Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-04/0-4184-P3		

4. Title and Subtitle	5. Report Date
USER'S GUIDE TO THE OVERWEIGHT TRUCK ROUTE ANALYSIS (OTRA) PROGRAM	December 2003 Resubmitted: April 2004
	6. Performing Organization Code
7. Author(s) Emmanuel G. Fernando and Wenting Liu	8. Performing Organization Report No. Product 0-4184-P3
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-4184
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Product 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Characterize the Effects of Permitted Overweight Loads on SH4/48 at the Port of Brownsville

16. Abstract

The 75th and 76th Texas Legislatures passed bills allowing trucks with gross vehicle weights (GVWs) of up to 125,000 lb to routinely use a route in south Texas along the Mexican border. This route proceeds from the Veterans International Bridge to the Port of Brownsville via US77, SH4, and SH48. The portion of the route along US77 is on a new concrete pavement and includes an elevated structure over half of its length. Most of the permitted truck route runs along SH4 and SH48 in Brownsville. Concerned about the effects of routine overweight truck traffic on its roadways, the Texas Department of Transportation (TxDOT) sponsored a research project with the Texas Transportation Institute (TTI) to characterize the effects of routine overweight truck traffic along SH4/48 and develop pavement design guidelines for roadways subjected to routine overweight trucks. A product of this project is the Overweight Truck Route Analysis (OTRA) program, which is described in this report. OTRA is a modification of the Program for Load-Zoning Analysis (PLZA) developed in an earlier TxDOT project. OTRA may be used to evaluate the structural adequacy of an existing route to carry routine overweight truck traffic over a specified design period. Additionally, it may be used to estimate the thickness of asphalt concrete overlay required to carry the expected number of truck axle loads over the design life based on a user-prescribed reliability level. The program incorporates a layered elastic pavement model for predicting the induced response under surface wheel loads. Both linear and nonlinear pavement materials may be modeled. The predicted horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade are used to determine the service life for a given pavement and loading condition. To combine the effects of different axle loads and axle configurations, Miner's hypothesis of cumulative damage is used to predict pavement service life. Instructions on using OTRA are provided in this guide.

17. Key Words	18. Distribution Statement
Overweight Loads, Overweight Permits, Nondestructive Testing, Pavement Evaluation, Pavement Performance Prediction	

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
		76	

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

USER'S GUIDE TO THE OVERWEIGHT TRUCK ROUTE ANALYSIS (OTRA) PROGRAM

by

Emmanuel G. Fernando
Research Engineer
Texas Transportation Institute

and

Wenting Liu
Associate Research Scientist
Texas Transportation Institute

Product 0-4184-P3
Project Number 0-4184
Research Project Title: Characterize the Effects of Permitted Overweight Loads on SH4/48 at the Port of Brownsville

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

December 2003
Resubmitted: April 2004

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

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. 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

The work reported herein was conducted as part of a research project sponsored by the Texas Department of Transportation and the Federal Highway Administration. The objectives of the study were to characterize the effects of routine overweight truck traffic on SH4/48 in Brownsville, and to develop guidelines for pavement design of routine overweight truck routes. The authors gratefully acknowledge the steadfast support and guidance of the project director, Mr. Joe Leidy, of the Materials and Pavements Section of TxDOT. Mr. Leidy ran TxDOT's ground penetrating radar equipment on SH4/48 as part of the efforts to characterize the pavement sections along the route. In addition, the contributions of the following individuals are noted and sincerely appreciated:

1. Mr. Luis Carlos Peralez of the Pharr District provided invaluable assistance to the data collection activities conducted along SH4/48. Mr. Peralez provided staff and equipment for collection of falling weight deflectometer (FWD), multi-depth deflectometer, and profile data at different times during the project; instrumentation of pavement sections to measure deflections under truck wheel loads; and collection of material samples for laboratory testing.
2. The pavement management staff of the Pharr District, in particular, Mr. Rene Castro, for the collection of FWD, profile data, and asphalt concrete cores along SH4/48.
3. Mr. Niño Gutierrez and Ms. Jo Saban of the Brownsville Navigation District provided researchers access to the port for monitoring permitted trucks and static axle weight data on these trucks.
4. Mr. Richard Peters, Mr. Jeff Reding, and Ms. Carolyn Markert provided weigh-in-motion (WIM) data that were used to characterize the existing truck traffic along SH4/48.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure Page

Figure Page

LIST OF TABLES

Table | Page

CHAPTER I
INTRODUCTION

BACKGROUND AND SCOPE OF REPORT

The 75th and 76th Texas Legislatures passed bills allowing trucks with gross vehicle weights (GVWs) of up to 125,000 lb to routinely use a route in south Texas along the Mexican border. This route proceeds from the Veterans International Bridge to the Port of Brownsville via US77, SH4, and SH48. The portion of the route along US77 is on a new concrete pavement and includes an elevated structure over half of its length. Most of the permitted truck route runs along SH4 and SH48 in Brownsville. Concerned about the effects of routine overweight truck traffic on its roadways, the Texas Department of Transportation (TxDOT) sponsored a research project with the Texas Transportation Institute (TTI) to characterize the effects of routine overweight truck traffic along SH4/48 and develop pavement design guidelines for roadways subjected to routine overweight truck traffic.

Project 0-4184 focused on studying the behavior and monitoring the performance of the asphalt concrete pavement sections supporting routine overweight truck traffic on SH4/48 in Brownsville. About 95 percent of the permitted truck traffic originates from the Port of Brownsville, where the route starts at the FM511 bridge and runs along SH48 until its intersection with Boca Chica Boulevard. From there, truckers proceed along SH4 up to the US77 intersection, where they turn left to proceed to the Veterans International Bridge and into Mexico.

The payloads carried by permitted trucks are mostly coiled metal sheets, oil, and powder mineral (fluorite), which are transported from the Port of Brownsville to Mexico and vice versa. Figure 1 illustrates the types of payloads transported along the permitted truck route. The route was established in response to the need expressed by truckers to haul cargo at their trucks' operating capacities to improve operational efficiency. This meant hauling weights in excess of legal load limits, thus requiring permits to be issued.

Figure 1. Types of Loads Carried by Permitted Trucks.

The permit fee is US $30 each way. From the time the permits were first issued in March 1998 to the end of 2002, about US $4.5 million was collected from permit sales, based on figures provided by the Brownsville Navigation District. The navigation district retains 15 percent of the funds generated to cover administrative costs, and the remainder goes to the TxDOT Pharr District to pay for route maintenance. Considering that the route was not designed to sustain routine overweight truck traffic, the potential for accelerated pavement deterioration exists. Since it is likely that TxDOT may need similar permitted routes in the future, it becomes prudent to study the effects of routine overweight loads on SH4/48 and to identify requirements for building pavements to sustain routine overweight truck traffic. This information could help maximize trucking productivity and enhance the economic competitiveness of the state.

As part of research efforts to develop guidelines for evaluating existing routes and establishing design requirements for routine overweight truck lanes, TTI researchers developed the computer program Overweight Truck Route Analysis (OTRA), which is described in this report. OTRA is a modification of the Program for Load-Zoning Analysis (PLZA) that is documented in earlier research reports by Fernando and Liu (1999, 2001). In this project, TTI researchers modified the PLZA program to include the capability for predicting pavement response under triple axle loads and to evaluate the thickness of overlay required to sustain routine overweight truck traffic for the user-specified design period.

This report provides a user's guide to the OTRA program. Chapter I of this guide describes the procedure for pavement structural evaluation using the computer program, identifies system requirements for its use, and provides easy instructions for installing the program on a microcomputer. Chapter II explains the application of OTRA to evaluate the adequacy of an existing route to sustain routine overweight truck loads over a user-specified design period, and Chapter III provides instructions on evaluating overlay thickness requirements using the computer program. Finally, the Appendix presents the formats of output files generated by OTRA during analysis, which may be of use to the pavement engineer in certain special applications. These output files present the predicted pavement strains based on the specified wheel loads and axle configurations, the corresponding predicted service lives based on fatigue cracking and rutting criteria, and the expected number of axle load applications during the specified design period.

PAVEMENT STRUCTURAL EVALUATION USING OTRA

Pavement engineers can use the OTRA program to evaluate the adequacy of an existing route to sustain routine overweight truck loads over a specified design period. Additionally, the program can estimate the thickness of asphalt concrete overlay required to carry the cumulative truck axle loads expected over the design life based on fatigue and rut depth criteria. For this purpose, the program uses the predicted horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade with the Asphalt Institute (1982) equations for fatigue cracking and rutting to predict service life for the given pavement and loading conditions.

To use the program, one must first characterize the route to be analyzed. This requires characterizing the truck traffic on the route, determining pavement layer thicknesses, and evaluating material properties. Table 1 summarizes the input requirements of the computer program, while Figure 2 illustrates the flow of data through the pavement structural evaluation process. Truck traffic data can be requested from the Transportation Planning and Programming (TP&P) Division of TxDOT. The beginning and ending average daily traffic (ADT) values, directional factor, and percent trucks are normally reported by TP&P in *Traffic Analysis for Highway Design* sheets that it provides in response to requests from the districts or the Materials and Pavements Section of TxDOT's Construction Division. These input values are used, along with data on average axle groups per truck and the percentages of single, tandem, and triple axle groups to determine the expected cumulative number of load applications for each axle group over the specified design period. OTRA permits the user to input the truck distribution by vehicle class to determine the average axle groups per truck and the percentages of single, tandem, and triple axle assemblies. TP&P can assist in establishing this truck distribution for a given site.

As indicated in Figure 2, pavement layer thicknesses can be determined nondestructively using ground penetrating radar (GPR) supplemented, as necessary, by coring or dynamic cone penetrometer (DCP) measurements. Researchers strongly suggest a GPR survey on the route to establish the variations in layer thicknesses along the route to be analyzed. This survey should be conducted at the beginning of the evaluation for the following purposes:

1. to detect possible changes in pavement cross-section along the route and divide the route into analysis segments, as appropriate;
2. to establish the need for cores or DCP data to supplement the radar survey and identify locations where coring or DCP measurements should be made; and
3. to establish the locations of falling weight deflectometer (FWD) measurements consistent with pavement section changes identified from the radar data on the route.

Additionally, a video log can be made during the radar survey to provide a record of the pavement surface condition at the time of the evaluation. GPR surveys can be scheduled

Table 1. Input Data Requirements for Pavement Structural Evaluation Using OTRA.

Data Requirements	Methods of Getting Data
Layer thicknesses	● Ground Penetrating Radar ● Coring ● Dynamic Cone Penetrometer
Nonlinear, stress-dependent material parameters, K_1, K_2, and K_3	● Falling Weight Deflectometer ● Resilient Modulus Test, Association of American State and Transportation Officials (AASHTO T-292-91) ● Correlations with physical soil properties
Truck traffic characteristics < Beginning and ending ADTs for design period < directional factor < percent trucks < average axles per truck < percent single axles < percent tandem axle groups < percent triple axle groups < design single axle load < design tandem axle load < design triple axle load	● Contact TP&P ● Truck counts and classifications ● Axle load measurements

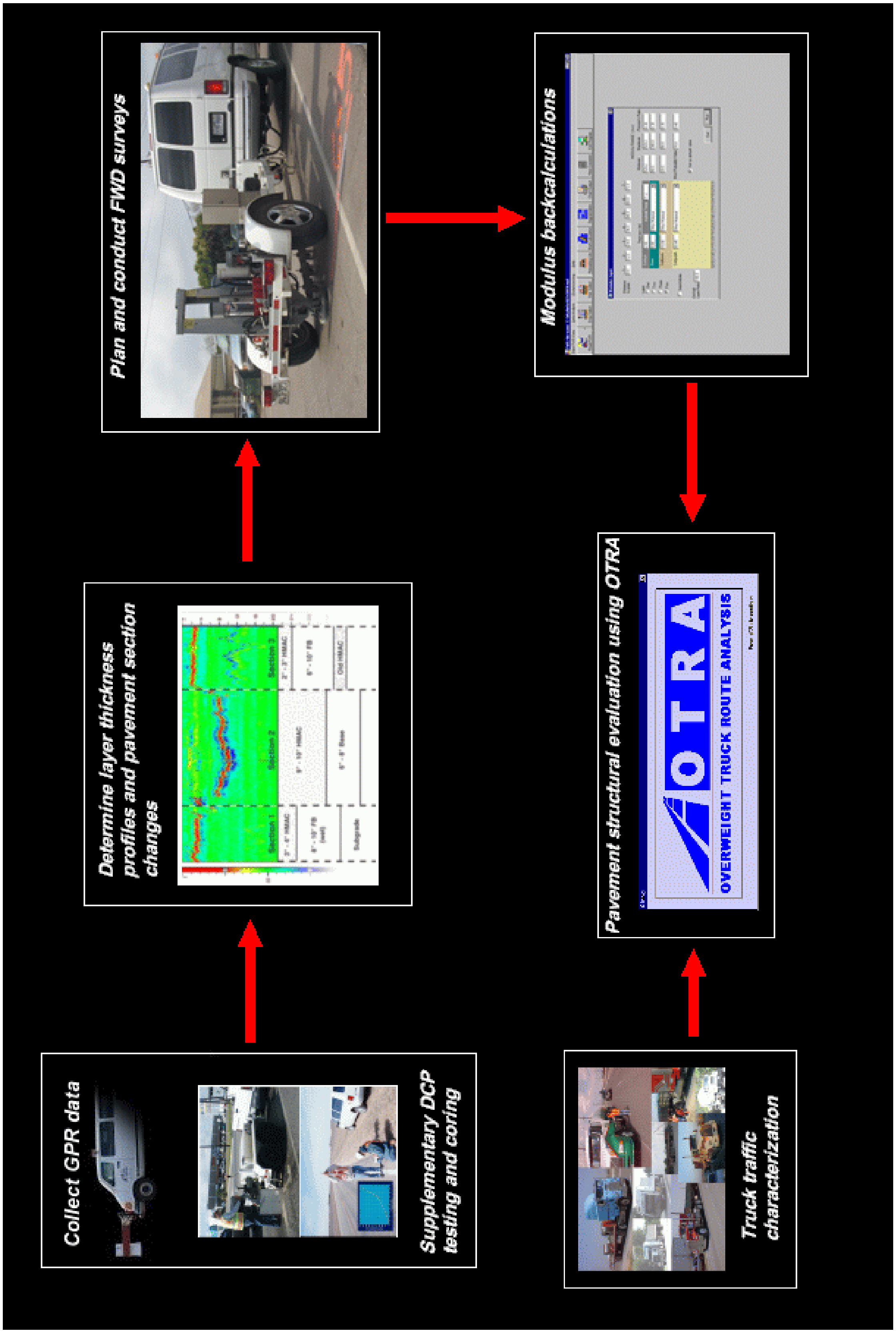


Figure 2. Data Flow through Pavement Structural Evaluation Process in OTRA.

with the Materials and Pavements Section, which is staffed with engineers trained to operate, maintain, and analyze radar data for pavement evaluation purposes.

GPR data should be used to subdivide the route into homogeneous segments based on the predicted layer thicknesses. This segmentation may be accomplished using the cumulative difference method as described by the American Association of State Highway and Transportation Officials (1993) and as illustrated by Fernando and Chua (1994). Because of the strong influence of layer thickness on predicted pavement response and layer moduli backcalculated from FWD deflections, it is important to establish the variability in layer thickness along the route to minimize the inaccuracies caused by layer thickness variations. The segments delineated from the GPR data are subsequently used to plan the FWD survey, the purpose of which is to characterize the materials that comprise the pavement in terms of the elastic modulus. Districts now routinely perform these surveys for pavement design, forensic investigations, load-zoning, and superheavy load analysis.

FWD data are collected on each homogeneous segment following the protocol established by TxDOT (1996). For asphalt concrete pavements with surface thicknesses greater than 3 inches, pavement temperature measurements should be made to correct backcalculated asphalt concrete moduli to a standard temperature. For this purpose, TxDOT's FWDs are equipped with cordless drills and temperature probes so that asphalt layer temperatures can be measured at least once at the beginning and again at the end of the test on a given segment. Researchers recommend taking temperatures at mid-depth of the existing asphalt concrete layer. Temperature data are necessary to correct the backcalculated moduli to a reference temperature of 75 °F in the analysis program. Because of the influence of the surface modulus on predicted service life, it is important that the pavement temperature is known with a reasonable degree of confidence so that the asphalt concrete modulus can be appropriately determined.

FWD data collection may take some time depending on the frequency of testing and the length of the segment to be surveyed. In certain applications, taking pavement temperature measurements at the beginning and end of the segment will not provide enough information to consider the spatial and temporal variation in pavement temperatures during the survey. For these cases, researchers recommend taking infrared surface temperatures at least on every other station, so that pavement temperatures can be estimated using the Texas-

Long Term Pavement Performance (LTPP) equation implemented in the Modulus Temperature Correction Program developed by Fernando, Liu, and Ryu (2001). This equation permits prediction of pavement temperatures for a given depth within the asphalt layer corresponding to the date and time of FWD testing. Use of this equation requires the previous day's maximum and minimum air temperatures, which are readily obtained from the local weather service, and will provide a better estimate of the spatial and temporal variation of pavement temperatures along the route surveyed. The pavement temperatures measured at the beginning and end of the segment should verify the temperature predictions from the Texas-LTPP equation.

Researchers recommend storing FWD data in a separate file for each segment of the route surveyed then analyzing each file with the MODULUS program (Michalak and Scullion, 1995) to estimate the resilient moduli of the pavement layers. The output file of the backcalculated moduli for each segment is directly input to the OTRA program to predict whether the existing pavement can sustain the expected number of axle load applications through the end of the specified design period.

To predict pavement response under loading, OTRA permits the engineer to model pavement materials as linear or nonlinear. The nonlinear material constants, K_1, K_2, and K_3 in Table 1, are the parameters of the model proposed by Uzan (1985) to characterize the stress dependency of the resilient modulus, E_r, of pavement materials. The following equation defines this model:

$$E_r = K_1 \, Atm \left(\frac{I_1}{Atm} \right)^{K_2} \left(\frac{\tau_{oct}}{Atm} \right)^{K_3} \qquad (1)$$

where I_1 = first stress invariant,

J_{oct} = octahedral shear stress, and

Atm = the atmospheric pressure = 14.5 psi.

Given the principal stresses, F_1, F_2, and F_3, predicted from layered elastic theory, the first stress invariant and octahedral shear stress are determined from the following equations:

$$I_1 = F_1 + F_2 + F_3 \qquad (2)$$

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \quad (3)$$

The coefficients in Eq. (1) can be obtained from laboratory testing of base and subgrade specimens following the procedure developed by the American Association of State Highway and Transportation Officials. This test method, designated as AASHTO T 292-91, is applicable for untreated base/subbase and subgrade materials. Glover and Fernando (1995) tested a number of base and subgrade materials used in Texas and provided ranges of values for the coefficients K_1, K_2, and K_3 at different moisture levels. Their results can be used to assign values for these coefficients in the absence of laboratory test data. Typical values of these coefficients for different materials are provided later in this report. However, the authors strongly recommend conducting resilient modulus tests on samples of the materials found along the route to determine the coefficients for the nonlinear analysis, should the engineer decide to use this option.

In the application of the OTRA program, the user specifies the K_2 and K_3 values. The program then estimates the coefficient K_1 using these values with the backcalculated layer modulus for the material. The effects of stress dependency are more pronounced for thin-surfaced pavements, making it particularly important to model this behavior for these pavements. For thicker pavements, the effects are less pronounced. The program permits the user to model a given layer as linear elastic or nonlinear elastic. To model materials as linear elastic, the coefficients K_2 and K_3 in Eq. (1) are set to zero. For these materials, K_1 is directly determined from the FWD backcalculated moduli that are input to the computer program.

In view of the possible variations in layer thicknesses and materials along the route, different results may be obtained for the different segments established from analysis of the GPR data. These results may be used by the engineer to:

1. identify segments that will require rehabilitation to sustain the expected number of axle load applications during the specified design period;
2. establish depths of milling and overlays along the route; and
3. identify weak areas (based on analysis of FWD data and visual inspection of the route) that will require additional work, such as base repairs or reconstruction.

The engineer should use the data and findings from the pavement structural evaluation to decide whether to permit routine overweight truck traffic, and if so, establish what rehabilitation measures are necessary to provide a route that will sustain the expected number of axle load applications over the specified design period, and at what cost.

SYSTEM REQUIREMENTS AND PROGRAM INSTALLATION

OTRA requires a microcomputer operating under Windows 98SE or higher. Program use requires a working knowledge of the Windows operating system. To install OTRA, load the installation disk into the computer's CD-ROM drive. Click on the ***Start*** button in Windows and select ***Run***. At the dialog box, type ***drive letter:\otrasetup***, where ***drive letter*** specifies the CD-ROM drive (e.g., ***E*:**\). Click on the ***OK*** button of the dialog box to run the OTRA installation program. Simply follow the instructions that appear on screen. The program will prompt for a subdirectory or folder in which to store the program files on the computer's hard drive. By default, the files are copied to ***C:\OTRA***; however, you have the option to specify a different subdirectory, such as ***C:\Program Files\OTRA***.

After installation, you can execute OTRA using the shortcut placed on your desktop during setup, or through your ***Programs*** list. To access this list, simply click on the ***Start*** button, move the pointer to ***Programs***, then to ***OTRA.*** The program icon will appear. Click on the icon to load the program. The remainder of this user's guide provides instructions in the use of OTRA.

CHAPTER II
EVALUATING PAVEMENT STRUCTURAL ADEQUACY

INTRODUCTION

To determine whether an existing route is suitable to use for routine overweight truck traffic, the analysis procedure in OTRA covers two stages:

1. In the first stage, the structural adequacy of the existing route is evaluated to determine if it can be expected to last the desired design life based on fatigue and rutting criteria, and for a target reliability level.
2. If the existing route is not structurally adequate, the second stage permits you to evaluate the thickness of asphalt concrete overlay required for the pavement to last the design life for the specified reliability level.

This chapter explains the application of OTRA to evaluate pavement structural adequacy. Herein, it is assumed that you have collected the data required to characterize the truck traffic, pavement materials, and layer thicknesses along the route to be evaluated. Further, the backcalculation of layer moduli from FWD deflections using the MODULUS program and resilient modulus tests to characterize stress-dependency should be completed, should you decide to perform a nonlinear analysis in OTRA. The output file from the modulus backcalculation is used directly in the OTRA program to predict pavement service life, which is assessed against the prescribed design life to determine the suitability of permitting overweight trucks to routinely use the route. Instructions for using OTRA for this evaluation are given in the following sections.

SPECIFYING INPUT DATA

User-interface screens in OTRA facilitate the entry of input data to perform a given analysis. Specifying input parameters is the first activity after loading the computer program. This is done by manually entering the required parameters using the interface screens. Before going further, here are two simple guidelines to remember when navigating through the different menus of OTRA:

1. To select a particular option, move the pointer to it and then click on the option with the left mouse button.

2. To enter data for a particular variable, move the cursor to the field or cell, then type in the required data. To position the cursor to an input field, move the pointer to the field and click on it.

To load the analysis program, click on the ***Start*** button, move the pointer to ***Programs***, and then to ***OTRA.*** The program icon will be displayed. Click on the icon to load the program. The title screen shown in Figure 3 will be displayed. Press the return key to clear this screen and proceed to the main menu shown in Figure 4. Click on the ***Data Preparation*** button to specify input data to the computer program and create input files needed for the analysis. Note that the main menu offers only two options: ***Data Preparation*** and ***Exit Program***. The other two options, ***Evaluate Reliability*** and ***Evaluate Overlay Thickness***, are inactive until the ***Data Preparation*** step is completed.

After clicking on the ***Data Preparation*** button on the menu shown in Figure 4, the program prompts for the file of backcalculated layer moduli generated from the MODULUS program. The dialog box in Figure 5 displays on screen for you to enter the name of the MODULUS output file. Click on the input field in the dialog box and type in the name of the output file corresponding to the analysis segment. If the program was used previously, the dialog box will display the MODULUS output file name used in the last analysis. You can overwrite this as appropriate or search the computer for the MODULUS file by clicking on the ***Select MODULUS ASCII FILE*** button of the dialog box in Figure 5. This will bring up another screen (Figure 6) from which you can browse the drives and subdirectories of your computer to search for the MODULUS output file of interest and select it for the overweight truck route analysis. Note that if there are MODULUS ASCII (*.ASC) files in the subdirectory where the OTRA program is installed, the names of these files are displayed, as illustrated in Figure 6. You can select a file by first clicking on its name in the dialog box and then on the ***Open*** button. The dialog box in Figure 5 again displays with the name of the selected file. To use this file in the analysis, click on the ***OK*** button of the dialog box. OTRA then reads the file and displays the information illustrated in Figure 7. At the bottom of this dialog box is information on the name of the selected MODULUS ASCII file, the number of stations tested, and the district and county numbers read from the file. Use this menu to select the FWD test data that will be analyzed in the program. Two selection

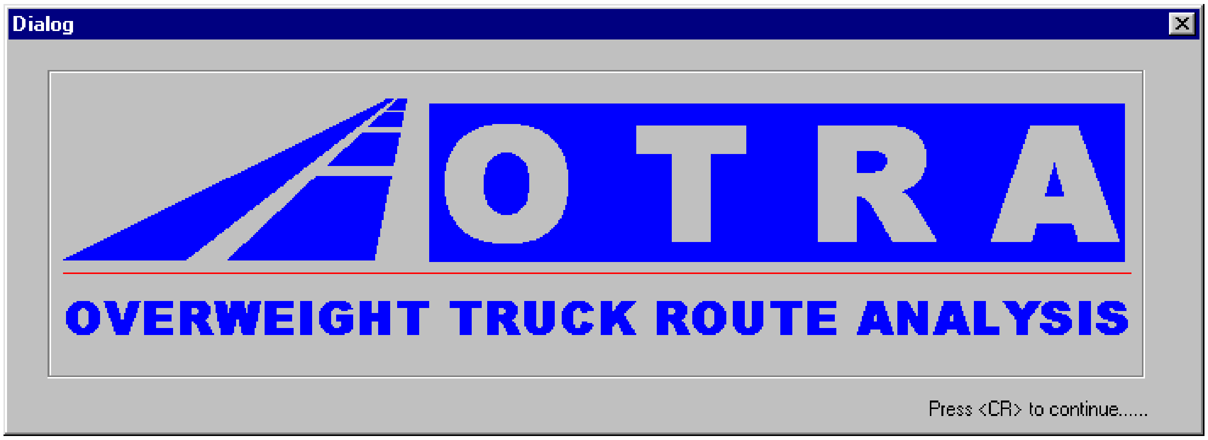


Figure 3. Header Screen of OTRA Program.

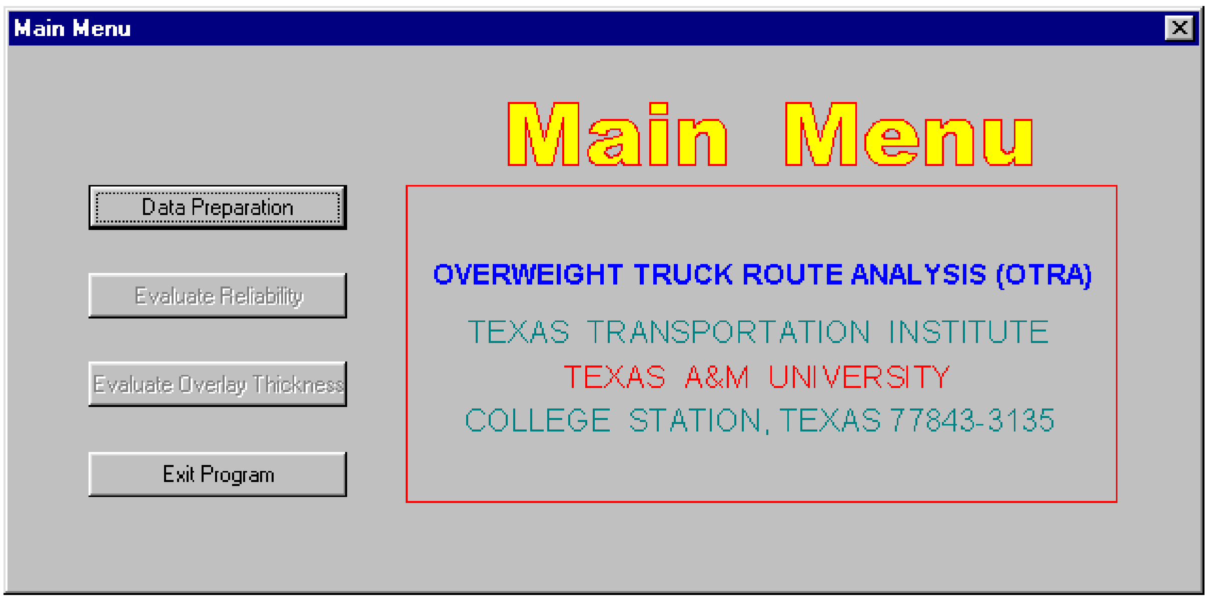


Figure 4. Initial Main Menu of OTRA Program.

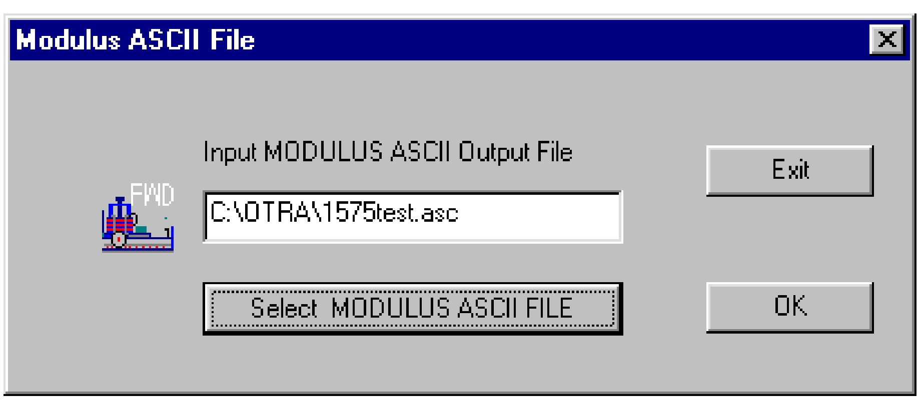


Figure 5. Dialog Box to Specify MODULUS Output File Name.

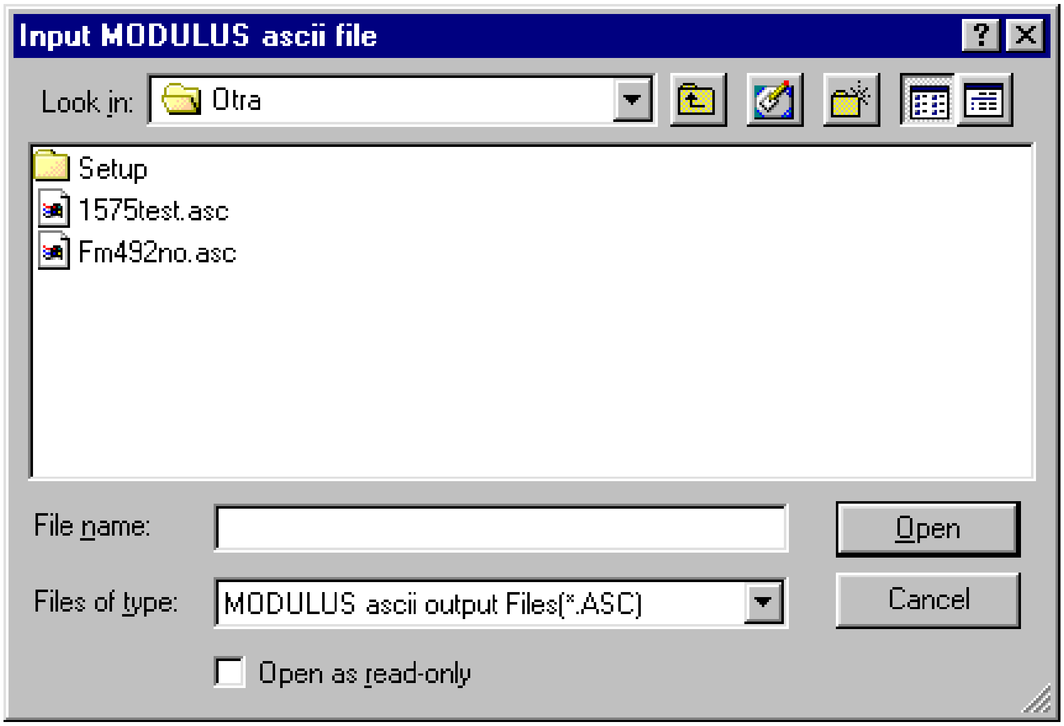


Figure 6. Dialog Box to Search for MODULUS ASCII Files.

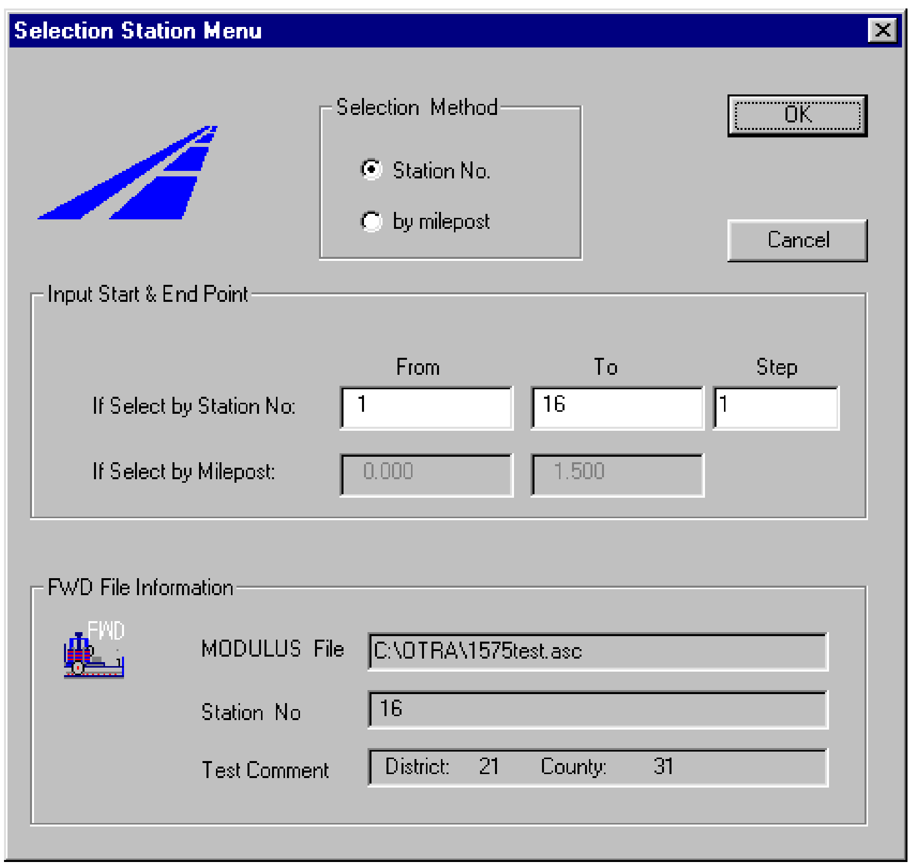


Figure 7. Dialog Box to Select FWD Stations for Analysis.

methods are available, as shown in Figure 7. You may specify the range of data to analyze by beginning and ending station numbers (the default choice in the OTRA program) or by milepost limits.

Note that the station numbers refer to the order in which the deflection data are written in the MODULUS output file. If the selection method is by station number, specify the beginning and ending station numbers that define the range of locations to analyze in the program. This option also allows you to specify the analysis frequency by entering a step size in the dialog box shown in Figure 7. For the example given, the analysis will use the backcalculated layer moduli at each of 16 stations where FWD data were collected and make predictions of pavement life at each of these locations. If a step size of 2 was specified, then the analysis would be made for every other station.

The range of locations to analyze can also be defined by entering the beginning and ending milepost limits. Click on the ***by milepost*** option of the dialog box and type in the beginning and ending milepost limits in the ***From*** and ***To*** fields, respectively, of the dialog box. By default, the program will show the milepost limits that cover the entire range of data in the MODULUS output file. You can choose these limits to analyze all locations where FWD deflections were measured or type in different limits corresponding to the interval within the section or route that you want to analyze. After specifying the analysis interval and frequency, click on the ***OK*** button of the dialog box to continue with the program. The screen given in Figure 8 is then displayed. This figure shows the pavement layering as read from the MODULUS output file. The following information is given:

1. layer thicknesses;
2. the modulus search range used in the backcalculations, as defined by the minimum and maximum moduli values specified for each layer; and
3. the Poisson's ratio of each layer.

The screen shown in Figure 8 does not require user input. However, it does provide information the OTRA program uses to predict pavement response under surface wheel loads, specifically the layer thicknesses and Poisson's ratios. By looking at the minimum and maximum values specified for the layer modulus, you can establish whether any of the pavement layer moduli were fixed in the backcalculations. In the example given in Figure 8,

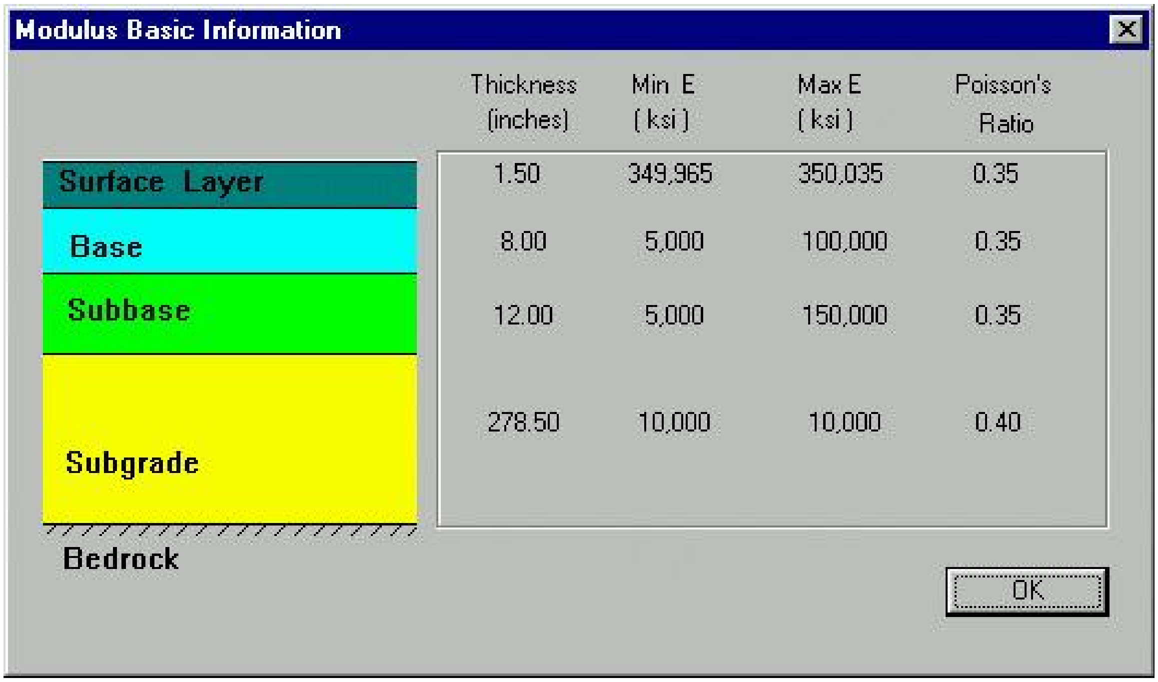


Figure 8. Pavement Layering Information Read from the MODULUS Output File.

the surface layer modulus was fixed at a value of around 350 ksi when the FWD data were analyzed using MODULUS. This action was done because the surface is only 1.5 inches thick, as shown in Figure 8. For thin-surfaced pavements, the predicted surface deflections are relatively less sensitive to changes in the surface modulus based on layered elastic theory, which underlies the MODULUS program. Thus, the surface modulus is typically fixed to a reasonable value in the backcalculation of layer moduli from surface deflections taken on thin-surfaced pavements. While this may be appropriate for this application, the predicted service life is influenced, to a significant degree, by the surface modulus because of its effect on the predicted service life. In fact, the surface modulus is an independent variable in the Asphalt Institute equation used in OTRA for predicting service life based on fatigue cracking. Thus, it is important that the surface modulus is assigned a value (during the backcalculation) appropriate for the particular mix and pavement temperature at which the FWD data were collected.

After viewing the information in Figure 8, click on the ***OK*** button to leave this screen. The next window (Figure 9) allows you to view the following information on each FWD test location selected in the dialog box given in Figure 7:

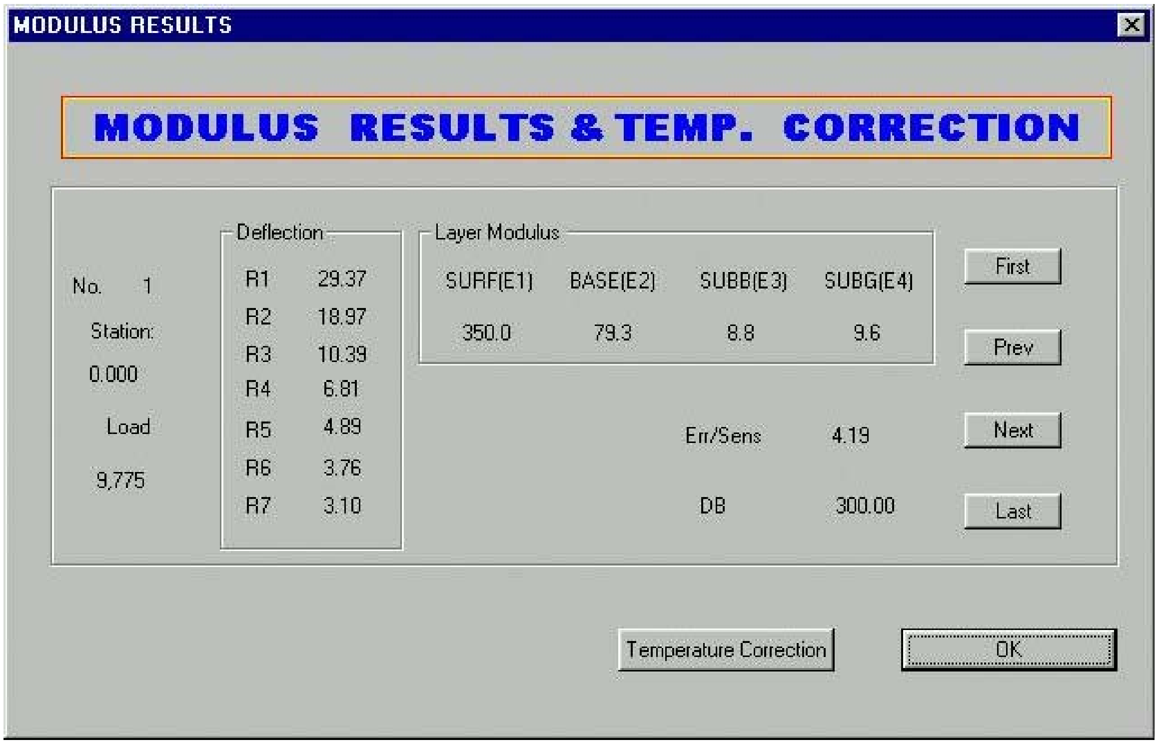


Figure 9. Window for Viewing FWD Data on Selected Test Locations.

1. measured sensor deflections, R1 to R7;
2. backcalculated layer moduli, E1 to E4;
3. absolute error per sensor (Err/Sens) from the backcalculation; and
4. predicted depth to bedrock (DB).

The above information is read from the MODULUS output file and displayed by the OTRA program. You can go through each selected FWD test location using the buttons located on the right side of the window. Clicking on ***First*** displays the data for the first FWD station selected. ***Prev*** displays the data for the previous station (relative to the current station that is displayed), while ***Next*** displays the data for the following station. ***Last*** displays the data for the last station in the range of locations you specified for the analysis.

The screen in Figure 9 also permits you to correct the backcalculated layer moduli to a reference temperature of 75 °F. If you want a temperature correction done on the MODULUS results, click on the ***Temperature Correction*** button in Figure 9. This will display the dialog box in Figure 10. In this screen, enter the pavement temperatures in °F at

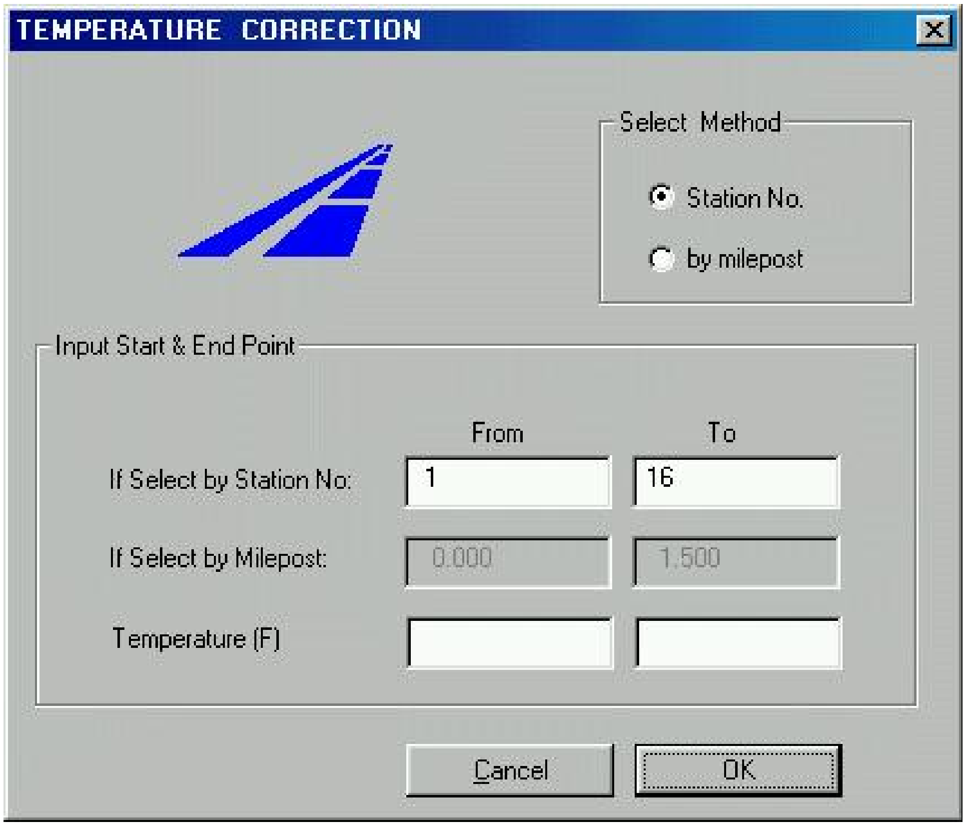


Figure 10. Temperature Correction of Asphalt Concrete Modulus.

the beginning and ending stations of the interval to be analyzed. The program then performs a linear interpolation to estimate the pavement temperatures at the time of testing for the stations within the beginning and ending limits specified in Figure 10. These pavement temperatures are then used with the following equation to determine a correction factor (*CF*) that is applied to the backcalculated asphalt concrete modulus at a given station to correct its value to the reference temperature of 75 °F:

$$CF = \frac{(T_{FWD})^{2.81}}{200,000} \tag{4}$$

where T_{FWD} is the pavement temperature in °F at the time of FWD testing. For the purpose of temperature correction, the analysis interval specified in Figure 7 can be further subdivided into subsections to better characterize the pavement temperature variation at the time of the FWD tests. This is accomplished by specifying the beginning and ending locations of the subsections and the corresponding pavement temperatures at these locations in the dialog box given in Figure 10. After specifying the temperature range for a given subsection, click on the ***OK*** button in Figure 10 to go back to the screen in Figure 9. You can then view from this screen the corrected asphalt concrete (AC) moduli for the subsection. To establish the temperature variation for another subsection, click again on the ***Temperature Correction*** button in Figure 9. This will re-display the screen in Figure 10 where you can enter the temperature range for another subsection. Then, click on ***OK*** to view the temperature-corrected AC moduli from the screen shown in Figure 9. Keep repeating this sequence until the temperature correction for all subsections is completed. At that point, the user-interface screen in Figure 9 will be active. Click on the ***OK*** button of this screen to proceed to the next step.

The screen shown in Figure 11 will then be displayed. On this screen, specify the K_2 and K_3 values that define the stress dependency of the pavement materials in the route or segment to be analyzed. By default, the values of these coefficients are zeros, corresponding to a linear elastic material. OTRA allows you to model stress-dependent materials by specifying the appropriate K_2 and K_3 values. The ranges of these coefficients for a number of unbound base and subgrade materials used in Texas are given in Tables 2 and 3. For asphalt concrete mixtures, Jooste and Fernando (1995) have used K_2 and K_3 values of 0.1 and 0.0, respectively, to model the response of flexible pavements to superheavy loads. Lytton et al. (1993) have also reported K_1, K_2, and K_3 values determined from laboratory data on asphalt concrete cores tested by the University of California at Berkeley during the Strategic Highway Research Program (SHRP) A-003A project. From analyses conducted by Lytton et al. (1993), K_1 was found to vary from about 700 to 3000 for tests conducted at 104 °F, 900 to 4400 for tests conducted at 68 °F, and 1000 to 18,000 for tests conducted at 39 °F. For K_2, the values varied from 0.0 to about 0.5 for the range in temperatures at which tests were conducted, with an average value of 0.33. Researchers also found that a K_3 value of zero provided the best fit to the test data for all cores tested.

In OTRA, K_1 is estimated from the FWD data and the K_2 and K_3 values you input. After specifying the coefficients for each layer, click on the ***Calculate K_1*** button in Figure 11 to estimate the K_1 values. This is done for each FWD station through layered elastic analysis using the specified K_2 and K_3 values, backcalculated layer moduli, and the FWD load used in the backcalculation. After the K_1 coefficients are calculated, a message box appears on screen notifying you of the completion of this step. Click on the ***K_1 Calculation Finished***

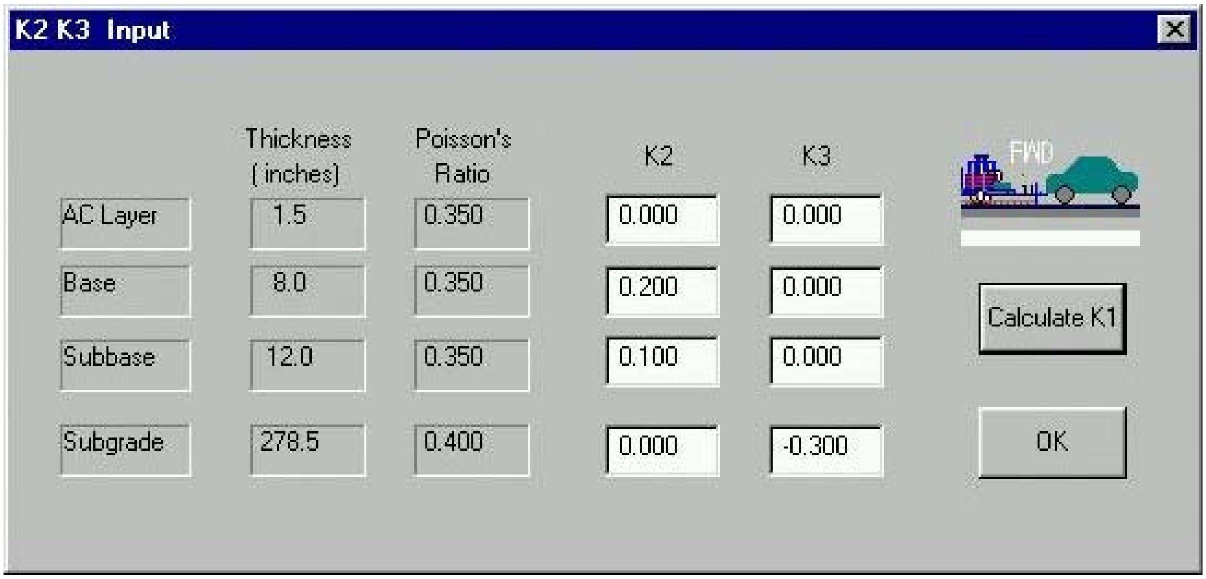


Figure 11. User-Interface Screen for Specifying K_2 and K_3 Values.

Table 2. Laboratory Test Values of K_2 and K_3 for Some Base Materials (Glover and Fernando, 1995).

Material Type	K_2			K_3		
	- opt.	at opt.	+ opt.	- opt.	at opt.	+ opt.
Caliche	1.18	0.83	0.19	0.00	0.00	0.00
Iron Ore Gravel	0.60	0.49	0.56	0.00	0.00	0.00
Shell Base	1.10	0.60	0.78	0.00	0.00	0.00
Crushed Limestone	0.90	0.90	-	-0.33	-0.33	-
Average	0.95	0.71	0.51	-0.33	-0.33	0.00
Std. Dev.	0.22	0.17	0.24	0.00	0.00	0.00

Table 3. Laboratory Test Values of K_2 and K_3 for Some Subgrade Materials (Glover and Fernando, 1995).

Material Type	K_2			K_3		
	- opt.	at opt.	+ opt.	- opt.	at opt.	+ opt.
Sand	0.44	0.51	0.40	0.00	0.00	-0.03
Sandy Gravel	0.63	0.67	-	-0.10	-0.28	-
Lean Clay	0.00	0.32	0.10	-0.27	0.10	-0.55
Fat Clay	0.66	1.25	0.66	-1.47	-0.50	-0.17
Silt	1.19	0.52	0.50	-0.11	-0.20	-0.10
Averages for Sandy Materials	0.53	0.59	0.40	-0.05	-0.14	-0.03
Std. Dev. for Sandy Materials	0.09	0.08	0.00	0.05	0.14	0.00
Averages for Clayey Materials	0.62	0.70	0.42	-0.62	-0.20	-0.27
Std. Dev. for Clayey Materials	0.49	0.40	0.24	0.61	0.24	0.20

button of the message box and then on the ***OK*** button of the screen in Figure 11 to return to the main menu of OTRA.

At this point, the material parameters and layer thicknesses have been specified or determined. To evaluate pavement structural adequacy, click on the ***Evaluate Reliability*** button of the main menu in Figure 12. The menu shown in Figure 13 is displayed. The buttons in this menu are used for the following purposes:

1. to define truck traffic characteristics (***Input Design Load*** and ***Input Traffic Information***),
2. to evaluate pavement structural adequacy (***Evaluate Reliability***),
3. to display and save the results from the evaluation (***List Results*** and ***Write Results to File***), and
4. to get a hard copy of the output (***View & Print Output File***).

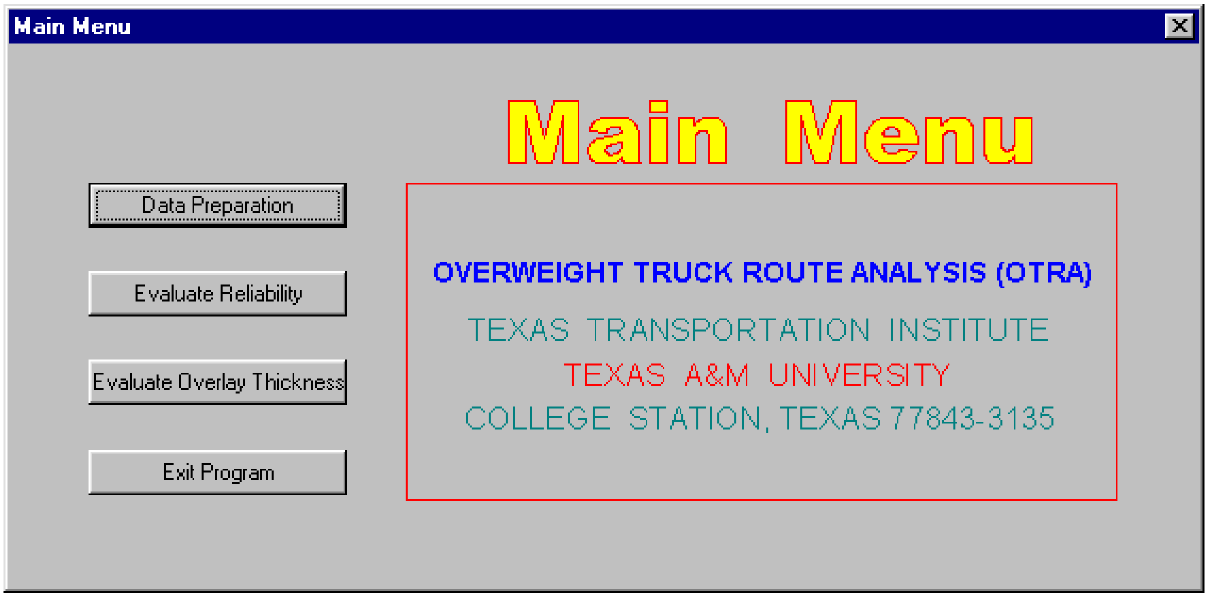


Figure 12. OTRA Main Menu after Data Preparation Step.

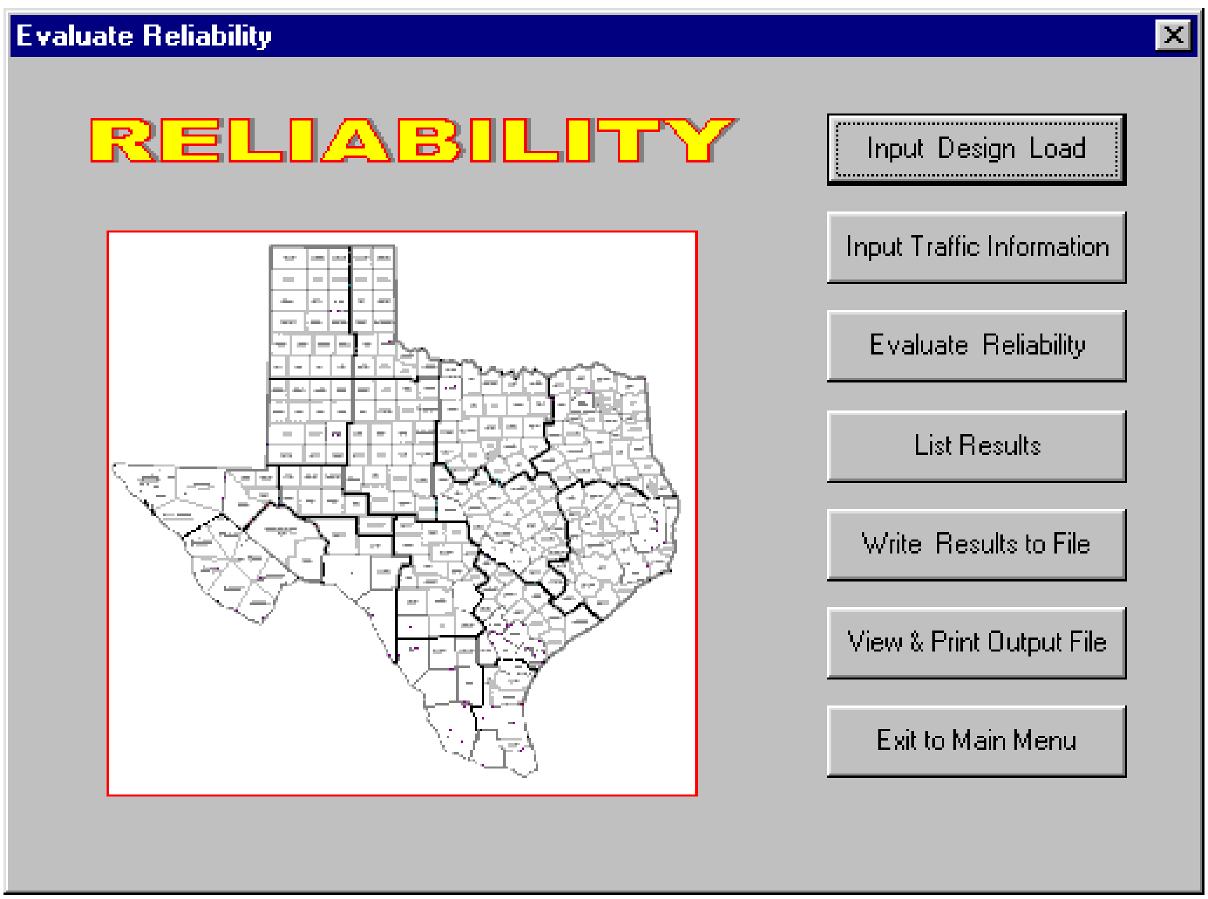


Figure 13. The Evaluate Reliability Menu in OTRA.

The truck traffic characteristics input into OTRA define the load geometry, load magnitudes, and the cumulative number of axle load applications during the prescribed design period. By clicking on the ***Input Design Load*** button of the menu in Figure 13, you can specify the load geometry and load magnitudes for the analysis. The required data, shown in Figure 14, are the:

1. tire contact pressure,
2. dual tire spacing,
3. spacing between axles of a tandem or triple axle group,
4. design single axle load,
5. design tandem axle load, and
6. design triple axle load.

The design axle loads input into the screen shown in Figure 14 should correspond to the maximum single, tandem, and triple axle loads that you are willing to permit on the road. In Figure 14, the design loads shown correspond to the maximum allowable axle loads established for the overweight truck route along SH4/48 in Brownsville. After entering the required data, click on the ***OK*** button to return to the previous menu shown in Figure 13. The next step is to input traffic information, so click on this button of the menu. The screen shown in Figure 15 is then displayed.

The traffic information entered into the screen shown in Figure 15 is used to establish the cumulative single, tandem, and triple axle load applications during the prescribed design period. In order to calculate the cumulative axle load applications, the following data are required:

1. beginning and ending ADT values,
2. length of design period,
3. directional factor,
4. percent trucks in the traffic stream,
5. average number of axle groups per truck,
6. percent of axle groups that are singles,
7. percent of axle groups that are tandems, and
8. percent of axle groups that are triples.

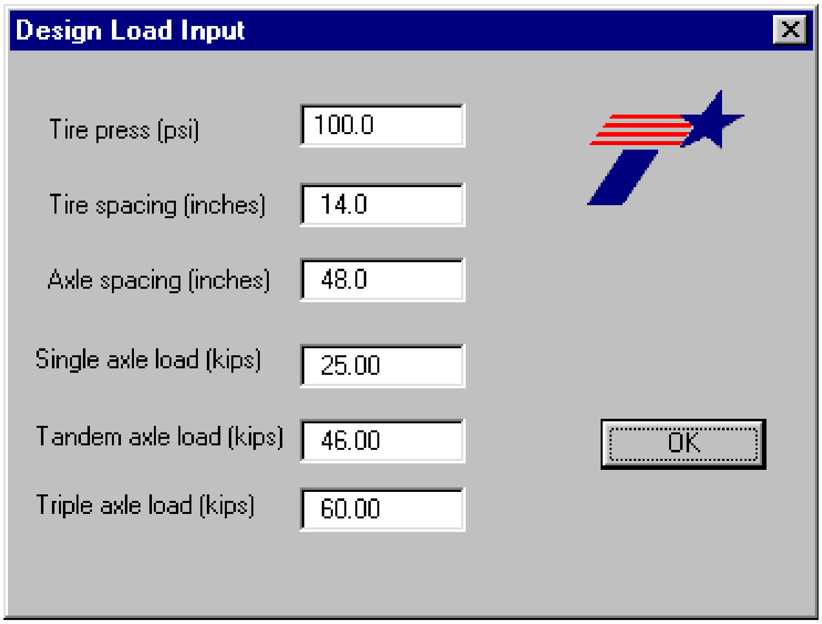


Figure 14. Screen for Entering Data on Load Geometry and Magnitudes.

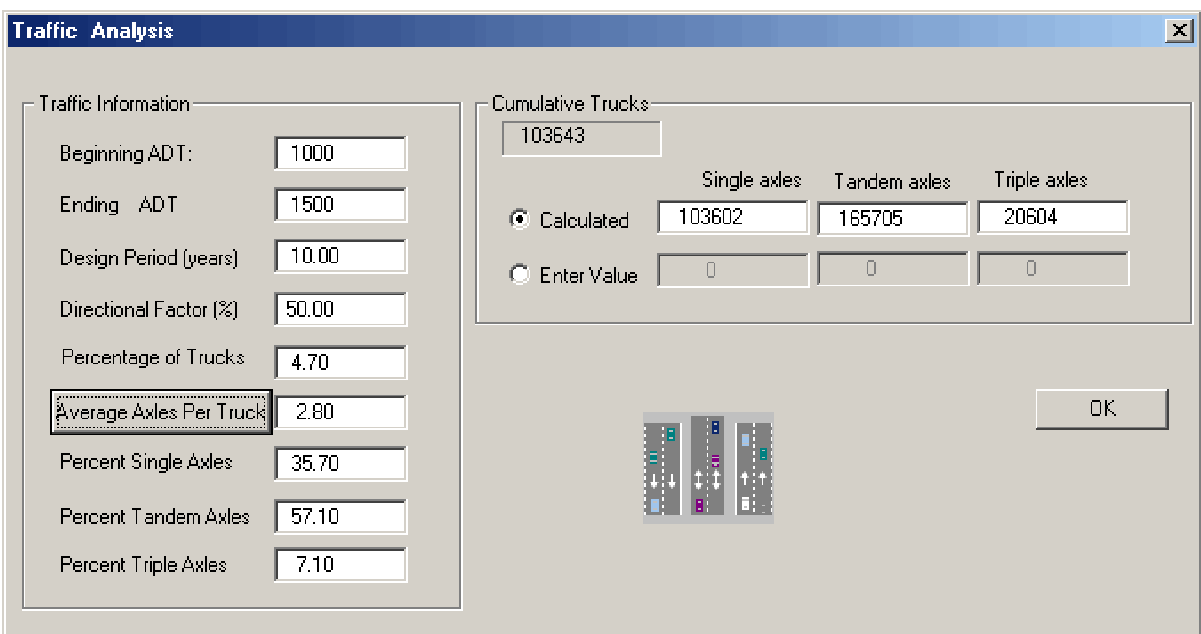


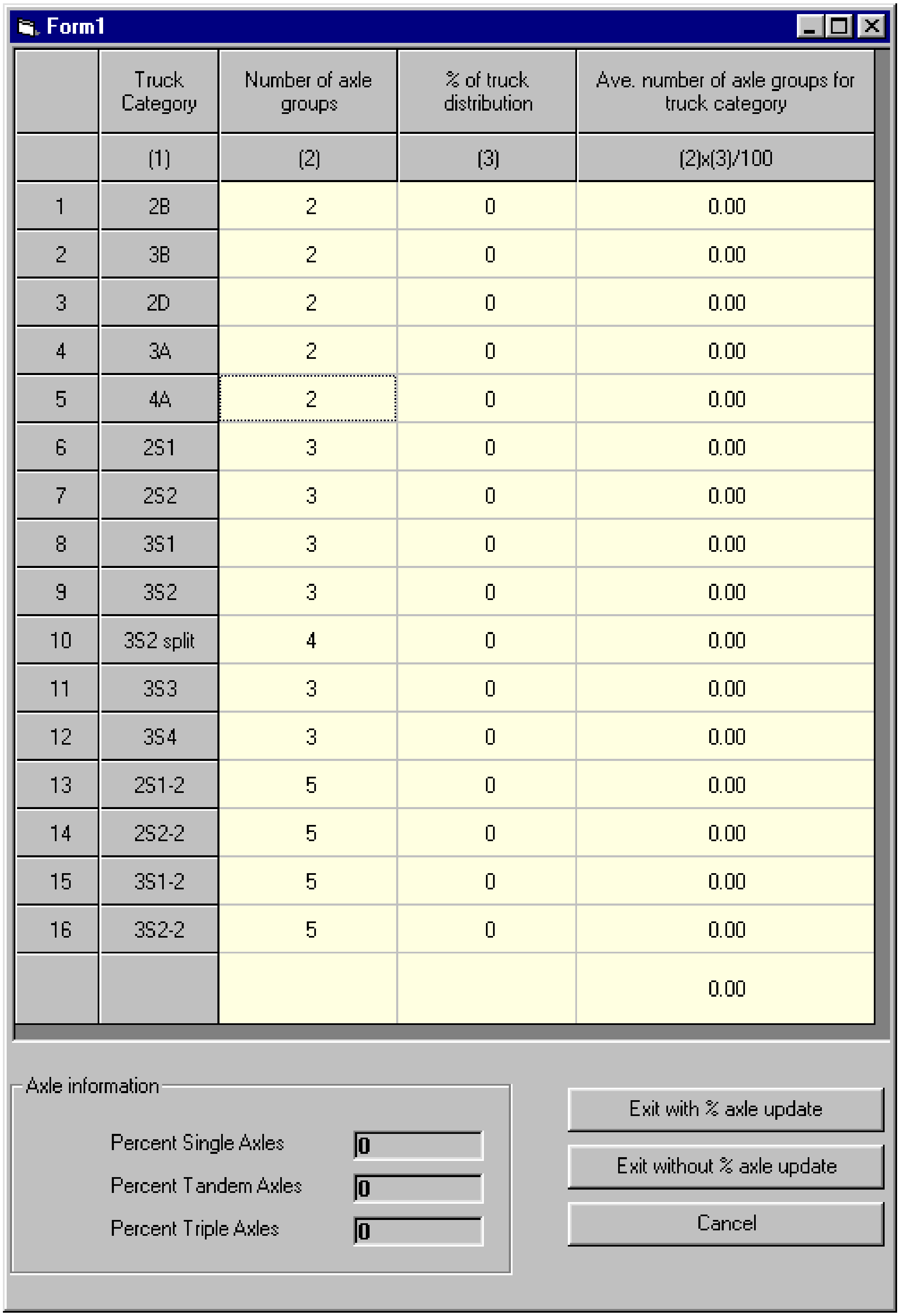
Figure 15. Input Screen for Establishing Cumulative Axle Load Applications.

To illustrate the meaning of the average axles per truck in Figure 15, assume that the trucks using a given route consist of conventional tractor-semitrailers (3S2s) and single unit trucks with tandem drive axles (3As). If the distribution of trucks is 75 percent 3S2s and 25 percent 3As, then the average number of axle groups per truck is calculated as 2.75, as shown in Table 4.

Table 4. Calculation of the Average Number of Axle Groups per Truck.

Truck category *(1)*	Number of axle groups *(2)*	Percentage of truck distribution *(3)*	Average number of axle groups for truck category *(2) x (3)/100*
3S2	3	75	2.25
3A	2	25	0.50
Average number of axle groups per truck			2.75

If you have the truck distribution by vehicle class, you can use this information to compute the average number of axle groups per truck, as well as the percentages of single, tandem, and triple axles, in lieu of entering these values directly into the menu shown in Figure 15. This truck distribution may be based on existing vehicle counts and classifications modified to reflect your projections of likely changes in the truck configurations used as a result of permitting overweight truck traffic on the route. To enter the truck distribution by vehicle class, click on ***Average Axles Per Truck*** in the menu given in Figure 15. The program then displays the form shown in Figure 16, where you can enter the percentage of each truck type expected to use the route. To enter the percentage for a given truck category, double-click the cell corresponding to that category under the column labeled ***% of truck distribution***. For example, to specify the percentage of 3S2s in the projected truck distribution, double-click on the cell corresponding to row 9, column 4 of the form. This action brings up the dialog box shown in Figure 17, where you enter the projected percentage of 3S2s. Do this for each truck category that you expect to travel on the route. Note that the percentages entered should add up to 100 percent. For any given truck category, the program gives a message at the top of the dialog box (Figure 17) to let you know what percentage you may enter to get all of the trucks.



Form1

	Truck Category	Number of axle groups	% of truck distribution	Ave. number of axle groups for truck category
	(1)	(2)	(3)	(2)x(3)/100
1	2B	2	0	0.00
2	3B	2	0	0.00
3	2D	2	0	0.00
4	3A	2	0	0.00
5	4A	2	0	0.00
6	2S1	3	0	0.00
7	2S2	3	0	0.00
8	3S1	3	0	0.00
9	3S2	3	0	0.00
10	3S2 split	4	0	0.00
11	3S3	3	0	0.00
12	3S4	3	0	0.00
13	2S1-2	5	0	0.00
14	2S2-2	5	0	0.00
15	3S1-2	5	0	0.00
16	3S2-2	5	0	0.00
				0.00

Axle information

Percent Single Axles 0

Percent Tandem Axles 0

Percent Triple Axles 0

Exit with % axle update

Exit without % axle update

Cancel

Figure 16. Form to Specify Truck Distribution by Vehicle Class.

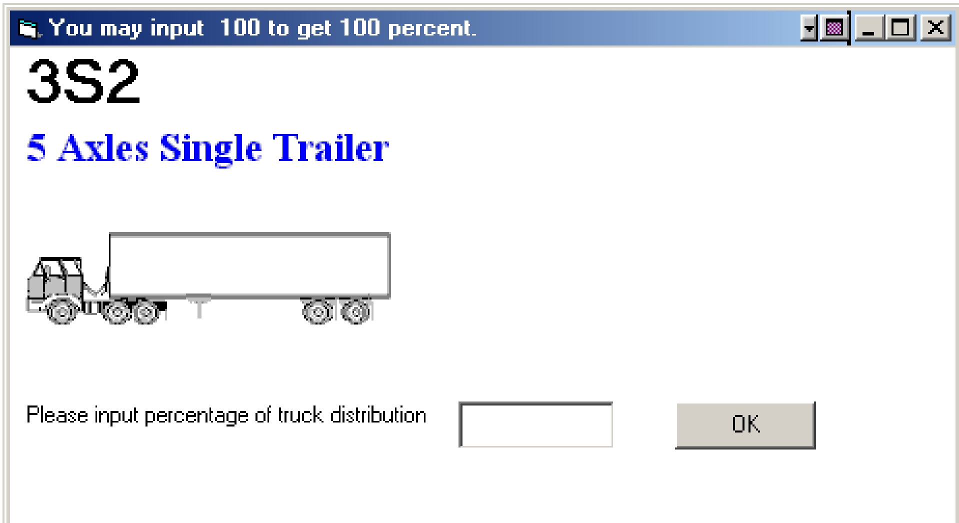
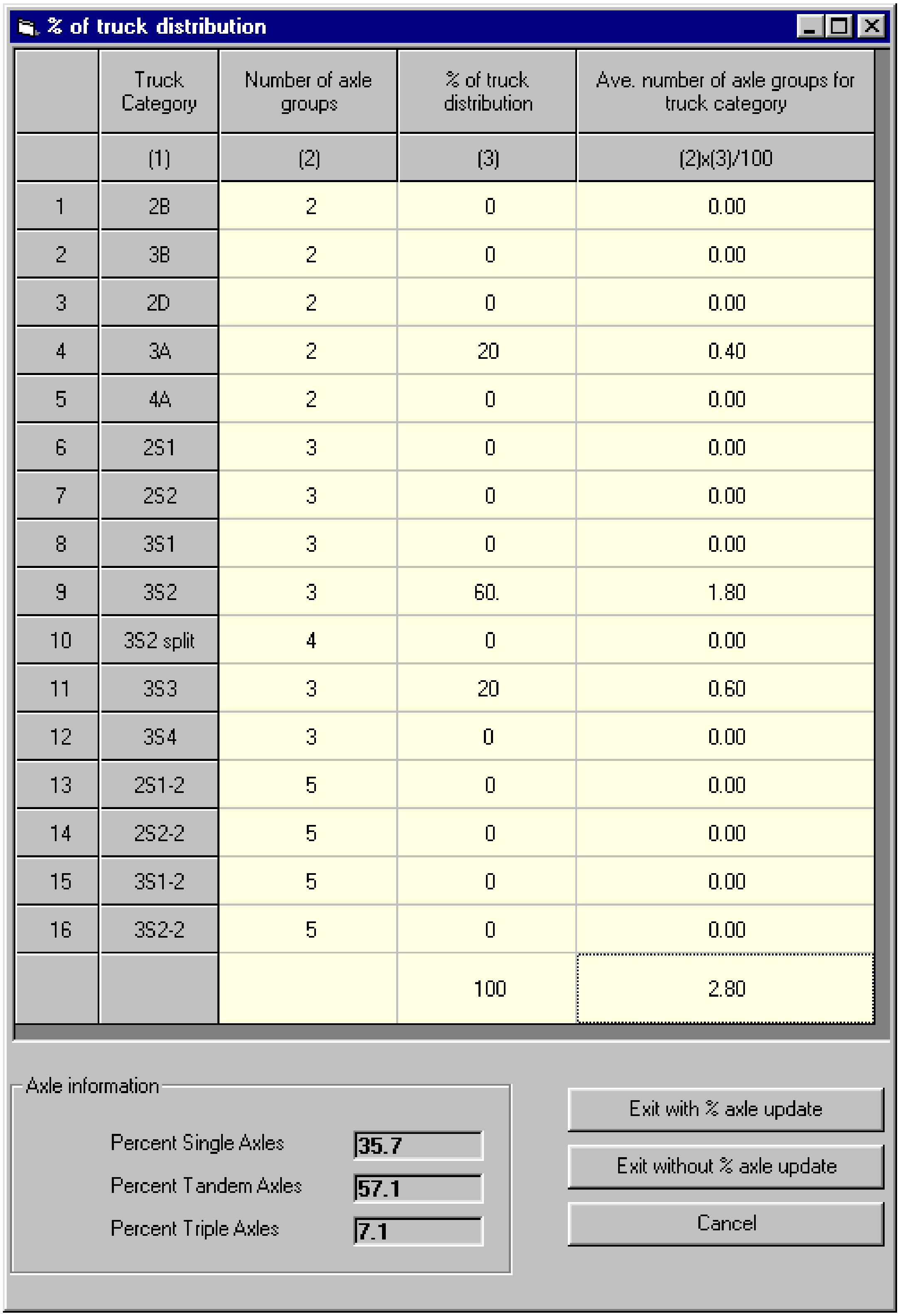


Figure 17. Example of Dialog Box to Specify Percent of Trucks Belonging to a Given Truck Category.

As you key in the percentages for the different truck categories, the program keeps a running sum of the values entered and displays this sum at the bottom of the column labeled ***% of truck distribution***. When 100 percent of the trucks have been entered, the program computes and displays the average number of axle groups per truck and the percentages of single, tandem, and triple axle groups as illustrated in Figure 18. At this point, you can click on ***Exit with % axle update*** to accept the computed values. The fields for these parameters are then updated in Figure 15. If you click on ***Exit without % axle update***, the calculated percentages of single, tandem, and triple axle groups are ignored and no updates are made to the corresponding fields for these input parameters in Figure 15. However, this option does update the average number of axle groups per truck with the value determined from the specified truck distribution by vehicle class. If you click ***Cancel***, none of the calculated values are accepted and no updates are made to the average number of axle groups per truck or the percentages of single, tandem, and triple axle groups in Figure 15.

The cumulative number of single, tandem, and triple axle load applications calculated from the traffic data shown in Figure 15 incorporates a traffic growth factor consistent with the specified beginning and ending ADTs and the duration of the design period. In lieu of calculating the cumulative load applications, Figure 15 also permits you to specify these numbers directly. To do this, simply click on the ***Enter Value*** option of the screen and type



% of truck distribution

	Truck Category	Number of axle groups	% of truck distribution	Ave. number of axle groups for truck category
	(1)	(2)	(3)	(2)x(3)/100
1	2B	2	0	0.00
2	3B	2	0	0.00
3	2D	2	0	0.00
4	3A	2	20	0.40
5	4A	2	0	0.00
6	2S1	3	0	0.00
7	2S2	3	0	0.00
8	3S1	3	0	0.00
9	3S2	3	60.	1.80
10	3S2 split	4	0	0.00
11	3S3	3	20	0.60
12	3S4	3	0	0.00
13	2S1-2	5	0	0.00
14	2S2-2	5	0	0.00
15	3S1-2	5	0	0.00
16	3S2-2	5	0	0.00
			100	2.80

Figure 18. Dialog Box Showing Results of Calculations Based on Specified Truck Distribution.

in the cumulative number of load applications for all three axle configurations. When done, click on the ***OK*** button to go back to the menu given in Figure 13. At this point, all input data to evaluate pavement structural adequacy have been specified. To run the analysis, click on the ***Evaluate Reliability*** button of Figure 13. You will then be asked to specify the limit on the number of iterations available to the program to achieve convergence for stress-dependent moduli. This limit is specified by choosing one of the options shown in Figure 19. By default, the maximum number of iterations is set at 1000. Note that this is only an upper limit. The program may actually take a much smaller number of iterations to achieve convergence, and for problems where all layers are characterized as linear elastic, no iterations are made.

Once the limit is set in Figure 19, the evaluation begins. The program analyzes each FWD test location as indicated in Figure 20, which shows how much of the evaluation is complete at any given time. During this evaluation, the following calculations are made:

1. At each selected FWD test location, the allowable number of load repetitions are determined using the Asphalt Institute equations for fatigue cracking and rutting. These predictions are made for the specified design axle loads. The service life based on fatigue cracking, $(N_f)^c$, is predicted from the equation:

$$(N_f)^c = 7.9488 \times 10^{-2} \left(\frac{1}{\varepsilon_{ac}}\right)^{3.29} \left(\frac{1}{E_{ac}}\right)^{0.854} \quad (5)$$

where g_{ac} = tensile strain at the bottom of the asphalt surface layer, and
E_{ac} = asphalt concrete modulus.

Equation (5) predicts the number of load applications prior to development of 20 percent fatigue cracking based on total pavement area (Asphalt Institute, 1982). The service life based on rutting, $(N_f)^r$, is determined from:

$$(N_f)^r = 1.365 \times 10^{-9} \left(\frac{1}{\varepsilon_{sg}}\right)^{4.477} \quad (6)$$

where g_{sg} is the vertical compressive strain at the top of the subgrade and $(N_f)^r$ is the number of allowable load applications based on a limiting rut depth criterion of 0.5 inches (Asphalt Institute, 1982). In the program, the strains induced under

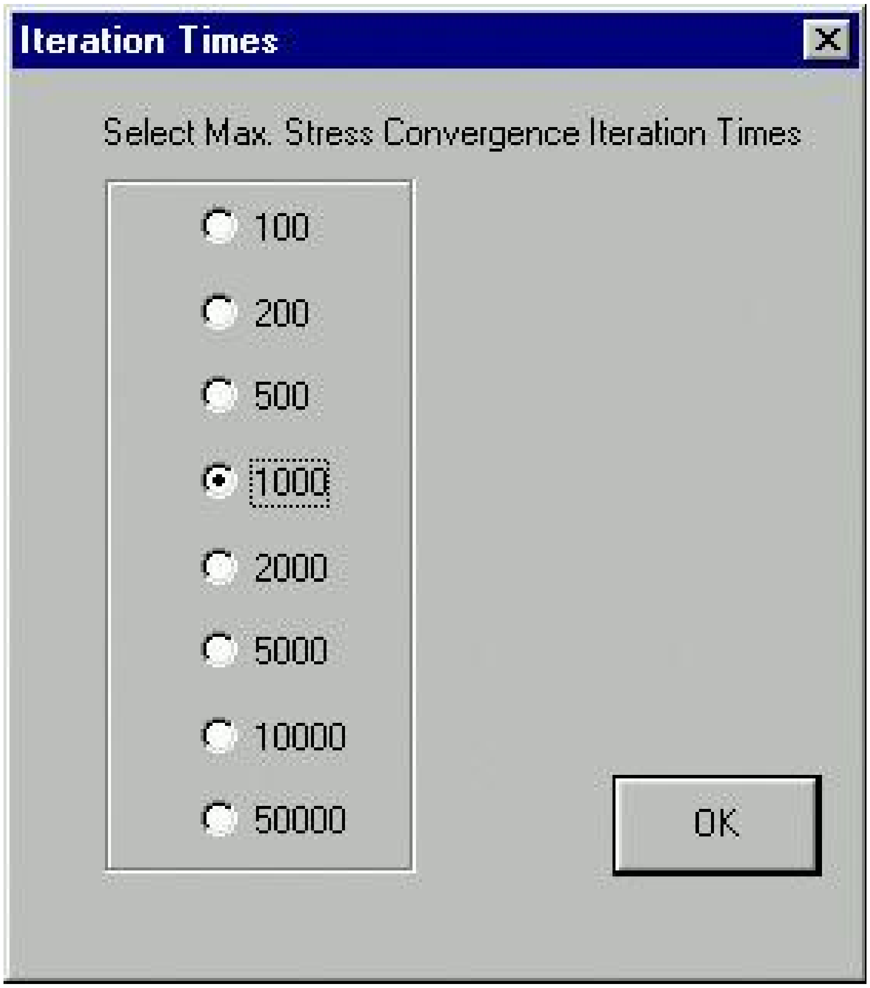


Figure 19. Screen to Specify the Maximum Number of Iterations for Convergence of Stress-Dependent Moduli.

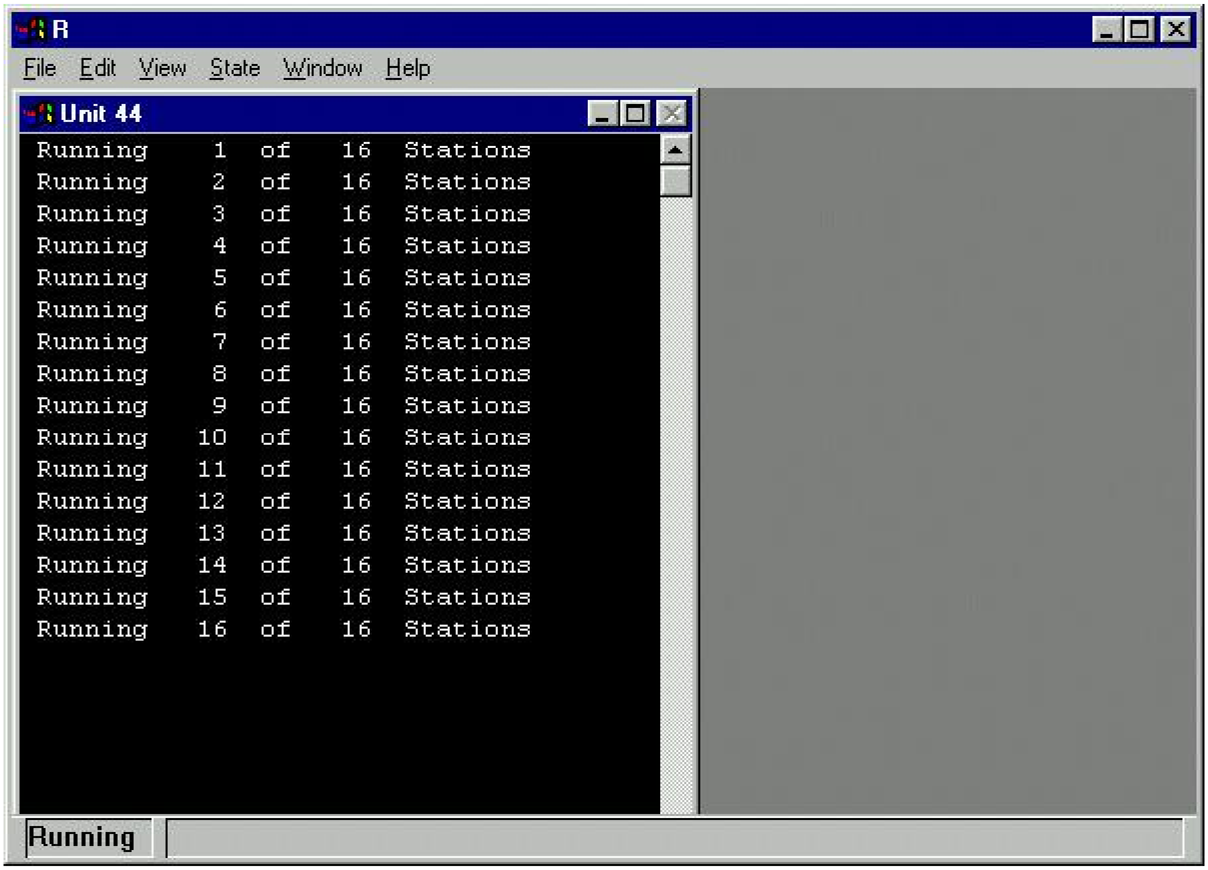


Figure 20. Display Screen Showing Completion of Analysis for Each FWD Station.

loading are determined at a number of lateral offsets beneath the wheel loads. These positions correspond to the outside tire edge, middle of a tire, inside tire edge, and midway between the dual tires for a single axle configuration. For tandem and triple axle assemblies, the program also predicts the strains at these lateral offsets at a distance corresponding to half the axle spacing. Additionally, for triple axle groups, the strains are predicted at these lateral offsets beneath the dual tires of the middle axle. OTRA uses the maximum predicted asphalt tensile strain and subgrade vertical compressive strain to predict the allowable number of repetitions of the design axle loads.

2. The ratio of the expected number of yearly load applications to the allowable number of repetitions prior to failure is computed for each axle configuration (single, tandem, and triple). This ratio is an estimate of the life consumed per year of the design period for the given axle configuration and load and for the

given failure criterion (fatigue cracking or rutting). Assuming Miner's (1945) hypothesis, the computed damage ratios for the axle configurations are summed to determine the yearly service life consumption for each failure criterion. Thus, at each selected FWD station, a prediction of service life (in years) is determined.

3. The service life predictions for the route or segment analyzed are then used to compute the probability P_{fail} that the service life is less than the design period. Pavement reliability R is then evaluated as $1 - P_{fail}$.

The reliability from OTRA is used to determine whether the existing route is structurally adequate to sustain the expected axle load applications over the design period. This computed reliability is compared with the desired or target value, which can be tied to the level of use of the facility. In the opinion of the authors, routine overweight truck routes are likely to have moderate to high traffic volumes, for which a reliability level between 80 to 99 percent would be appropriate.

The program plots service life predictions on screen for both fatigue cracking and rutting criteria. Figure 21 illustrates the output from the evaluation of pavement reliability. The circles in the figure are the predicted service lives based on cracking, while the squares are the predictions based on rutting. For comparison, the specified design period is also plotted as a horizontal line.

For reporting purposes, an upper limit of 40 years is imposed on the performance predictions. However, in evaluating reliability, the actual values of the predicted service lives are used. The chart in Figure 21 can be printed by clicking on ***File*** at the top of the figure and selecting the ***Print*** option (Figure 22). For identification purposes, the name of the MODULUS ASCII file prints at the top of the chart, along with the date and time of the analysis. In addition to printing, the chart can be saved as a bitmap file by using the ***Save*** option within the ***File*** function. This graphics file can later be imported into a document reporting the results of the analysis.

To clear the chart from the screen, double-click on it as instructed at the bottom right of the figure. The reliability statistics will then be displayed, as illustrated in Figure 23. The minimum of the computed statistics is reported as the pavement reliability. This should be compared with the desired reliability level to determine whether the existing route is structurally adequate to carry routine overweight truck traffic over the specified design life.

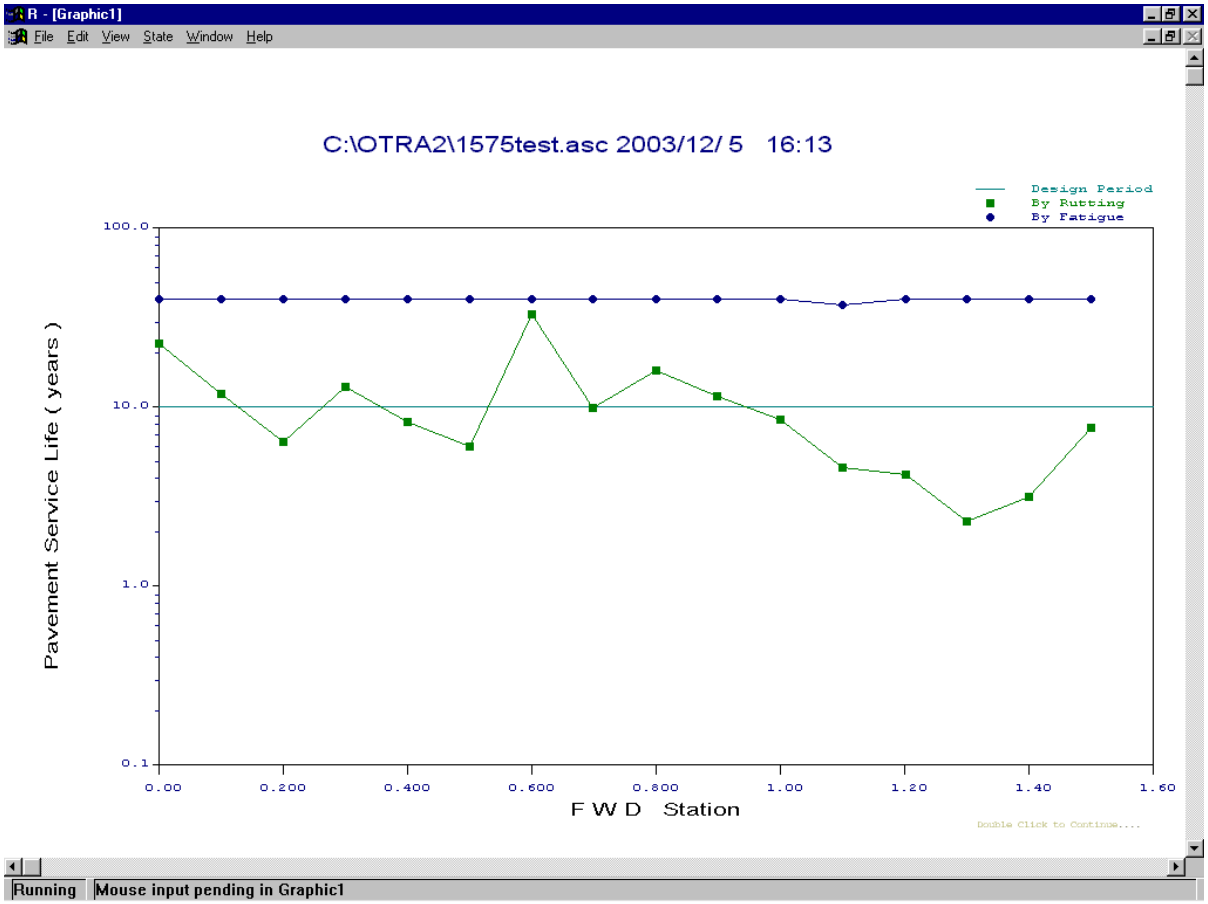


Figure 21. Plot of Performance Predictions from the Reliability Analysis.

In addition to the chart, the results for each FWD station can be viewed using the ***List Results*** option of the reliability analysis menu given in Figure 13. The information provided for each station is shown in Figure 24, which illustrates the screen displayed after clicking on the ***List Results*** button of the menu in Figure 13. For each FWD station, the following information is provided:

1. layer moduli backcalculated from FWD deflections,
2. K_1 coefficients backcalculated from the layer moduli,
3. service life predictions for both fatigue cracking and rutting criteria, and
4. the prescribed design period.

You can view the results for individual stations using the ***First***, ***Last***, ***Previous***, and ***Next*** buttons of Figure 24, which function as described previously. There is also an output field labeled ***Result,*** which shows whether the pavement at the given location is adequate to handle the expected traffic loads based on the performance predictions. If the pavement is

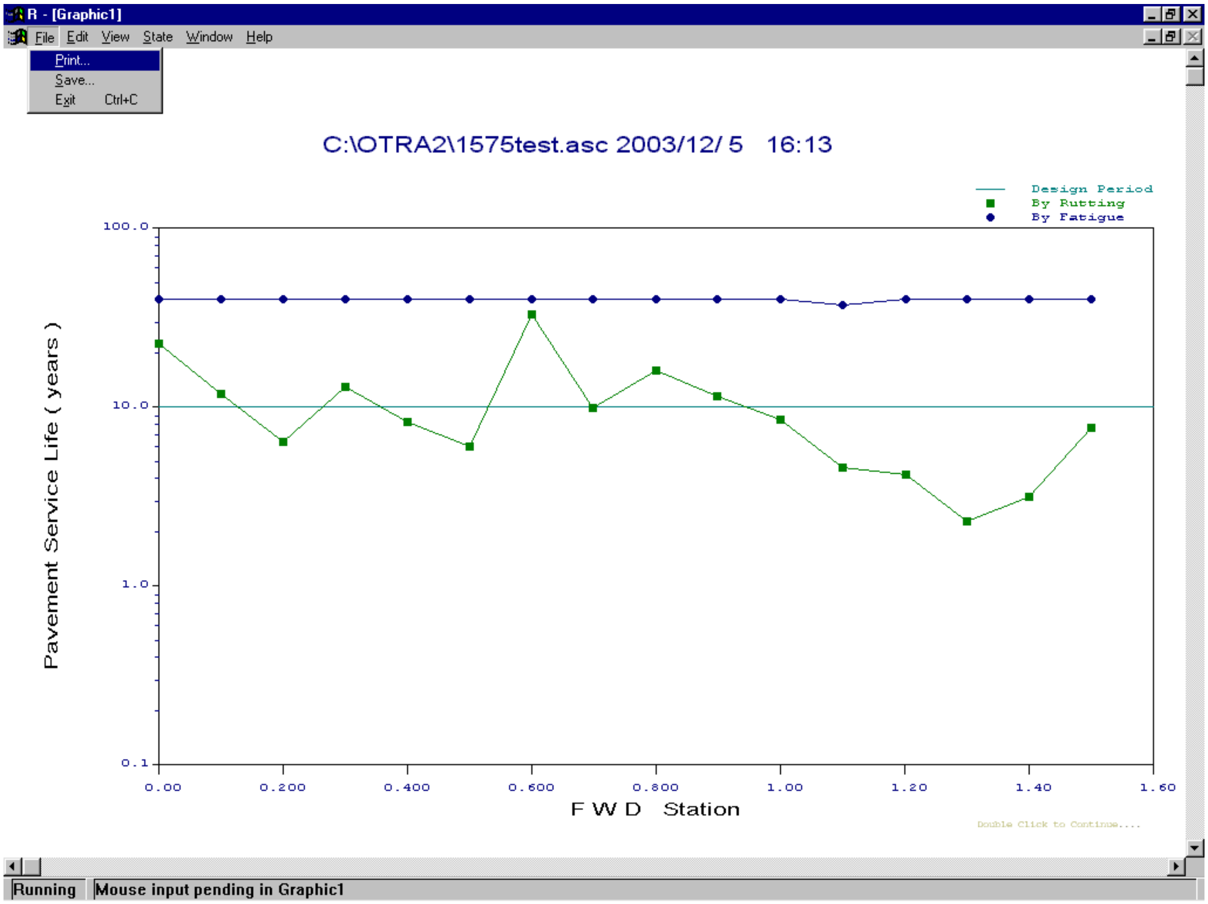


Figure 22. Using the *File* Function to Print or Save the Reliability Analysis Chart.

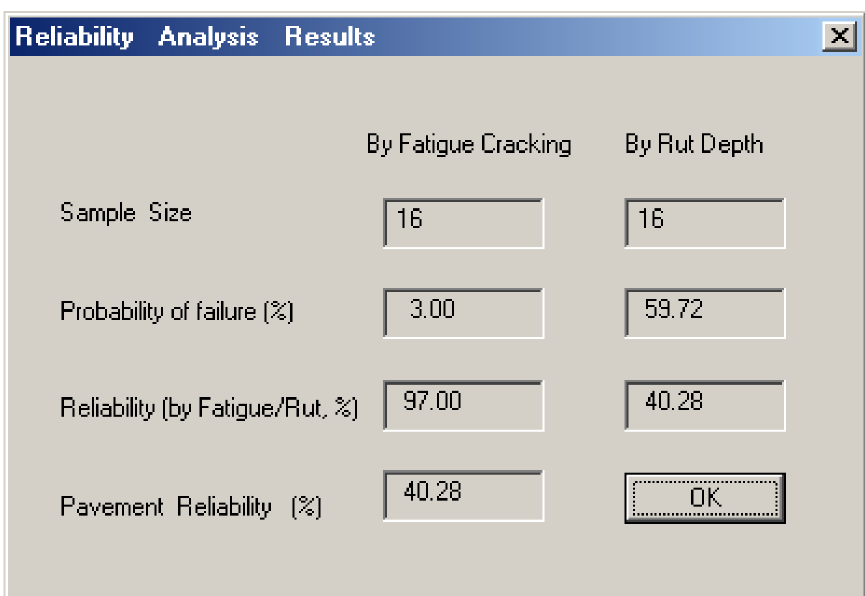


Figure 23. Screen Showing Computed Reliability Statistics.

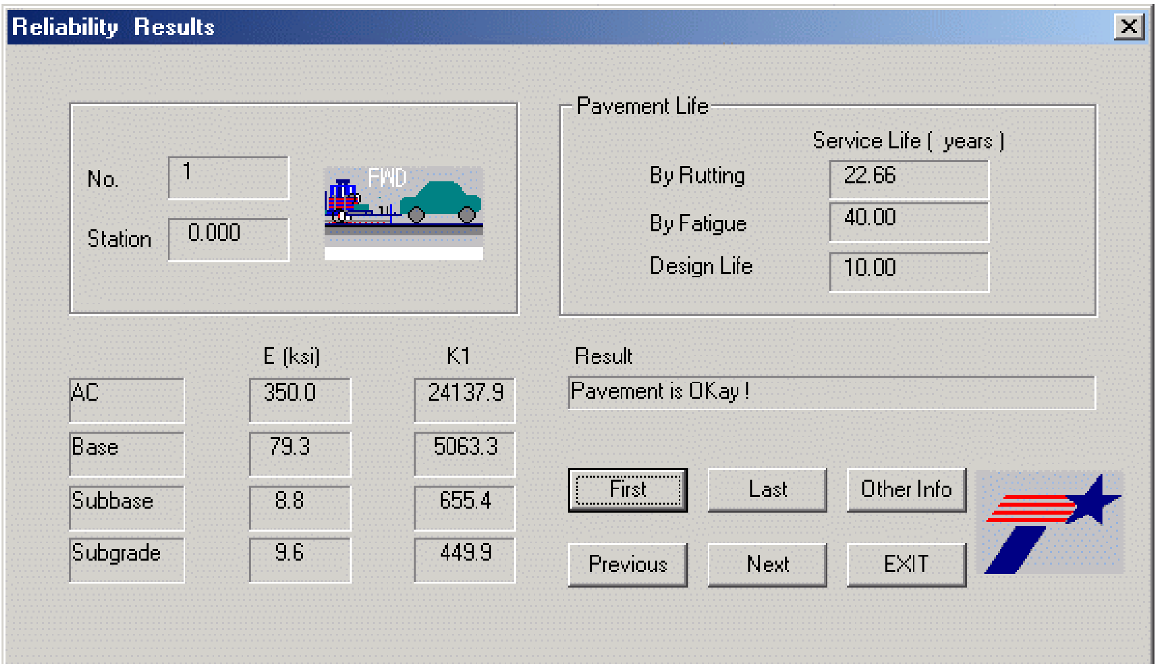


Figure 24. Data Displayed on Each FWD Station in the *List Results* Option.

predicted to fail during the prescribed design period, a message is displayed that shows the predicted mode of failure (fatigue cracking or rutting) at the given FWD test location.

The ***Other Info*** button in Figure 24 can be used to view other data that are common to all FWD stations selected for the analysis. Figure 25 identifies these other data. For each pavement layer, the thickness, Poisson's ratio, and K_2 and K_3 values display on the screen.

To save the results from the reliability analysis, click on the ***Write Results to File*** button of the menu given in Figure 13. A dialog box will be displayed for you to specify the name of the output file. By default, the output file is given the name of the MODULUS ASCII file, concatenated with the characters *REL*, as illustrated in Figure 26. The default file extension is *OUT*. After the output file is written to disk, it can be viewed on screen using the ***View & Print Output File*** option of the reliability analysis menu in Figure 13. The window illustrated in Figure 27 is then displayed. If this window displays in the background after clicking on the ***View & Print Output File*** button, simply click on any part of the window to bring it to the foreground.

At the top of the screen, the name of the MODULUS ASCII file and the date and time of analysis are reported to help identify a particular output. In addition, the following input data are echoed for verification purposes:

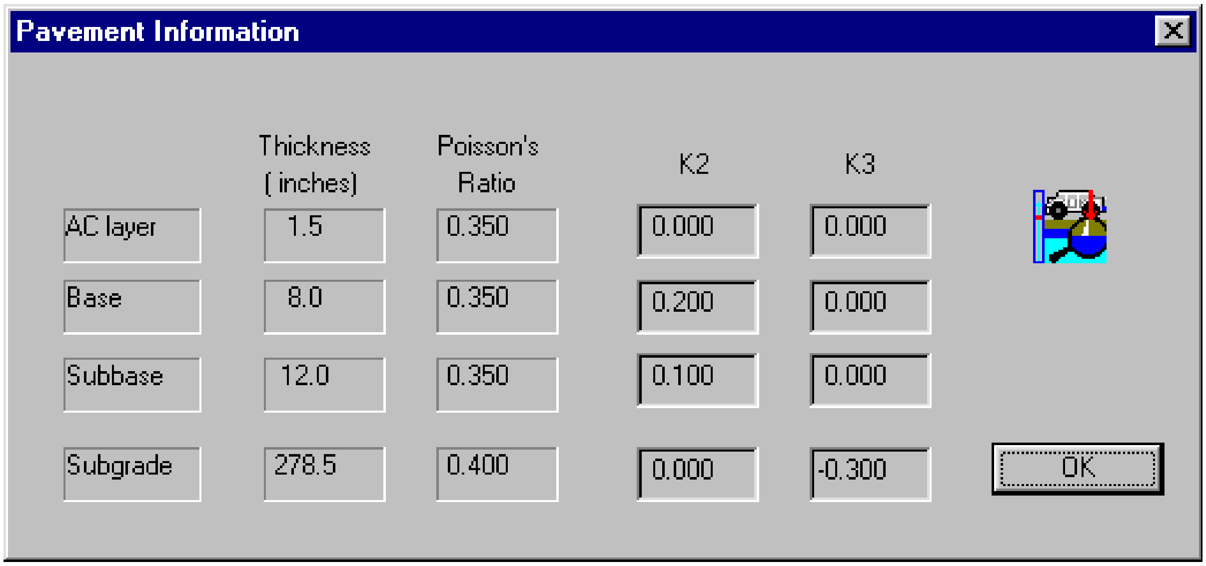


Figure 25. Pavement Data Common to All FWD Stations Displayed under the *List Results* Option.

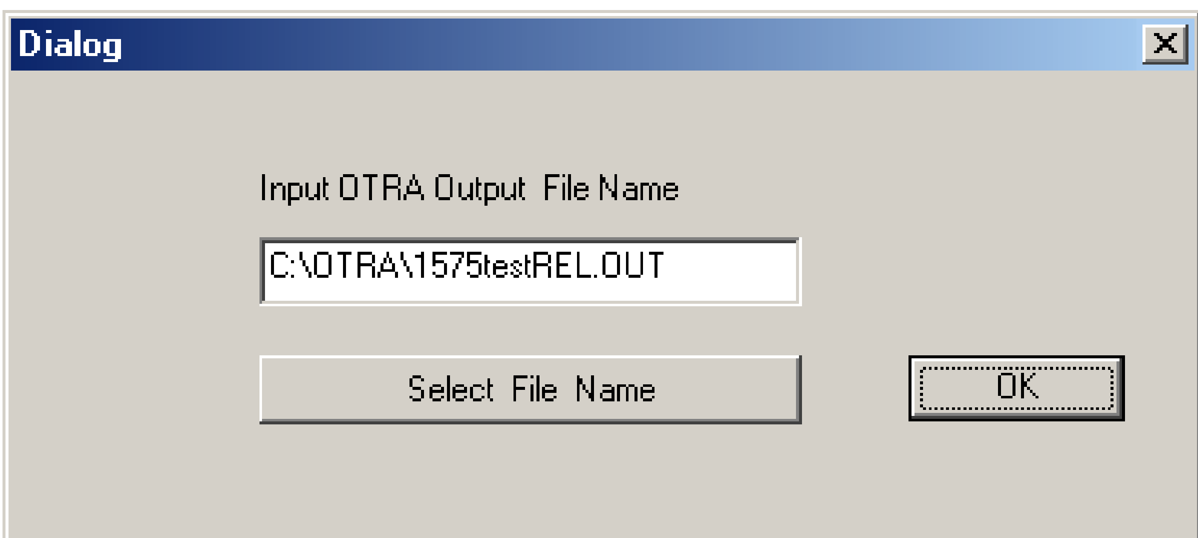
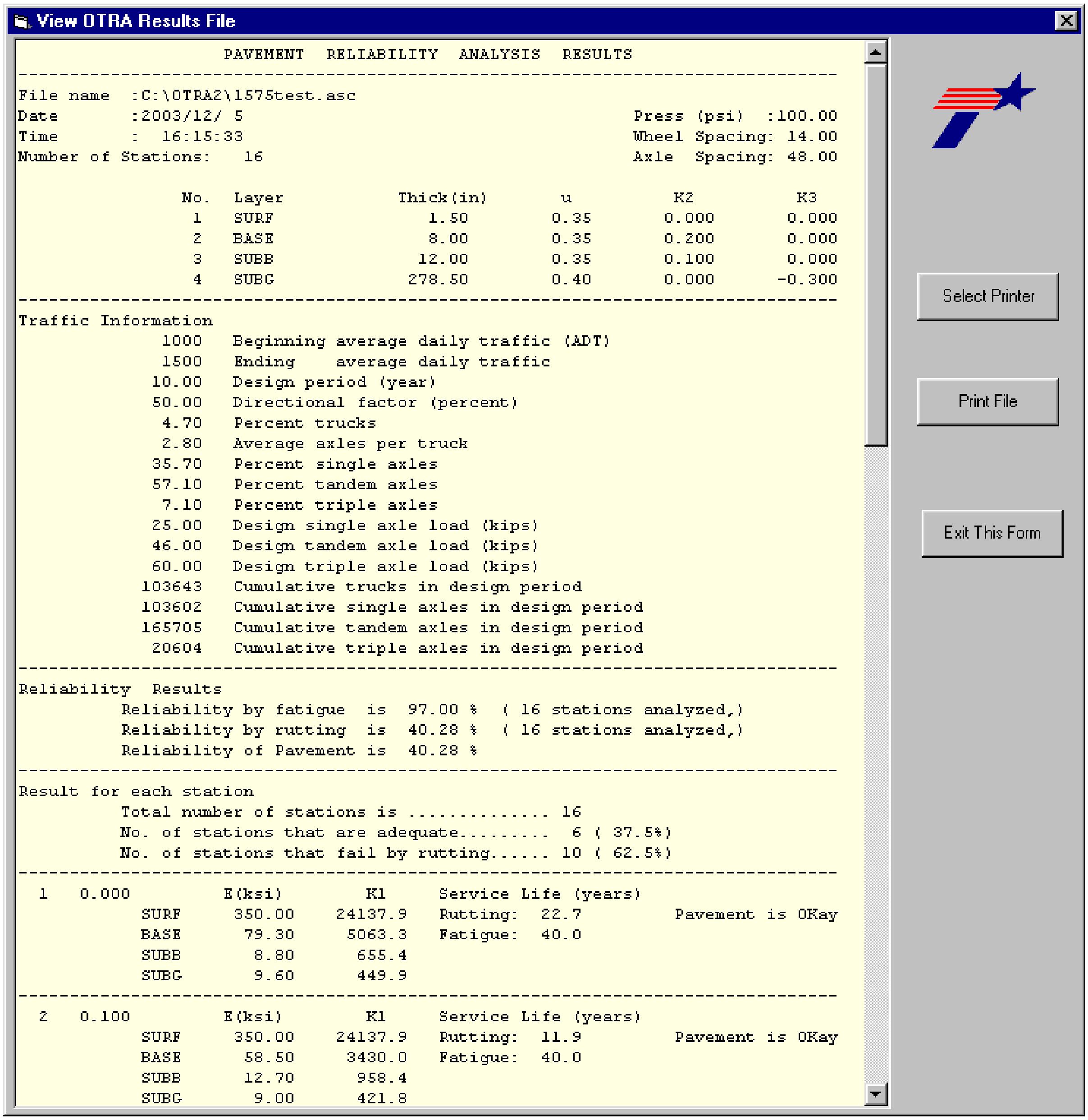


Figure 26. Dialog Box to Save Results from the Reliability Analysis.




```
                    PAVEMENT  RELIABILITY  ANALYSIS  RESULTS
--------------------------------------------------------------------------------
File name   :C:\OTRA2\1575test.asc
Date        :2003/12/ 5                                   Press (psi)  :100.00
Time        :  16:15:33                                   Wheel Spacing: 14.00
Number of Stations:   16                                  Axle  Spacing: 48.00

                No.  Layer           Thick(in)      u         K2          K3
                 1   SURF               1.50       0.35      0.000       0.000
                 2   BASE               8.00       0.35      0.200       0.000
                 3   SUBB              12.00       0.35      0.100       0.000
                 4   SUBG             278.50       0.40      0.000      -0.300
--------------------------------------------------------------------------------
Traffic Information
              1000   Beginning average daily traffic (ADT)
              1500   Ending    average daily traffic
             10.00   Design period (year)
             50.00   Directional factor (percent)
              4.70   Percent trucks
              2.80   Average axles per truck
             35.70   Percent single axles
             57.10   Percent tandem axles
              7.10   Percent triple axles
             25.00   Design single axle load (kips)
             46.00   Design tandem axle load (kips)
             60.00   Design triple axle load (kips)
            103643   Cumulative trucks in design period
            103602   Cumulative single axles in design period
            165705   Cumulative tandem axles in design period
             20604   Cumulative triple axles in design period
--------------------------------------------------------------------------------
Reliability  Results
          Reliability by fatigue  is  97.00 %  ( 16 stations analyzed,)
          Reliability by rutting  is  40.28 %  ( 16 stations analyzed,)
          Reliability of Pavement is  40.28 %
--------------------------------------------------------------------------------
Result for each station
          Total number of stations is .............. 16
          No. of stations that are adequate.........  6 ( 37.5%)
          No. of stations that fail by rutting...... 10 ( 62.5%)
--------------------------------------------------------------------------------
  1   0.000          E(ksi)         K1       Service Life (years)
            SURF      350.00     24137.9     Rutting:   22.7        Pavement is OKay
            BASE       79.30      5063.3     Fatigue:   40.0
            SUBB        8.80       655.4
            SUBG        9.60       449.9
--------------------------------------------------------------------------------
  2   0.100          E(ksi)         K1       Service Life (years)
            SURF      350.00     24137.9     Rutting:   11.9        Pavement is OKay
            BASE       58.50      3430.0     Fatigue:   40.0
            SUBB       12.70       958.4
            SUBG        9.00       421.8
```

Figure 27. Viewing the Output File from the Reliability Analysis.

1. pavement layer thicknesses,
2. the K_2 and K_3 parameters for each layer,
3. the number of FWD test locations analyzed,
4. the load geometry (dual tire spacing and axle spacing),
5. tire contact pressure, and
6. traffic data.

From the reliability analysis, the following results are also reported:

1. the computed reliability levels for both fatigue cracking and rutting criteria;
2. the reliability of the existing pavement, which is the minimum of the computed reliability statistics for fatigue cracking and rutting;
3. the number of test locations along the route where the pavement structure is predicted to be adequate for the specified axle loadings;
4. as applicable, the number of test locations where the pavement may experience failure within the prescribed design period based on fatigue cracking and/or rutting criteria; and
5. the backcalculated layer moduli, estimated K_1 values, and predicted service lives for the different FWD test locations analyzed.

You can use the vertical scroll bar of the output display window in Figure 27 to scroll up and down the output file. In addition, you can print the file by clicking on the ***Print File*** button to the right of the window. To use a particular printer, click on the ***Select Printer*** button before printing the output file. You will then be presented with the printer dialog box in Figure 28, which lists printers defined for your computer. Select the printer you want to use. You can also vary the printer settings within this dialog box. Simply go over the available options and make your selections. When done, go back to the output display window in Figure 27 and print the results by clicking on the ***Print File*** option. Figure 29 shows an example of the printed output that may be generated from evaluating the structural adequacy of an existing route using the OTRA program. Should the results show that the route is inadequate, the thickness of overlay required to achieve the desired level of reliability is determined using the ***Evaluate Overlay Thickness*** option of the main menu in Figure 12. The application of this program function is described in the succeeding chapter.

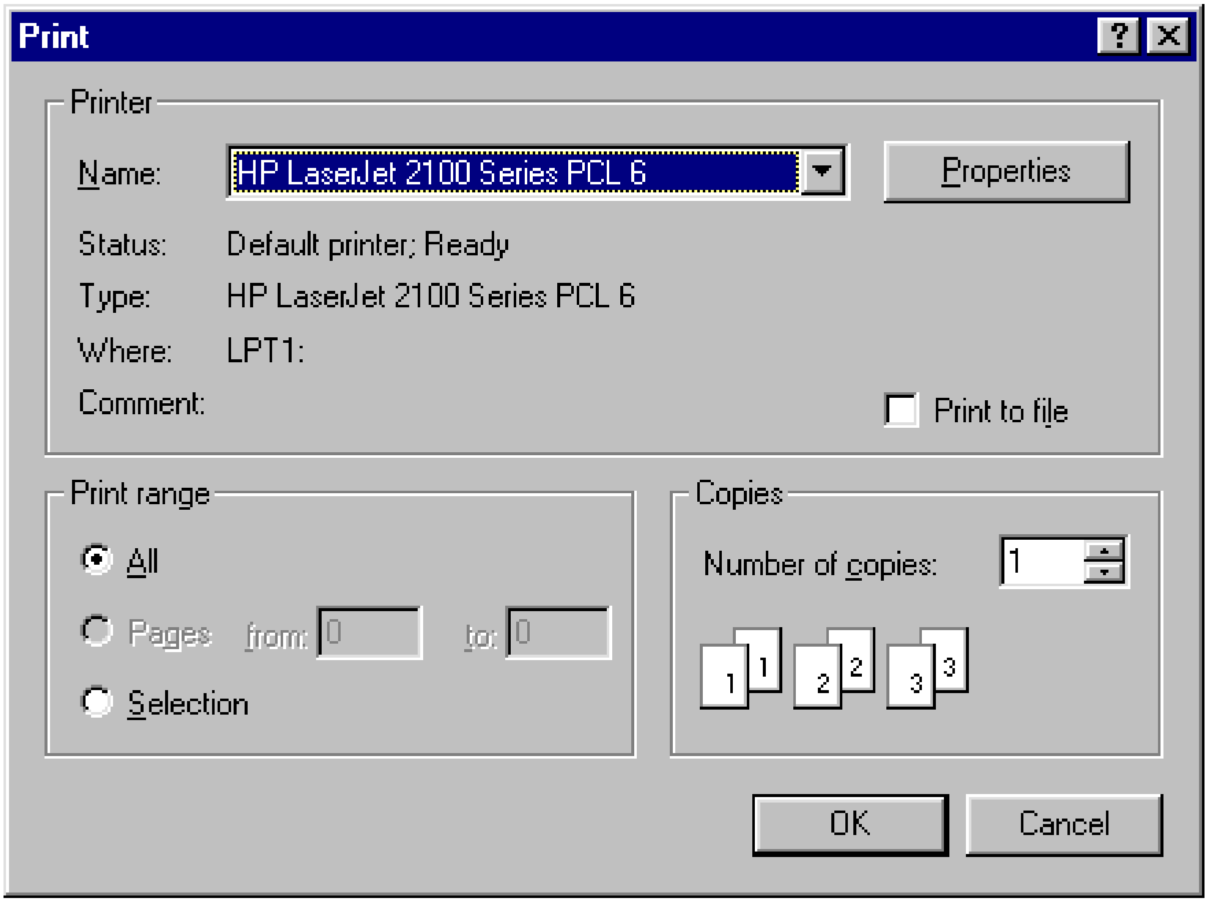


Figure 28. Printer Dialog Box.

Texas Department of Transportation

PAVEMENT RELIABILITY ANALYSIS RESULTS

File name :C:\OTRA2\1575test.asc

Date :2003/12/ 5
Time : 16:15:33
Number of Stations: 16

Press (psi) :100.00
Wheel Spacing: 14.00
Axle Spacing: 48.00

No.	Layer	Thick(in)	u	K2	K3
1	SURF	1.50	0.35	0.000	0.000
2	BASE	8.00	0.35	0.200	0.000
3	SUBB	12.00	0.35	0.100	0.000
4	SUBG	278.50	0.40	0.000	-0.300

Traffic Information

1000	Beginning average daily traffic (ADT)
1500	Ending average daily traffic
10.00	Design period (year)
50.00	Directional factor (percent)
4.70	Percent trucks
2.80	Average axles per truck
35.70	Percent single axles
57.10	Percent tandem axles
7.10	Percent triple axles
25.00	Design single axle load (kips)
46.00	Design tandem axle load (kips)
60.00	Design triple axle load (kips)
103643	Cumulative trucks in design period
103602	Cumulative single axles in design period
165705	Cumulative tandem axles in design period
20604	Cumulative triple axles in design period

Reliability Results

Reliability by fatigue is 97.00 % (16 stations analyzed,)
Reliability by rutting is 40.28 % (16 stations analyzed,)
Reliability of Pavement is 40.28 %

Result for each station

Total number of stations is 16
No. of stations that are adequate......... 6 (37.5%)
No. of stations that fail by rutting...... 10 (62.5%)

			E(ksi)	K1	Service Life (years)	
1	0.000					
		SURF	350.00	24137.9	Rutting: 22.7	Pavement is OKay
		BASE	79.30	5063.3	Fatigue: 40.0	
		SUBB	8.80	655.4		
		SUBG	9.60	449.9		

			E(ksi)	K1	Service Life (years)	
2	0.100					
		SURF	350.00	24137.9	Rutting: 11.9	Pavement is OKay
		BASE	58.50	3430.0	Fatigue: 40.0	
		SUBB	12.70	958.4		
		SUBG	9.00	421.8		

			E(ksi)	K1	Service Life (years)	
3	0.200					
		SURF	350.00	24137.9	Rutting: 6.4	Fails by rutting
		BASE	45.00	2778.1	Fatigue: 40.0	
		SUBB	7.90	586.7		
		SUBG	8.00	374.9		

			E(ksi)	K1	Service Life (years)	
4	0.300					
		SURF	350.00	24137.9	Rutting: 13.1	Pavement is OKay
		BASE	65.60	4157.1	Fatigue: 40.0	
		SUBB	8.90	668.3		
		SUBG	8.70	407.7		

Texas Transportation Institute print Time: 12/5/03 4:18:05 PM Page : 1

Figure 29. Sample Printout of Reliability Analysis Results.

Texas Department of Transportation

PAVEMENT RELIABILITY ANALYSIS RESULTS

			E(ksi)	K1	Service Life (years)	
5	0.400		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 8.3	Fails by rutting
		BASE	43.60	2616.9	Fatigue: 40.0	
		SUBB	9.40	697.7		
		SUBG	8.90	417.1		
6	0.500		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 6.0	Fails by rutting
		BASE	37.50	2221.6	Fatigue: 40.0	
		SUBB	9.20	681.3		
		SUBG	8.50	398.3		
7	0.601		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 33.1	Pavement is OKay
		BASE	93.10	5265.9	Fatigue: 40.0	
		SUBB	21.00	1635.0		
		SUBG	10.40	487.4		
8	0.699		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 10.0	Fails by rutting
		BASE	43.10	2571.0	Fatigue: 40.0	
		SUBB	9.70	717.2		
		SUBG	9.50	445.2		
9	0.800		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 16.1	Pavement is OKay
		BASE	46.80	2647.5	Fatigue: 40.0	
		SUBB	14.00	1035.4		
		SUBG	10.80	506.1		
10	0.900		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 11.5	Pavement is OKay
		BASE	41.40	2313.9	Fatigue: 40.0	
		SUBB	15.30	1143.7		
		SUBG	10.00	468.6		
11	1.001		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 8.5	Fails by rutting
		BASE	51.10	3208.8	Fatigue: 40.0	
		SUBB	8.10	604.7		
		SUBG	8.30	389.0		
12	1.100		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 4.6	Fails by rutting
		BASE	27.50	1563.4	Fatigue: 37.4	
		SUBB	10.10	741.1		
		SUBG	8.80	412.4		
13	1.202		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 4.2	Fails by rutting
		BASE	41.90	2534.6	Fatigue: 40.0	
		SUBB	9.30	704.0		
		SUBG	7.20	337.4		
14	1.301		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 2.3	Fails by rutting
		BASE	29.20	1883.5	Fatigue: 40.0	
		SUBB	5.20	386.4		
		SUBG	6.50	304.6		
15	1.401		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 3.1	Fails by rutting
		BASE	34.50	2226.2	Fatigue: 40.0	
		SUBB	5.70	424.2		
		SUBG	6.80	318.7		
16	1.500		E(ksi)	K1	Service Life (years)	
		SURF	350.00	24137.9	Rutting: 7.7	Fails by rutting
		BASE	40.30	2424.8	Fatigue: 40.0	
		SUBB	8.90	658.8		
		SUBG	8.90	417.1		

Texas Transportation Institute print Time: 12/5/03 4:18:05 PM Page : 2

Figure 29. Sample Printout of Reliability Analysis Results (continued).

CHAPTER III

EVALUATING OVERLAY THICKNESS

Figure 30 shows the menu for evaluating overlay thickness in the OTRA program. There are six options available from this menu:

1. ***Input Minimum Reliability***,
2. ***Input Load***,
3. ***Run Overlay Analysis***,
4. ***Write Results to File***,
5. ***View & Print Output File***, and
6. ***Exit to Main Menu***.

The first two options are used to establish the minimum reliability required of the route, the design single, tandem, and triple axle loads, and the cumulative axle load applications for each axle configuration. The third option runs the analysis to determine overlay thickness requirements that satisfy the prescribed level of reliability. When this analysis is completed, the results can be saved, viewed, or printed using Options 4 and 5. The steps in the overlay analysis are further described in the following sections.

INPUT SCREENS FOR OVERLAY ANALYSIS

Before overlay thickness requirements can be evaluated, you should first specify the minimum reliability required of the route. Click on the ***Input Minimum Reliability*** button of the overlay analysis menu in Figure 30. The user-interface screen in Figure 31 will then be displayed, which shows the computed reliability levels for both fatigue and rutting criteria and the existing pavement reliability. The sample size reported in the figure refers to the number of FWD stations along the route that were used in calculating the existing pavement reliability.

To evaluate overlay thickness requirements along the route, specify on the user-interface screen shown in Figure 31 the minimum reliability level that you want to achieve. Obviously, this must be greater than the existing pavement reliability; otherwise, no overlay analysis is necessary.

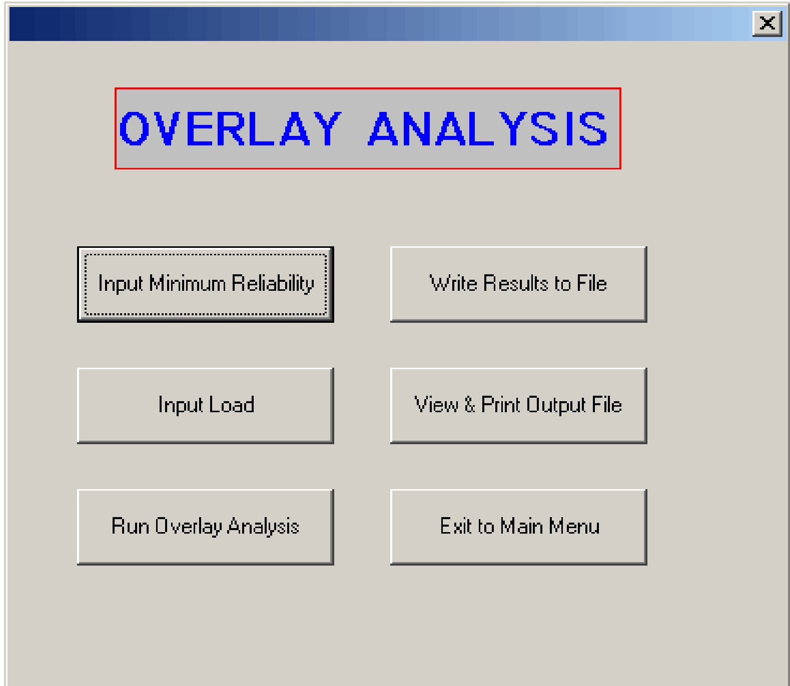


Figure 30. Overlay Analysis Menu.

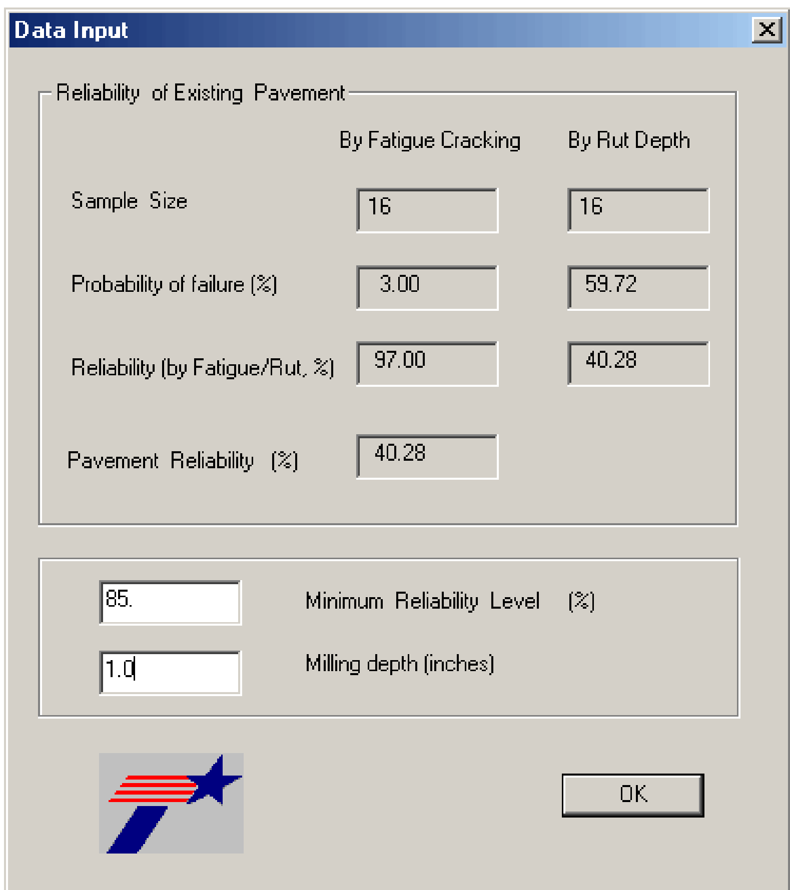


Figure 31. Data Input Screen to Specify Minimum Reliability Level.

Additionally, you can specify a depth of milling on the screen shown in Figure 31. This depth can range from zero (no milling) to the thickness of the existing asphalt concrete layer. After specifying the desired reliability level and the milling depth, click on the ***OK*** button of the dialog box to return to the overlay analysis menu.

The cumulative axle load applications used in the analysis are defined by clicking on the ***Input Load*** button of this menu. This action will bring up the screen shown in Figure 32. The data displayed on this screen are those used in the previous overlay analysis. Note that the traffic information need not necessarily correspond to the same traffic data specified in the most recent reliability analysis. If you want to use the traffic data from this analysis, simply click on the ***Use Reliability Traffic Data*** button at the bottom of the screen in Figure 32. This will update the traffic information so that the data are the same as those specified in the most recent reliability analysis. In addition, the cumulative axle load applications will update so that the values displayed correspond to the traffic information.

The traffic data, design axle loads, and cumulative axle load applications in Figure 32 can be changed by the user. Thus, you can specify values for the cumulative load applications that are different from those calculated using the traffic data. In this case, the cumulative load applications will have the label *User Input* in the overlay analysis output. The data in Figure 32 can also differ from the corresponding data used in the previous reliability analysis. For consistency, the overlay analysis first computes the reliability of the existing pavement for the given data in Figure 32. If this reliability is less than the prescribed minimum, the program evaluates overlay thickness.

RUNNING THE OVERLAY ANALYSIS

To evaluate the overlay thickness required for the prescribed level of reliability and the specified load parameters, click on ***Run Overlay Analysis*** in the menu given in Figure 30. You will then be prompted for the settings of two parameters that control the number of iterations the program goes through to determine the overlay thickness that satisfies the prescribed minimum reliability. These two parameters are specified on the screen shown in Figure 33. One parameter is the tolerance between the calculated reliability and the required minimum. If the former differs from the latter by more than this tolerance, additional iterations are performed until the magnitude of the difference is within the tolerance specified in the screen shown in Figure 33.

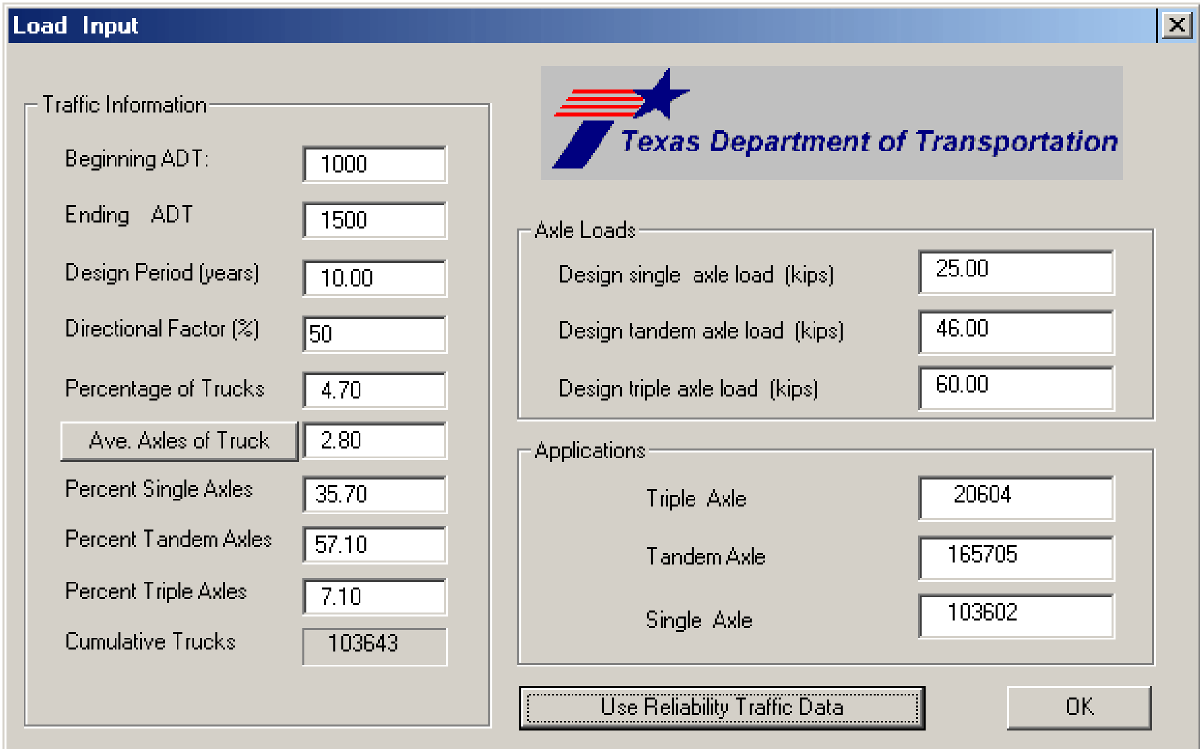


Figure 32. Menu to Specify Traffic Data and Design Axle Load Magnitudes and Repetitions for the Overlay Analysis.

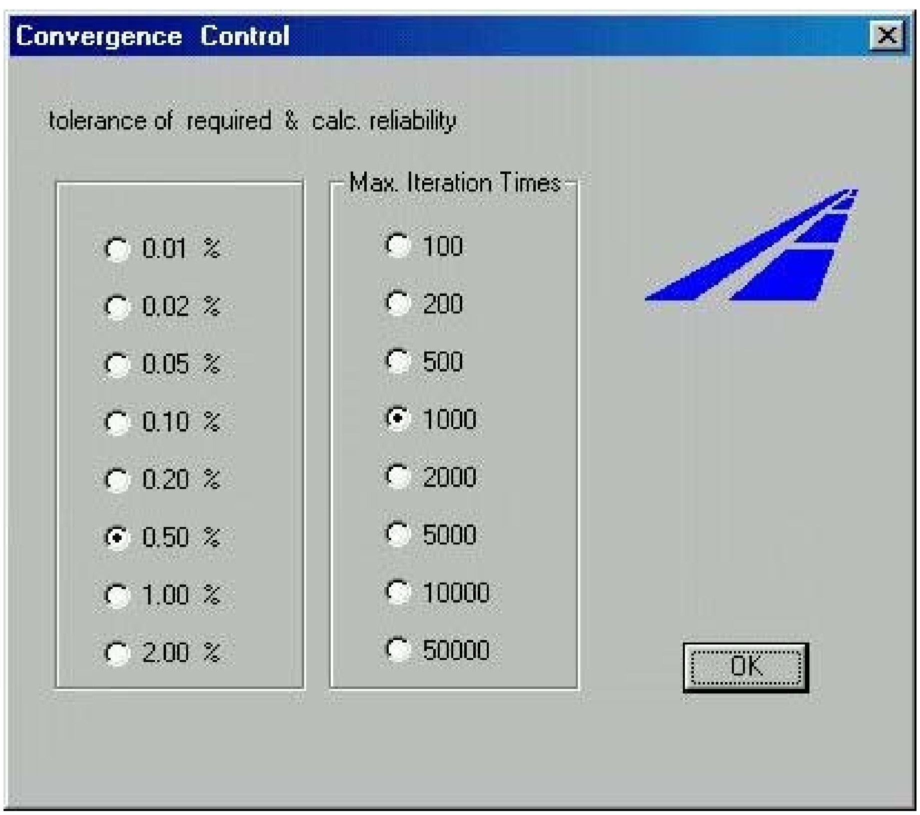


Figure 33. Screen to Specify Run Parameters to Control Number of Iterations in the Overlay Analysis.

By default, this parameter is set to 0.5 percent. The other parameter controls the number of iterations to achieve stress-compatible moduli values when one or more pavement layers are characterized as nonlinear. This parameter was explained in the previous chapter. By default, the limit on the number of iterations for convergence of stress dependent moduli is 1000.

To proceed with the analysis, click on the ***OK*** button of the menu in Figure 33. The trial overlay thickness for each iteration is displayed on screen during the analysis, along with the corresponding level of reliability. Figure 34 illustrates the run-time screen of the overlay analysis. At the end of the analysis, the menu shown in Figure 30 is again displayed. From this menu, you can save, view, or print the results.

SAVING AND PRINTING OVERLAY ANALYSIS RESULTS

To save your results from the last run, click on ***Write Results to File*** in the overlay analysis menu. A dialog box will then be displayed for you to specify the name of the output file. By default, this name is formed by concatenating the MODULUS ASCII file name with the characters *LOD*, as illustrated in Figure 35. In this figure, the MODULUS ASCII file is identified as *C:\OTRA\1575test*. The default extension for the output file is *OUT*. You can accept the default output file name or type a new name in the input field of the dialog box in Figure 35. Alternatively, you may click on ***Select File Name*** in the box to look at the files on your computer's hard disk and select an existing file to write the output to.

After saving the results to a file, you can view this file on screen by clicking on the ***View & Print Output File*** button of the overlay analysis menu. OTRA then displays the screen shown in Figure 36 (you may have to click on the output screen to bring it to the foreground). At the top of the screen, the name of the MODULUS ASCII file and the date and time of analysis are reported to help identify a particular output. In addition, the following data that were input to the analysis are reported:

1. pavement layer thicknesses,
2. the K_2 and K_3 parameters for each layer,
3. the number of FWD test locations analyzed,
4. the load geometry (dual tire spacing and axle spacing),
5. assumed tire contact pressure,

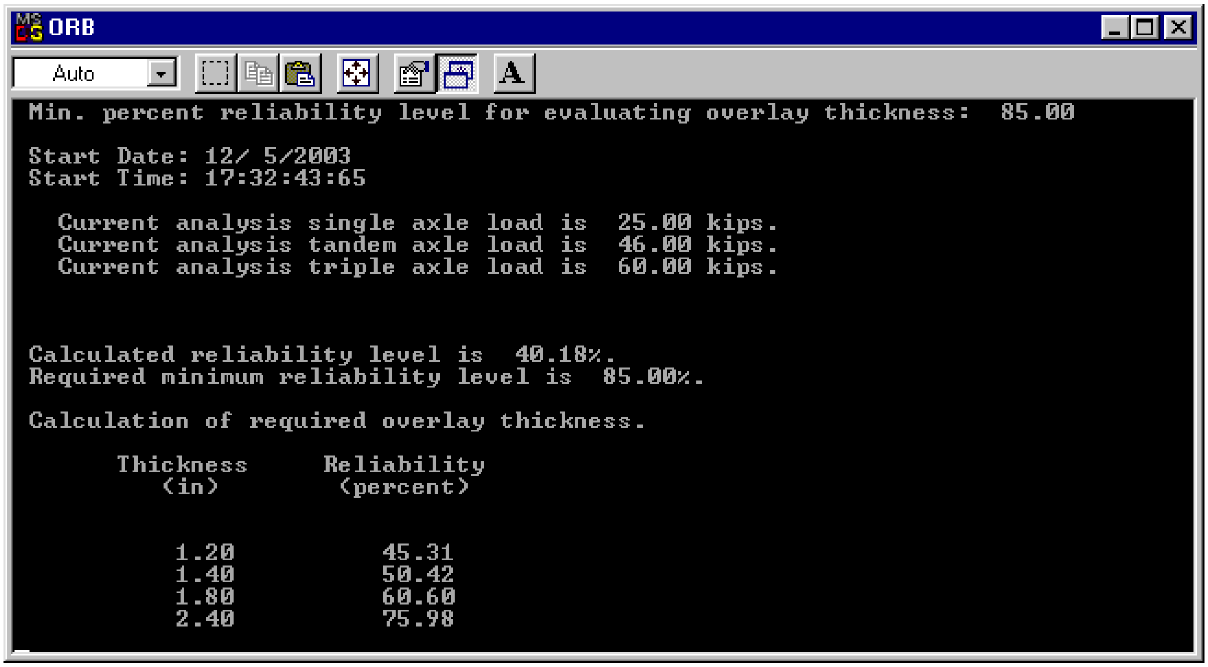


Figure 34. Run-Time Screen Displayed during Overlay Analysis.

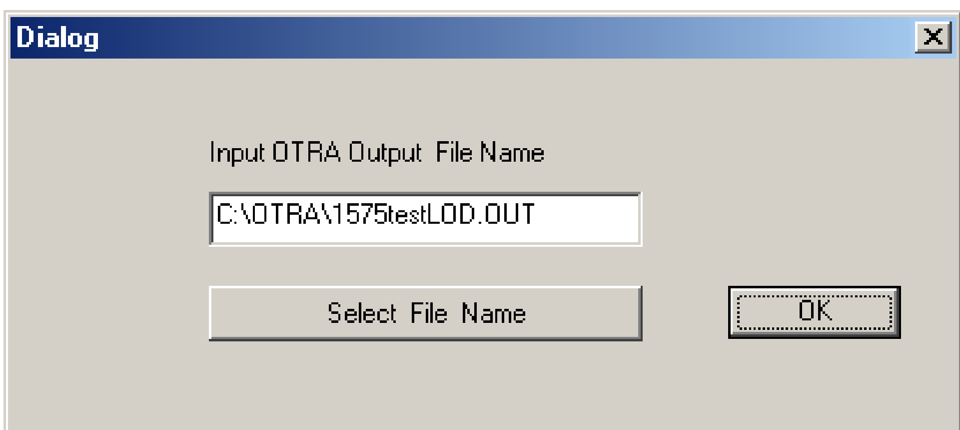


Figure 35. Dialog Box for Specifying Name of Output File from Overlay Analysis.

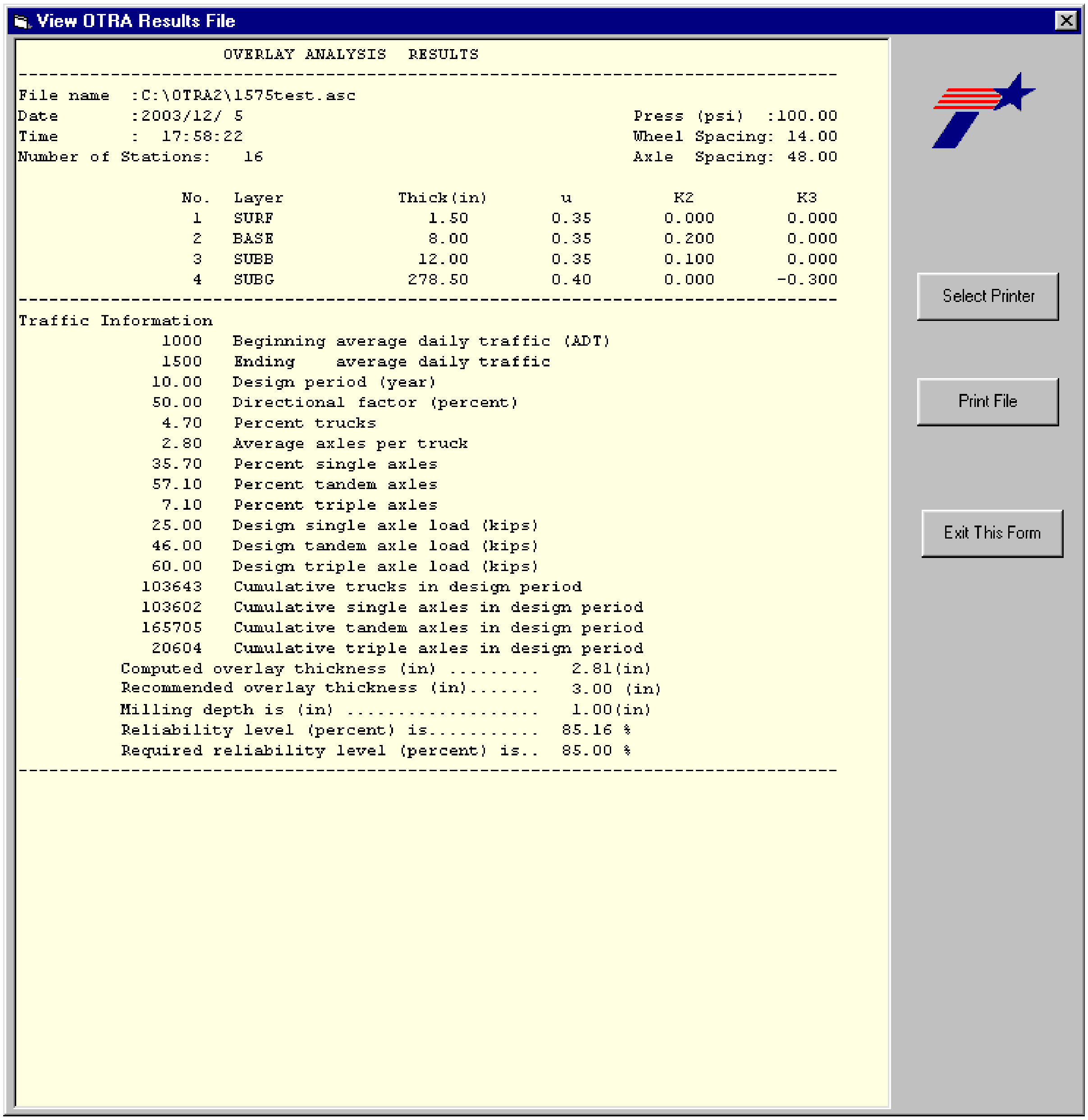


Figure 36. Window for Viewing and Printing Overlay Analysis Results.

6. traffic data,
7. the minimum required reliability for determining overlay thickness, and
8. the specified milling depth.

From the analysis, the following results are also reported:

1. the reliability level corresponding to the computed overlay thickness,
2. the computed and recommended overlay thicknesses, and
3. the estimated cumulative number of applications for each axle load.

The recommended overlay thickness is the computed thickness rounded to the nearest half-inch. You can print the output displayed by clicking on the ***Print File*** button, which will print the output to the default printer. You can select another printer by clicking on the ***Select Printer*** button of the screen shown in Figure 36. This will bring up the printer dialog box from where you can specify another printer and change printer settings as desired. After you have made your selections, click on the ***OK*** button of the printer dialog box to return to the output screen in Figure 36. Then click on ***Print File*** to get a hard copy of the overlay analysis results. Figure 37 illustrates a sample printout from the program.

Texas Department of Transportation

OVERLAY ANALYSIS RESULTS

File name :C:\OTRA2\1575test.asc

```
Date        :2003/12/ 5                                   Press (psi)   :100.00
Time        :  17:58:22                                   Wheel Spacing: 14.00
Number of Stations:   16                                  Axle  Spacing: 48.00
```

No.	Layer	Thick(in)	u	K2	K3
1	SURF	1.50	0.35	0.000	0.000
2	BASE	8.00	0.35	0.200	0.000
3	SUBB	12.00	0.35	0.100	0.000
4	SUBG	278.50	0.40	0.000	-0.300

Traffic Information

1000	Beginning average daily traffic (ADT)
1500	Ending average daily traffic
10.00	Design period (year)
50.00	Directional factor (percent)
4.70	Percent trucks
2.80	Average axles per truck
35.70	Percent single axles
57.10	Percent tandem axles
7.10	Percent triple axles
25.00	Design single axle load (kips)
46.00	Design tandem axle load (kips)
60.00	Design triple axle load (kips)
103643	Cumulative trucks in design period
103602	Cumulative single axles in design period
165705	Cumulative tandem axles in design period
20604	Cumulative triple axles in design period

```
Computed overlay thickness (in) .........   2.81(in)
Reccommended overlay thickness (in) .....   3.00(in)
Milling depth is (in) ..................   1.00(in)
Reliability level (percent) is..........  85.16 %
Required reliability level (percent) is..  85.00 %
```

Texas Transportation Institute   print Time: 12/5/03 5:59:54 PM   Page : 1

Figure 37. Sample Printout of Results from Overlay Analysis.

REFERENCES

American Association of State Highway and Transportation Officials. *AASHTO Guide for Design of Pavement Structures.* Washington, D.C., 1993.

Asphalt Institute. *Research and Development of the Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition*. Research Report No. 82-2, Asphalt Institute, Lexington, Ky., 1982.

Fernando, E. G., and T. Chua. *Development of a Route Segmentation Procedure Using Predicted Layer Thicknesses from Radar Measurements*. Proceedings, Fifth International Conference on Ground Penetrating Radar, Vol. 1, Ontario, Canada, 1994, pp. 335–349.

Fernando, E. G., and W. Liu. *Development of an Analysis Procedure for Load-Zoning Pavements.* Research Report 2123-2, Texas Transportation Institute, Texas A&M University, College Station, Tex., 2001.

Fernando, E. G., and W. Liu. *Program for Load-Zoning Analysis (PLZA): User's Guide.* Research Report 2123-1, Texas Transportation Institute, Texas A&M University, College Station, Tex., 1999.

Fernando, E. G., W. Liu, and D. Ryu. *Development of a Procedure for Temperature Correction of Backcalculated AC Modulus.* Research Report 1863-1, Texas Transportation Institute, Texas A&M University, College Station, Tex., 2001.

Glover, L. T., and E. G. Fernando. *Evaluation of Pavement Base and Subgrade Material Properties and Test Procedures.* Research Report 1335-2, Texas Transportation Institute, Texas A&M University, College Station, Tex., 1995.

Jooste, F. J., and E. G. Fernando. *Development of a Procedure for the Structural Evaluation of Superheavy Load Routes*. Research Report 1335-3F, Texas Transportation Institute, Texas A&M University, College Station, Tex., 1995.

Lytton, R. L., J. Uzan, E. G. Fernando, R. Roque, D. Hiltunen, and S. M. Stoffels. *Development and Validation of Performance Prediction Models and Specifications for Asphalt Binders and Paving Mixes*. SHRP-A-357, Strategic Highway Research Program, National Research Council, Washington, D.C., 1993.

Michalak, C. H., and T. Scullion. *MODULUS 5.0: User's Manual*. Research Report 1987-1, Texas Transportation Institute, Texas A&M University, College Station, Tex., 1995.

Miner, M. A. *Cumulative Damage in Fatigue*. Journal of Applied Mechanics, Vol. 12, No. 1, 1945.

Texas Department of Transportation. *Falling Weight Deflectometer Operator's Manual.* Austin, Tex., 1996.

Uzan, J. *Granular Material Characterization.* Transportation Research Record 1022, Transportation Research Board, Washington, D.C., 1985, pp. 52–59.

APPENDIX
FORMATS OF OTRA RUN-TIME FILES

FILES CREATED AFTER DATA PREPARATION STEP

OTR1.INP (Figure A1)

1. First record - number of FWD test locations selected for analysis and name of MODULUS output file containing backcalculated layer moduli for the route or segment under investigation. This MODULUS output file is used as input to the OTRA software.
2. For each FWD test location, the following data are given:
   a) number of pavement layers and distance of test location from start of FWD measurements (one record);
   b) then, for each pavement layer, the following data are given (one record per layer): backcalculated layer modulus, Poisson's ratio, layer thickness, and K_2 and K_3 coefficients. For the surface layer, the pavement temperature is given as the last entry of the record if temperature corrections were specified. Otherwise, the text *No Correct* is written at the end of the record;
   c) FWD load and plate radius.

OTR1.OUT (Figure A2)

1. First record - number of FWD test locations selected for analysis;
2. For each FWD test location, the following data are given:
   a) number of pavement layers (one record);
   b) for each layer, the calculated K_1 coefficient is given (one record per layer).

FILES CREATED AFTER RELIABILITY ANALYSIS

OTR2.INP (Figure A3)

1. First record - number of FWD test locations selected for analysis;
2. For each FWD test location, the following data are given:

```
  16    C:\OTRA2\1575test.asc

       4      0.000
350000.0    0.35    1.50  0.0000  0.0000  No Correct
 79300.0    0.35    8.00  0.2000  0.0000
  8800.0    0.35   12.00  0.1000  0.0000
  9600.0    0.40  278.50  0.0000 -0.3000
    9775  5.91
       4      0.100
350000.0    0.35    1.50  0.0000  0.0000  No Correct
 58500.0    0.35    8.00  0.2000  0.0000
 12700.0    0.35   12.00  0.1000  0.0000
  9000.0    0.40  278.50  0.0000 -0.3000
    9827  5.91
       4      0.200
350000.0    0.35    1.50  0.0000  0.0000  No Correct
 45000.0    0.35    8.00  0.2000  0.0000
  7900.0    0.35   12.00  0.1000  0.0000
  8000.0    0.40  278.50  0.0000 -0.3000
    9644  5.91
```

Figure A1. Illustration of OTR1.INP File Showing Data for First Three Stations.

```
        16
         4
  24137.93
  5063.302
  655.3646
  449.8947
         4
  24137.93
  3429.978
  958.4162
  421.7762
         4
  24137.93
  2778.055
  586.6757
  374.9122
```

Figure A2. Illustration of OTR1.OUT File Showing Data for First Three Stations.

```
      16
       4     0.000
350000.0      0.35      1.50   24137.9     0.000     0.000
 79300.0      0.35      8.00    5063.3     0.200     0.000
  8800.0      0.35     12.00     655.4     0.100     0.000
  9600.0      0.40    278.50     449.9     0.000    -0.300
  4500.0    100.00     14.00     48.00
       4     0.100
350000.0      0.35      1.50   24137.9     0.000     0.000
 58500.0      0.35      8.00    3430.0     0.200     0.000
 12700.0      0.35     12.00     958.4     0.100     0.000
  9000.0      0.40    278.50     421.8     0.000    -0.300
  4500.0    100.00     14.00     48.00
       4     0.200
350000.0      0.35      1.50   24137.9     0.000     0.000
 45000.0      0.35      8.00    2778.1     0.200     0.000
  7900.0      0.35     12.00     586.7     0.100     0.000
  8000.0      0.40    278.50     374.9     0.000    -0.300
  4500.0    100.00     14.00     48.00
```

Figure A3. Illustration of OTR2.INP File Showing Data for First Three Stations.

a) number of pavement layers and distance of test location from start of FWD measurements (one record);

b) then, for each pavement layer, the following data are given (one record per layer): backcalculated layer modulus, Poisson's ratio, layer thickness, and K_1, K_2, and K_3 coefficients;

c) wheel load for standard 18-kip single axle, tire contact pressure, dual tire spacing, and axle spacing (one record).

OTR2B.OUT (Figure A4)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
    a) run number (one record);
    b) for each axle configuration, the following data are given (one record per axle type, i.e., single, tandem, and triple, beginning with the single axle): maximum horizontal strain at the bottom of the surface layer, maximum vertical strain at the top of the subgrade, and surface layer modulus.

```
         16
          1
6.3586191E-07
5.5499159E-04
 350000.0
3.6088273E-05
5.1219342E-04
 350000.0
3.5356847E-05
4.4316665E-04
 350000.0
          2
5.7817553E-05
6.4022426E-04
 350000.0
6.0276579E-05
5.9280935E-04
 350000.0
8.0405422E-05
5.1471003E-04
 350000.0
          3
9.2656024E-05
7.3780766E-04
 350000.0
1.0010790E-04
6.7768915E-04
 350000.0
1.1883802E-04
5.8743660E-04
 350000.0
```

Figure A4. Illustration of OTR2B.OUT File Showing Data for First Three Stations.

OTR2B.$$$ (annotated file illustrated in Figure A5)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
    a) predicted number of allowable applications of design single axle load based on fatigue cracking and rutting criteria (one record);
    b) predicted number of allowable applications of design tandem axle load based on fatigue cracking and rutting criteria (one record);
    c) predicted number of allowable applications of design triple axle load based on fatigue cracking and rutting criteria (one record);
3. Expected cumulative applications of design single axle load during design period (one record);

```
        16    No. of stations analyzed
 0.3569E+15  0.5140E+06    1 fatigue & rut
 0.6052E+09  0.7362E+06    2 fatigue & rut
 0.6474E+09  0.1408E+07    3 fatigue & rut
 0.1284E+09  0.2711E+06    1 fatigue & rut
 0.1119E+09  0.3826E+06    2 fatigue & rut
 0.4338E+08  0.7202E+06    3 fatigue & rut
 0.2721E+08  0.1437E+06    1 fatigue & rut
 0.2109E+08  0.2102E+06    2 fatigue & rut
 0.1200E+08  0.3986E+06    3 fatigue & rut
 0.1942E+10  0.2977E+06    1 fatigue & rut
 0.1006E+10  0.4241E+06    2 fatigue & rut
 0.3090E+09  0.8034E+06    3 fatigue & rut
 0.1739E+08  0.1868E+06    1 fatigue & rut
 0.1312E+08  0.2731E+06    2 fatigue & rut
 0.8074E+07  0.5148E+06    3 fatigue & rut
 0.7155E+07  0.1361E+06    1 fatigue & rut
 0.5101E+07  0.1965E+06    2 fatigue & rut
 0.3621E+07  0.3711E+06    3 fatigue & rut
 0.2825E+12  0.7876E+06    1 fatigue & rut
 0.6418E+10  0.1032E+07    2 fatigue & rut
 0.3105E+10  0.1968E+07    3 fatigue & rut
 0.1490E+08  0.2224E+06    1 fatigue & rut
 0.1121E+08  0.3295E+06    2 fatigue & rut
 0.7288E+07  0.6216E+06    3 fatigue & rut
 0.1665E+08  0.3619E+06    1 fatigue & rut
 0.1236E+08  0.5250E+06    2 fatigue & rut
 0.7828E+07  0.9827E+06    3 fatigue & rut
 0.8562E+07  0.2603E+06    1 fatigue & rut
 0.5968E+07  0.3746E+06    2 fatigue & rut
 0.4138E+07  0.6914E+06    3 fatigue & rut
 0.8161E+08  0.1918E+06    1 fatigue & rut
 0.7166E+08  0.2783E+06    2 fatigue & rut
 0.3098E+08  0.5275E+06    3 fatigue & rut
 0.1221E+07  0.1037E+06    1 fatigue & rut
 0.1040E+07  0.1529E+06    2 fatigue & rut
 0.8795E+06  0.2865E+06    3 fatigue & rut
 0.1680E+08  0.9555E+05    1 fatigue & rut
 0.1201E+08  0.1356E+06    2 fatigue & rut
 0.7427E+07  0.2564E+06    3 fatigue & rut
 0.2883E+07  0.5078E+05    1 fatigue & rut
 0.2203E+07  0.7593E+05    2 fatigue & rut
 0.1716E+07  0.1424E+06    3 fatigue & rut
 0.7420E+07  0.7039E+05    1 fatigue & rut
 0.5322E+07  0.1036E+06    2 fatigue & rut
 0.3747E+07  0.1958E+06    3 fatigue & rut
 0.1100E+08  0.1707E+06    1 fatigue & rut
 0.8180E+07  0.2530E+06    2 fatigue & rut
 0.5455E+07  0.4754E+06    3 fatigue & rut
  103602.000000000         Expected cumulative single axle loads
  165705.000000000         Expected cumulative tandem axle loads
  20604.0000000000         Expected cumulative triple axle loads
  10.0000000000000         Design period (years)
        16    No. of FWD stations with fatigue pred.
 3.002266804682352E-002  0.969977331953176        Pfail and Rel. (fatigue)
        16    No. of FWD stations with rutting pred.
 0.597243654720722       0.402756345279278        Pfail and Rel. (rutting)
```

Figure A5. Sample Illustration of OTR2B.$$$ File.

4. Expected cumulative applications of design tandem axle load during design period (one record);
5. Expected cumulative applications of design triple axle load during design period (one record);
6. Length of design period (one record);
7. Number of FWD test locations where the predicted horizontal strain at the bottom of the surface layer is tensile. (Note that for thin surface layers overlying a stiff base and/or subgrade, the predicted horizontal strain may be compressive. In this instance, no fatigue prediction using the Asphalt Institute equation is made. The predicted service life based on fatigue cracking is simply set to a high number, 10^{30});
8. Predicted probability of failure and reliability based on fatigue cracking (one record);
9. Number of FWD test locations used in computing the reliability based on rutting (one record);
10. Predicted probability of failure and reliability based on rutting (one record).

OTR2B.NF (annotated file illustrated in Figure A6)

1. First record - number of FWD test locations analyzed;
2. For each FWD test location, the following data are given:
    a) predicted number of allowable applications of design single axle load based on fatigue cracking and rutting criteria (one record);
    b) predicted number of allowable applications of design tandem axle load based on fatigue cracking and rutting criteria (one record);
    c) predicted number of allowable applications of design triple axle load based on fatigue cracking and rutting criteria (one record);
3. Expected cumulative applications of design single axle load during design period (one record);
4. Expected cumulative applications of design tandem axle load during design period (one record);
5. Expected cumulative applications of design triple axle load during design period (one record);
6. Length of design period (one record);

```
          16
   356947024278572.        514000.074755467                1
   605247462.825176        736202.731609822                2
   647425129.873397        1407513.88814960                3
   128378118.083809        271134.312493784                1
   111938269.496826        382642.121176499                2
   43378919.0800964        720223.894593082                3
   27205274.8592812        143665.298265262                1
   21092429.1182798        210188.861653962                2
   11996766.3520911        398561.184536837                3
   1942199546.48945        297665.896870406                1
   1006352031.32079        424070.968493316                2
   308990362.351985        803408.542738438                3
   17391569.0397570        186823.347917068                1
   13121513.6059464        273144.685356827                2
   8074041.93435584        514770.197794721                3
   7155387.54596002        136083.311203143                1
   5101007.75059125        196501.232587653                2
   3620573.16526585        371137.022587750                3
   282501660501.007        787624.897645647                1
   6418272731.88964        1032206.56304972                2
   3105182672.32044        1967555.84581235                3
   14898282.8638518        222367.010769854                1
   11209636.6975576        329510.659291773                2
   7287875.16979883        621566.719985354                3
   16652769.8214233        361857.010375645                1
   12355394.8747622        525020.390201829                2
   7828450.05430548        982707.261051342                3
   8562340.64668371        260251.773949739                1
   5967521.79768273        374597.729632137                2
   4138267.79174467        691406.405311134                3
   81612299.0120362        191794.940200108                1
   71658438.6704277        278258.252805341                2
   30984311.9448115        527538.871987758                3
   1221458.08183209        103717.413160786                1
   1040439.44486887        152893.302498572                2
   879472.237050317        286542.469293432                3
   16796150.4776985        95554.6417988255                1
   12008677.2105465        135579.957465783                2
   7427465.23913830        256424.716885046                3
   2883486.92518191        50775.6882109150                1
   2203429.88141937        75927.2846501809                2
   1716163.18189077        142424.280213159                3
   7419863.53971253        70390.6631975702                1
   5322386.11711968        103599.028355586                2
   3747427.42997255        195844.583854863                3
   10998629.1692150        170713.623832930                1
   8179568.63885262        253040.489089556                2
   5455395.93520908        475432.308261500                3

 Expected number of single axle loads:        103602.
 Expected number of tandem axle loads:        165705.
 Expected number of triple axle loads:         20604.
 Design period (years):  10.00

 Average fatigue life (log based, years):     972.9236
 Std. dev. of fatigue life (log based, years):      11.4085
 Probability of failure by fatigue cracking: 0.030023
 Reliability of pavement based on fatigue cracking: 0.969977

 Average rut life (log based, years):       8.4114
 Std. dev. of rut life (log based, years):       2.0190
 Probability of failure by rutting: 0.597244
 Reliability of pavement based on rut depth criterion : 0.402756
```

Figure A6. Sample Illustration of OTR2B.NF File.

7. Average of fatigue life predictions at FWD stations analyzed. (The average of the logarithms, base 10, of the fatigue life predictions is first determined. Then, the antilog of this average is taken and reported in this record. This procedure is also used for the statistics based on rutting);
8. Standard deviation of fatigue life predictions at FWD stations analyzed (one record);
9. Probability of failure based on fatigue cracking (one record);
10. Pavement reliability based on fatigue cracking (one record);
11. Average of service life predictions based on rutting (one record);
12. Standard deviation of service life predictions based on rutting (one record);
13. Probability of failure based on rutting (one record);
14. Pavement reliability based on rutting (one record).

OTR2C.DI (Figure A7)

1. First record - number of FWD stations analyzed and length of design period;
2. For each FWD test location, the predicted service lives (in years) are reported for fatigue cracking and rutting criteria (one record per station). Note that these predictions are based on Miner's hypothesis of cumulative damage to combine the effects of single, tandem, and triple axle loads.

FILES CREATED AFTER OVERLAY ANALYSIS

OTR4.OUT

This file has the same format as OTR2B.OUT. However, the data correspond to the design single, tandem, and triple axle loads used in the overlay analysis.

OTR4.$$$ (annotated file)

The format of this file is the same as OTR2B.$$$. However, the data in the file correspond to the design axle loads and the estimated cumulative number of load repetitions used in the overlay analysis.

```
        16   10.0000000000000
  32721.9351890026        22.6613732934146
  3620.16009192781        11.8515937350608
  747.285983636114        6.40535855697074
  35126.7425908672        13.0814381933962
  473.095006143337        8.32481856637944
  189.917473030460        6.02371144058682
  304694.277325922        33.0530613170581
  407.108314758028        9.98067745297165
  449.139523019029        16.0542158909821
  222.983180983308        11.4911041295714
  2354.68586921491        8.51255493143851
  37.3817210163665        4.64125893349240
  439.734407271063        4.18977618816504
  81.2093852126466        2.28965546539837
  197.649728360151        3.14811453739897
  298.911199053302        7.66242971724888
```

Figure A7. Sample Illustration of OTR2C.DI File.

OTR4.NF (annotated file)

This file has the same format as OTR2B.NF. However, the data correspond to the design axle loads and the estimated cumulative number of load repetitions used in the overlay analysis.

OTR4.DI

The format of this file is the same as OTR2C.DI. However, the data in the file correspond to the design axle loads and the estimated cumulative number of load repetitions used in the overlay analysis. In addition, the first record in the file only reports the number of FWD stations analyzed.

TRUCKS.$$$ (annotated file illustrated in Figure A8)

This file shows the total payload carried by trucks using the route, computed from the equation:

$$Payload = P_{single}\, n_{single} + P_{tandem}\, n_{tandem} + P_{triple}\, n_{triple} \tag{A1}$$

where

P_{single} = design single axle load;

P_{tandem} = design tandem axle load;

P_{triple} = design triple axle load;

n_{single} = expected cumulative applications of design single axle load;

```
Record of estimated axle load applications:

Total payload (kips):      11448720.

 25.00  46.00  60.00     103602.     165705.      20604.
```

Figure A8. Sample Illustration of TRUCKS.$$$ File.

n_{tandem} = expected cumulative applications of design tandem axle load; and

n_{triple} = expected cumulative applications of design triple axle load.

In addition, P_{single}, P_{tandem}, P_{triple}, n_{single}, n_{tandem}, and n_{triple} are reported in the record following the payload.