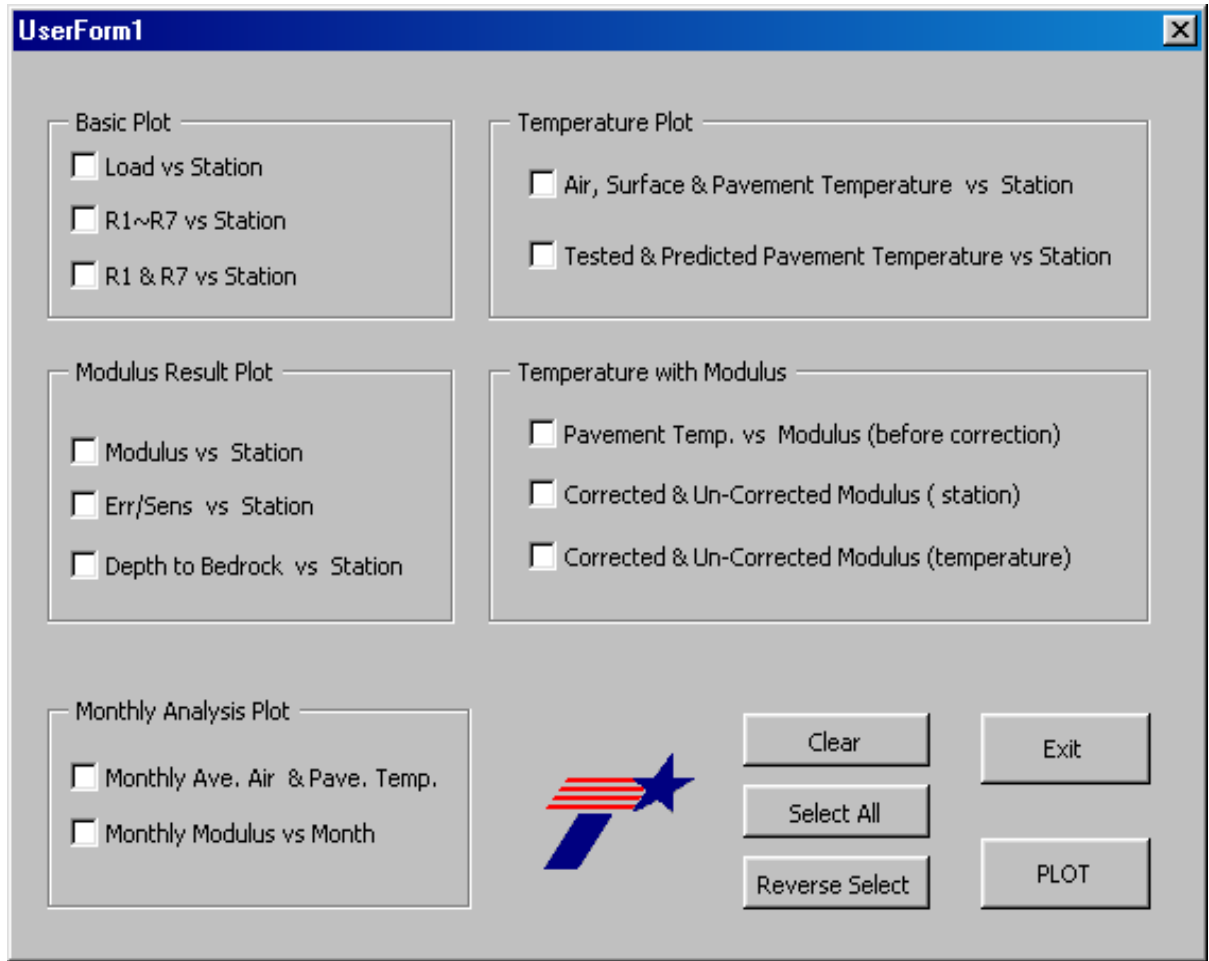
Figure 22. MTCP Plot Menu.

Table 4. Available Charts in MTCP.

Chart Group	Chart Label	Description	Default Worksheet Name
Basic Plot	Load vs Station	Plot of measured FWD load for stations tested	Load
	R1 ~ R7	FWD sensor deflections plotted for each station	Deflec-1
	R1 & R7	Plot of FWD sensor 1 and sensor 7 deflections by station	Deflec-2
Modulus Result Plot	Modulus vs Station	Plot of backcalculated layer moduli for each station	Modu
	Err/Sens vs Station	Plot of the average absolute errors per sensor for the different stations tested	Err
	Depth to Bedrock vs Station	Plot of the depths to bedrock predicted from the sensor displacements measured at the different stations	DB
Monthly Analysis Plot	Monthly Ave. Air & Pave. Temp.	Mean monthly average air temperatures and predicted mean monthly pavement temperatures at the project surveyed	Month-1
	Monthly Modulus vs Month	Bar chart of predicted monthly variations in AC modulus	Month-2
Temperature Plot	Air, Surface, & Pavement Temp. vs Station	Plot of air, surface, and pavement temperatures by station	Temp-1
	Tested & Calculated Pavement Temperature vs Station	Plot of measured vs predicted pavement temperatures by station	Temp-2
Temperature with Modulus	Pavement Temp. vs Modulus (before correction)	Plot of backcalculated AC modulus versus pavement temperature	Mod-Temp-1
	Corrected & Un-corrected Modulus (station)	Plot of corrected and backcalculated AC moduli by station	Mod-Temp-3
	Corrected & Un-corrected Modulus (temperature)	Plot of corrected and backcalculated AC moduli versus pavement temperature	Mod-Temp-4

Once you have made your selections, click on the **_PLOT_** button. Each chart selected gets drawn on a separate worksheet. Table 4 identifies the worksheets assigned to the different charts. To view the charts, first leave the plot menu by clicking on its **_Exit_** button. This brings you back to the program main menu. From here, click on **_Exit the Program_**. You may then view a particular chart by clicking on its worksheet tab which you may identify from Table 4. Figures 23 and 24 illustrate two of the charts that you may produce from MTCP. To print a given chart, simply bring that chart into view by clicking on its worksheet tab. Then use Excel's _Print_ function to get a hardcopy.

The plots that you generate in the spreadsheet are automatically updated as data get changed. This situation occurs, for example, when you do another analysis using a temperature correction equation that is different from that used to generate the charts initially. In this instance, you do not have to rerun the plot function to get the same charts using the new analysis results. However, you have the option to generate additional charts that were not selected in the previous analysis.

You may also rename the chart worksheets in Excel. To use a name different from the default value given in Table 4, simply double click the tab of the worksheet you wish to rename. Then type in the label that you want that worksheet to have and press the _Enter_ key. Alternatively, you may right click on the worksheet tab and select the _Rename_ function in Excel to re-label the selected worksheet.

SAVING THE ANALYSIS RESULTS

Once you finish with your analysis, you may save your results by using Excel's _Save_ or _Save As_ function. To do this, you must first exit the MTCP main menu by clicking on **_Exit the Program_**. Then you may click on the _Save_ icon in the top toolbar to save your results using the default file name assigned by the program. The Excel spreadsheet, with all the accompanying data and charts, is saved in a file with the same name as the MODULUS summary output file but with the extension _XLS_.

If you do not wish to use the default file name, you may save the spreadsheet using the _Save As_ function in Excel's _File_ menu. Click on _File_ at the top of the spreadsheet, then on _Save As_. A dialog box will then be displayed where you can specify the name of the file where the results will be saved. In addition, you may specify the drive and subdirectory
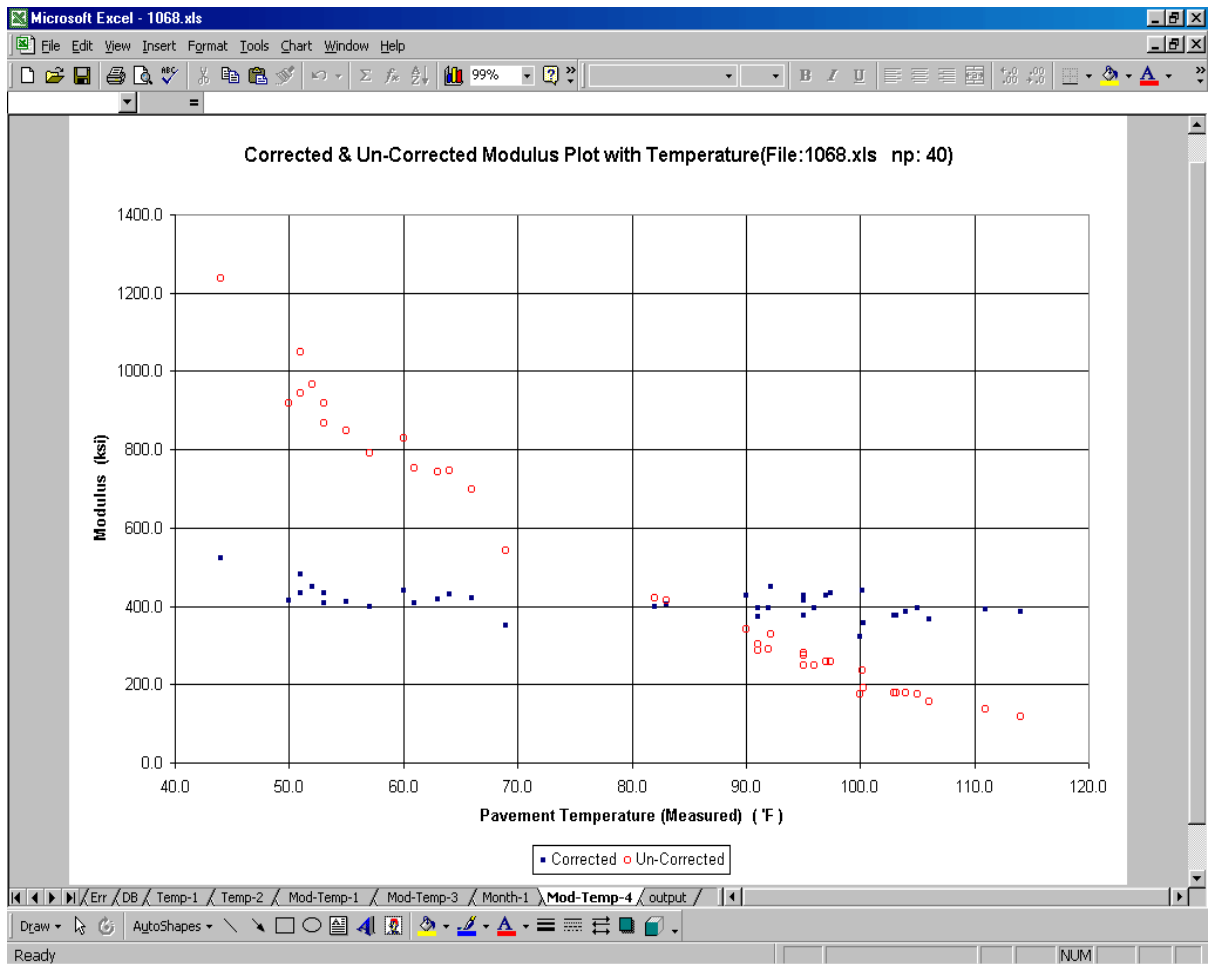
Figure 23. Example Plot of Corrected and Backcalculated AC Moduli vs Pavement Temperature.
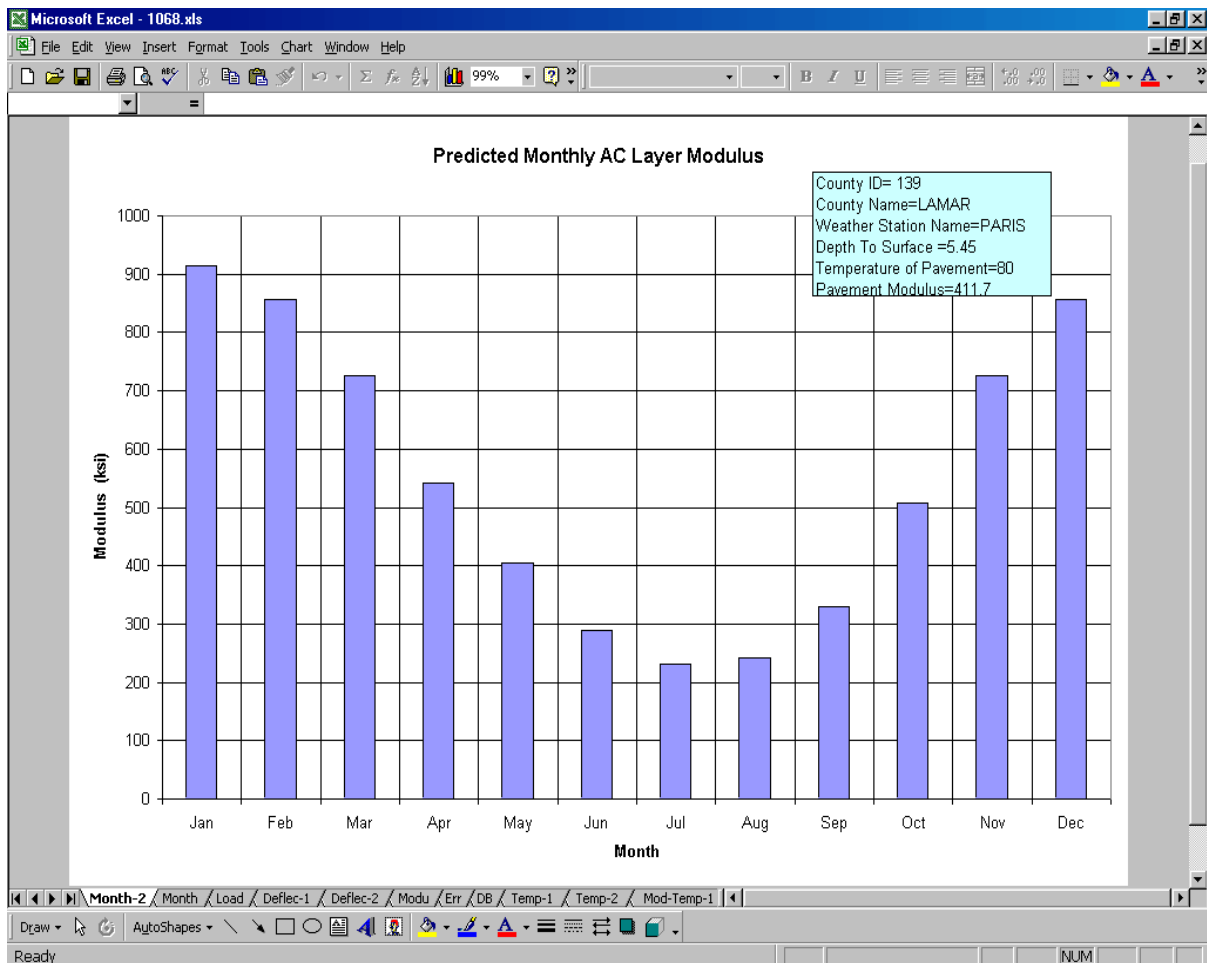
Figure 24. Example Plot of Predicted Monthly Variations in AC Modulus.

where this file will be written. By default, the file is written in the same subdirectory where MTCP was loaded. You may open the spreadsheet in Excel at a later time should you wish to conduct additional analyses with the same MODULUS and FWD input files used to generate the spreadsheet.

After saving your results, you may exit Excel by clicking on *File*, then on *Exit* or by clicking on the *X* button at the top right corner of the spreadsheet. Alternatively, you may conduct a new analysis with a different set of input data. To perform a new analysis, reload the main menu by pressing *Ctrl+Shift+M*. Then clear the results of the previous analysis by clicking on the ***Clear Program Sheets*** button of the main menu. The dialog box shown in Figure 25 will be displayed to confirm that you wish to delete the worksheets created by the program. If you have saved the results, you may click on *Yes* in the dialog box. Otherwise, click *No* for an opportunity to save the existing spreadsheet as described previously.
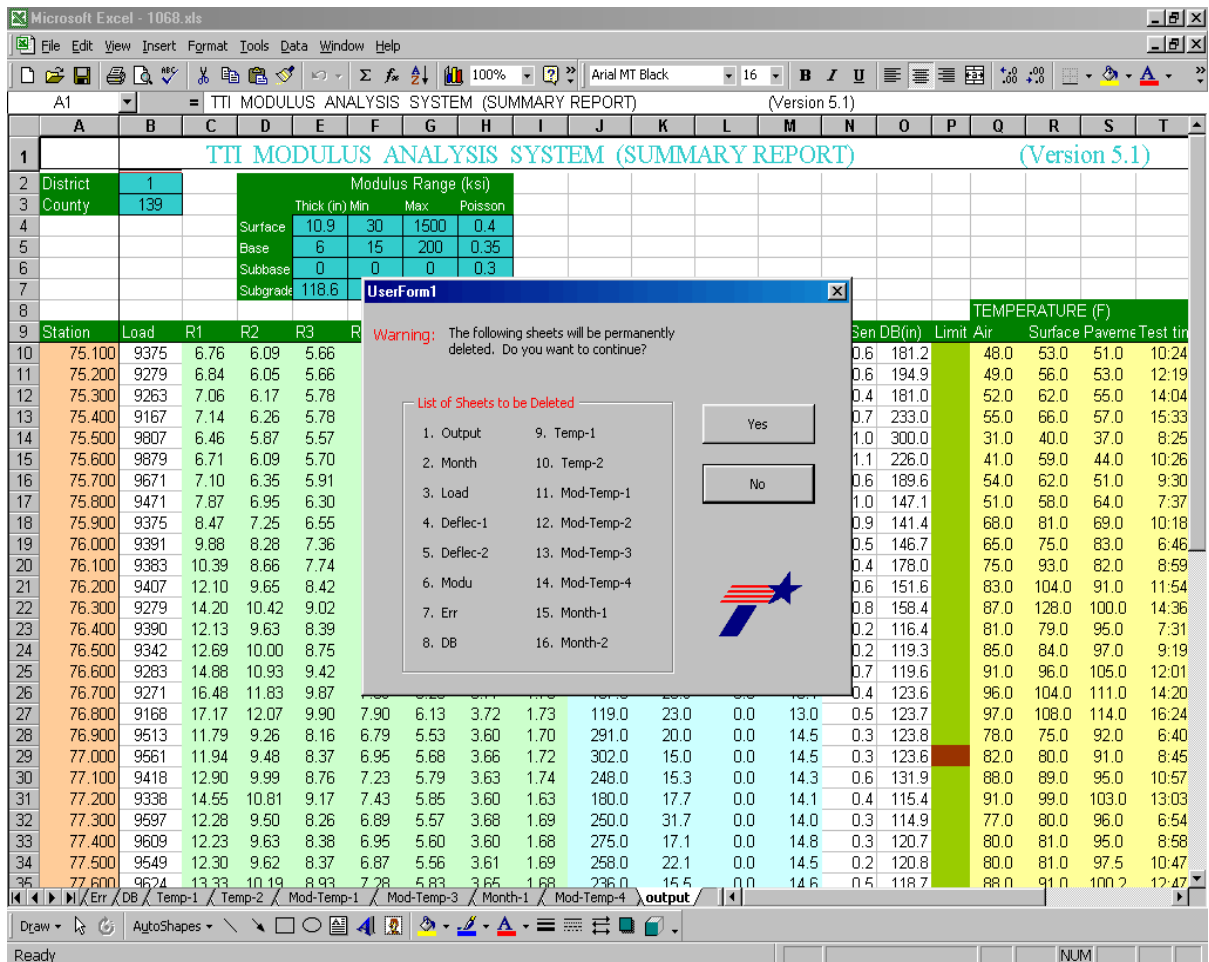
Figure 25. Dialog Box to Delete Program Worksheets Prior to a New Analysis.

After the existing program worksheets have been deleted, the main menu is again displayed. From here, the user may read another MODULUS output file and conduct a new analysis as described in this user's guide. It is noted that the *Clear Program Sheets* function will only delete the worksheets created by the program (identified in the dialog box shown in Figure 25). Worksheets that were manually created by the user during the previous analysis are not deleted.

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APPENDIX: FLOW CHART OF MODULUS TEMPERATURE CORRECTION PROGRAM

Run MTCP Macro By "Ctrl+Shift+M"

- **Read MODULUS output file** — "Output" worksheet is created and the MODULUS results are read into the worksheet
- **Read FWD file & get temps.** — Read the FWD deflections; air, surface, and pavement temperatures; and test time for each station
- **Interpolate temperatures** — If pavement temperatures were measured at two or more stations, interpolate the pavement temperatures at other stations
- **Predict pavement temperatures** — Available equations for predicting pavement temperatures if infrared surface temperatures were collected during FWD tests
  - Bells2
  - Bells3
  - Texas – LTPP
- **Modulus temp. correction** — Available equations for temperature correction of AC modulus
  - TxDOT
  - Dynamic Modulus
  - Chen
- **Monthly modulus prediction** — Predict monthly variations in AC modulus
  - Input reference modulus and temperature
  - Input County
  - Dynamic Modulus
    - Chen
- **Plot output** — Plots produced from analysis
  - FWD load/deflection
  - MODULUS results
  - Air & pavement temps.
  - Modulus-temperature
  - Modulus by month
- **Clear program sheets** — Allows user to delete program sheets created from a previous analysis prior to conducting a new analysis
- **Exit the program** — Allows user to exit the macro to view results from the analysis