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Traffic and Data Preparation for AASHTO DARWin-ME Analysis and Design

by

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16. Abstract
Pavement ME Design (MEPDG/DARWin-ME) is a significant advancement in pavement design, but requires much more inputs from various sources. Through the transportation pooled fund study TPF-5(242), a full-production software Prep-ME with comprehensive database features has been developed to assist state DOTs in data preparation and improve the management and workflow of Pavement ME Design input data. Prep-ME is capable of pre-processing, importing, checking the quality of raw Weigh-In-Motion (WIM) traffic data, and generating three levels of traffic data inputs with in-built clustering analysis methods for Pavement ME Design. A number of additional modules in Prep-ME may be useful to any highway agency, including those for climate, materials and FWD. The ultimate goal of Prep-ME is to be the companion tool that can seamlessly communicate with Pavement ME Design in a full production environment for the local calibration and implementation. This tool can be used by pavement design engineers to prepare input for Pavement ME Design, but also traffic engineers to collect better traffic data and manage those data for other applications. In addition, the 1-mm 3D laser imaging PaveVision3D Ultra technology developed by the research team has been demonstrated for the potential use of calibrating Pavement ME Design.

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ABSTRACT

Pavement ME Design (MEPDG/DARWin-ME) is a significant advancement in pavement design, but requires much more input from various data sources. Through the transportation pooled fund study TPF-5(242), a full-production software called Prep-ME with comprehensive database features has been developed to assist state DOTs in data preparation and improve the management and workflow of Pavement ME Design input data. Particularly, Prep-ME is capable of pre-processing, importing, checking the quality of raw Weigh-In-Motion (WIM) traffic data, and generating three levels of traffic data inputs with in-built clustering analysis methods for Pavement ME Design. This tool can be used not only by pavement design engineers to prepare input for Pavement ME Design, but also traffic data collection engineers to collect better traffic data and manage those data for other applications. The software has the following basic functions with more specific features requested by individual states.

- Imports an agency's WIM traffic data complying with FHWA Traffic Monitoring Guide (TMG) file formats, and stores the data in SQL server Local database with exceptional computation efficiency.
- Conduct Travel Monitoring Analysis System (TMAS 2.0) data check and generate TMAS check error log for each imported raw file.
- Perform automatic quality control checks by direction and lane of a WIM station for both classification and weight data following algorithms defined in TMG.
- Provide user friendly interfaces to review monthly, weekly and daily traffic data, and investigate the WIM data that is incomplete or fails the automatic QC check through various manual, sampling, and analyzing operations.
- Generate three levels of traffic inputs and defaults: Level 1 site specific, Level 2 clustering average, Level 3 state average, and LTPP TPF-5(004) defaults.
- Fully implement clustering methods developed by North Carolina and Michigan DOTs, the Kentucky Transportation Cabinet (KYTC), the Truck Traffic Classification (TTC) method, and the simplified TTC approach are fully implemented, offering state agencies the flexibility of generating Level 2 loading spectra inputs for Pavement ME Design based on the availability of traffic data.
- Generate input files in the file formats that can be directly imported into MEPDG and Pavement ME Design software.

A number of other features in Prep-ME may be useful to any highway agency, including (1) importing raw climatic data and exporting XML climate files for Pavement ME Design; (2) populating and exporting material inputs including E* for HMA, CTE for PCC, and soil properties based on soil map for Pavement ME Design; and (3) importing FWD raw files and preparing FWD XML file for Pavement ME Design inputs.

The ultimate goal of Prep-ME is to be the companion tool that can seamlessly communicate with Pavement ME Design in a full production environment for the local calibration and implementation.

In addition, in working with FHWA pavement performance office, the 1-mm 3D laser imaging PaveVision3D Ultra technology developed by the research team is used to collect field data at high-friction sites and LTPP sites on nationwide basis. Cracking and other distress data extracted from the 3D survey data have demonstrated the potential to be used as basis for calibrating Pavement ME Design and application of other pavement related needs, particularly in PMS.

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IMPLEMENTATION STATEMENT

Although the Mechanistic Empirical Pavement Design Guide (MEPDG) is a significant advancement in pavement design, it requires many more inputs from designers. Many data sets, such as Weigh-In-Motion (WIM) traffic data, need to be pre-processed before use in the MEPDG procedure. This pooled-fund study will help participating state highway agencies use MEPDG with full-production software called Prep-ME. The goals of this study included: (1) Recognizing the differences in loading patterns or traffic groups and estimate full axle load spectrum data occurring under different conditions based on large amount of WIM data; (2) developing algorithms to examine raw WIM data for quality and conduct data operations to salvage usable information in WIM data; (3) customizing Prep-ME for participating states; and (4) preparing and conducting training for personnel from participating states.

The Prep-ME software can be implemented within a state highway agency to

- Help state traffic data collection engineers conduct an effective QA/QC check on traffic data collected for all kinds of applications, such as pavement design, Highway Performance Monitoring System (HPMS), traffic planning, bridge design, etc.
- Help state pavement design engineers analyze the traffic loading data collected through the WIM technology and select the best load spectra for pavement design purpose among WIMs, national, and local defaults.
- Improve the operation of above tasks tremendously.

The ultimate goal of Prep-ME is to be the companion tool that can seamlessly communicate with Pavement ME Design in a full production environment for the local calibration and implementation.

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INTRODUCTION

The Mechanistic Empirical Pavement Design Guide (MEPDG) (also named as DARWin-ME and now called Pavement ME Design) is a significant advancement in pavement design. MEPDG, DARWin-ME, and Pavement ME Design are used interchangeably in this report. However, Pavement ME Design is substantially more complex than the 1993 AASHTO Guide, which is currently used in many states, and requires significantly more inputs from designers. Among them are many parameters with which today's pavement designers are not familiar. Some of the required data are not currently measured or tracked in the 1993 AASHTO Guide. Many data sets need to be pre-processed before their use for MEPDG. In addition, MEPDG provides methodologies for the analysis and performance prediction of different types of flexible and rigid pavements for the specific climatic and traffic conditions. However, the models were developed using available Long Term Pavement Performance (LTPP) wide data sets. These models require local calibration before MEPDG can be used by highway agencies efficiently.

Based on the review of the related MEPDG research projects conducted by many state highway agencies, it is apparent that many data sets preparation activities have been completed, and it is time to move forward with the local calibration process. However, the data sets required for the implementation of MEPDG are stored in different locations that are not familiar to pavement designers. Many data sets need to be pre-processed before they can be used in the MEPDG design procedure. In particular, the load spectra approach adopted in MEPDG is much more complex than the existing equivalent single axle load (ESAL) based approach and several challenges exist.

First, for a long time there was a gap between traffic and pavement engineers in understanding the needs for traffic data in pavement design. Pavement and traffic engineers needed to share their knowledge and experience when using MEPDG. Secondly, NCHRP Project 1-37A researchers (1) found that roadways within the same Highway Functional Classification (HFC) had significant variability in truck distribution and introduced the Truck Traffic Classification (TTC) system in MEPDG to describe the distribution of trucks traveling on the roadway. The third challenge was that the traffic data collected from the automated traffic collection sites often have errors, especially the data collected from the WIM sites, which use temperature-dependent piezoelectric sensors. It consumed a large amount of resources to process the data by using currently available methods to conduct the data check. Fourth, the sizes of the raw traffic data files are huge. For example, the size of truck weight data collected can be 200 MB to 300 MB in text file format per month for a single WIM station. With several years of raw data in a state highway agency, the processing of the data becomes tedious and time consuming. It is impractical to manually process the data files even with computer assistance.

In addition, there will be tens of thousands of traffic data sets needed to be prepared to characterize traffic load for a particular design. This process needs to be automated with software, which was not available before the development of Prep-ME. Although several existing software programs process data and generate reports, the resultant reports do not provide all axle load spectra data required in MEPDG analysis software. It would take additional resources to conduct further analysis for MEPDG. For example, Trafload, a computer program developed under NCHRP Project 1- 39 for generating traffic inputs for MEPDG, still cannot fulfill many of the requirements for MEPDG. Several state highway agencies developed spreadsheets to reduce raw vehicle classification data and weight data, and to generate volume adjustment factors and axle load spectra for MEPDG. However, the updating procedure needs to be repeated manually if new traffic monitoring data are available.

Therefore, it is critical and important to have a supporting software system that is able to pre-process certain input data sets for pavement ME Design for both quality and format. The supporting software shall support the local calibration effort by concurrently developing a database platform for calibration data collection, storage, and analysis. Specifically in this pooled-fund project TPF-5(242) the software and services in Prep-ME should be able to:

- Recognize the differences in loading patterns or traffic groups and estimate the full axle load spectrum data occurring under different conditions based on large amounts of WIM data;
- Add more functions based on the consensus of participating states and customize Prep-ME for participating states;
- Prepare and conduct training for the personnel of participating states; and
- Provide participating states technical support throughout the three-year period.

OBJECTIVE

The objective of the Prep-ME software was to assist state DOTs in the data preparation and improve the management and workflow of the Pavement ME Design input data to make the Pavement ME Design software more accessible and input data sets of high quality. The final objective of Prep-ME was to be used as a critical tool for calibrating and implementing the Pavement ME Design. For production use, the Prep-ME software needs to excel in speed, usability, functionality, and stability.

SCOPE

The scope of this project was to develop a new version of full-production Prep-ME software for the pooled-fund study participating states that is able to: (1) recognize the differences in loading patterns or traffic groups and estimate full axle load spectrum data occurring under different conditions based on large amount of WIM data; (2) develop advanced algorithms to examine raw WIM data for quality and conduct data repair operations to salvage usable information in WIM data for MEPDG and other purposes; (3) add more functions based on the consensus of participating states; (4) customize Prep-ME for participating states; (5) prepare and conduct training for personnel from participating states; and (6) provide technical support to participating states. It is envisioned that a nationwide platform for MEPDG data preparation can be established, with guidelines and support provided to individual states during implementation.

METHODOLOGY

Taking advantage of multiple years of experience with Pavement ME Design and Prep-ME, the team was tasked to enhance the existing Prep-ME software and help participating states utilize the tool in their implementations of Pavement ME Design through this pooled-fund study. Based on the features and stability of the existing Prep-ME originally developed for the Arkansas Highway and Transportation Department (AHTD) in 2009, a unified and consistent architecture was designed, documented, and implemented in this project. The redesign allowed for the most seamless integration of the design recommendations by the Prep-ME participating states while giving end users a stable, fast, and modern software system. The improvements of the user interfaces, software efficiency, and software flexibility in comparison to the current Prep-ME version was implemented based on close consultation with participating states' requirements.

Develop Objective and Scope for Prep-ME

Three face-to-face meetings were held during this project. The attendees included the representatives of participating states as well as experts from other states, industry partners, and universities. The purpose of the meetings was to develop the objective and scope of the study, and explore the opportunity of cooperation to help state highway agencies by reviewing the best approach available to the issues to be addressed in this study, brainstorming the scope and tasks that the study should include in addition to the current functions in the Prep-ME software, and prioritizing tasks based on the available funding.

From March 29 – 31, 2011, representatives of participating states and potential participating states of the pooled fund met in New Orleans to discuss necessary changes and improvements in Prep-ME to accommodate the new Pavement ME Design. The Prep-ME Technical Advisory Committee used the information and knowledge available and brainstormed the functionality of the to-be-developed new version of the Prep-ME software based on state highway agencies' needs. In accordance with the current funding level, the following to-do lists with different priorities were approved by the committee as the result of the two-day meeting and discussion. The content in the "High Priority List" is the scope of service of the project from the Prep-ME team, while many items in the "Like-To-Have List" either depend on the functionality of Pavement ME Design or need further research work to be accomplished in the future on the state level.

(1) High Priority List (to be accomplished in current phase with current funding)

- General

- Make current features of Prep-ME software compatible with Pavement ME Design.
- Survey participating states for state polices on SQL Server/Oracle and GIS/Arch information transition and management.

- The new Prep-ME should have the following functions in addition to its current functions:
  - Preprocess raw ASCII WIM data for individual states, QC for weight and classification data.
  - Accept quality-checked data without processing.
  - Provide three levels of data input for Pavement ME Design.
  - Group and characterize pre-clustered WIM sites.
  - Develop tables of station data in addition to geo-map (age, type, etc.).
  - Make QC more flexible so states can choose not to use certain features.
  - Calculate ESALs if Pavement ME Design does not have this feature.
  - Monitor and check daily W-card files, screen for bad traffic data, but still retain good data for Pavement ME Design.
  - Follow the AASHTO guide and the to-be-released Traffic Monitoring Guide (TMG) for screening.
  - Accept geospatial soil property database for each state.

(2) Like-to-Have List (to be accomplished in the future with additional funding)

- General
  - Identify Pavement ME Design inputs based on importance.
  - Provide robust documentation of Prep-ME software.
  - Provide post analysis: Prep-ME software provides summary sheets (reports) of input and output from Pavement ME Design runs based on user selections.
  - Provide existing layer information for overlay design.
- Traffic
  - Provide damage based clustering based on Pavement ME Design runs.
  - Accept traffic growth factor input and assign same traffic growth factor to individual groups.

    - Develop seasonal factors, short-term counts for Vehicle Class Distribution (VCD) and support decision tree for selecting Truck Traffic Class (TTC).
    - Develop new algorithm for assisting selection of TTC from the default list.
    - Use adjacent state WIM data.
- Climate
    - Help identify weather stations from adjacent states.
    - Conduct quality check on climate data per Pavement ME Design capability.
    - Predict climate conditions with new method (presented by Mike Heitzman).
    - Use non-standard state weather data.
    - Clean nationwide NOAA database.
- Materials
    - Establish geospatial soil property database for each state.
    - Calculate averages of moduli and other input parameters (gradation etc.).
    - Store FWD and back calculated values.
    - Store and help select modulus values through a visual interface.
    - Call back-calculation software to calculate moduli within Prep-ME.
    - Establish a format to hold back-calculation results, including data.
    - Store performance and condition data.
- Distress Models
    - A tool/module to assist the effort in validating/calibrating distress models.

The second and third face-to-face meetings were held in Detroit, Michigan, and Louisville, Kentucky, in 2012 and 2013, respectively. During the two meetings, the newly developed software capabilities were demonstrated and feedback gained from participating states. All the comments were documented and were later addressed in the improved Prep-ME software by the research team.

Execute the Work Plan for Prep-ME

In order to conduct tasks in accordance with the items listed in the "High Priority List" with current funding, the following methodology and work plan was executed:

Improve Efficiency of Prep-ME

This task was primarily to improve the speed of execution of the numerical engines in Prep-ME. The project team implemented storage procedure and multi-threading techniques to investigate possible run time efficiencies that could be realized. The computation efficiency had dramatically enhanced for functions of the raw data import/update and output data interpolation. Currently, it took around 5 minutes to import 6GB of WIM raw data into the Prep-ME database.

It was also realized that there were substantial changes in data formats and user interface of Pavement ME Design over MEPDG. During this task, the research team had studied the differences in input data formats between MEPDG and Pavement ME Design and developed the updated Prep-ME software that was fully compatible with Pavement ME Design. In addition, significant amount of testing efforts were devoted to ensure that the newly modified code produces the same results as the original version.

Improve Functionality of Prep-ME

In addition to its features in the 2009 version, the following core new functionalities were added to the Prep-ME software:

- Import an agency's WIM traffic data complying with FHWA Traffic Monitoring Guide (TMG) file formats, and store the data in SQL server Local database with exceptional computation efficiency.
- Conduct Travel Monitoring Analysis System (TMAS 2.0) data check and generate TMAS check error log for each imported raw file.
- Perform automatic quality control checks by direction and lane of a WIM station for both classification and weight data following algorithms defined in TMG.
- Provide user friendly interfaces to review monthly, weekly, and daily traffic data, and investigate the WIM data that is incomplete or fails the automatic QC check through various manual, sampling, and analyzing operations.

- Generate three levels of traffic inputs: Level 1 site specific, Level 2 clustering average, Level 3 state average, and LTPP TPF-5(004) defaults.
- Fully implement clustering methods developed by North Carolina, and Michigan DOTs, the Kentucky Transportation Cabinet (KYTC), the Truck Traffic Classification (TTC) method, and the simplified TTC approach are fully implemented, offering state agencies the flexibility of generating Level 2 loading spectra inputs for Pavement ME Design based on the availability of traffic data.
- Generate input files in the file formats that can be directly imported into MEPDG and Pavement ME Design software.
- Use a number of other features in Prep-ME for any highway agency, including (1) importing raw climatic data and exporting XML climate files for Pavement ME Design; (2) populating and exporting material inputs including E* for HMA, CTE for PCC, and soil properties based on soil map for Pavement ME Design; and (3) importing FWD raw files and preparing FWD XML file for Pavement ME Design inputs.

Specifically, the research team has developed C++ functions to generate multi-dimensional traffic results based on automatic and manual QC checking processes, such as sampling, replacement operations for incomplete traffic data. In addition, the OSU team has developed C++ implementation of Ward-based hierarchical Agglomerative clustering algorithm, which is used in both NCDOT and MIDOT clustering analysis methodologies. As a result, Prep-ME has built-in clustering analysis features that are independent of third party clustering software packages, such as Matlab, Microsoft Excel VBA, et al.

Improve User Friendliness/Usability of Prep-ME

The Graphical User Interface (GUI) had been completely redesigned to improve user friendliness of the Prep-ME software. The new redesigned interfaces included:

- Traffic and climatic data import.
- Traffic weight and classification data check with automatic, monthly and daily sampling capabilities.
- Integration of Google Map API 3.0 in several modules.
- Three levels of traffic data output including Level 1 site-specific, Level 2 clustering method, and Level 3 regional defaults.

- Climate data interpolation and output.
- Material module to retrieve E* and CTE data.
- Soil map module.
- FWD module.
- Several other features to aid users viewing data and performing data check.

In the phase II delivery of Prep-ME 3.0, the database platform has been changed from Microsoft Access to SQL Server. As a result, the data storage capability has been increased from 2GB to 10 GB (for Express version of SQL Server) or 16 TB (for Standard version of SQL Server). The team has re-designed all the database structure of the entire Prep-ME, including using SQL commands for DB functions and consolidating tables to make the overall database more efficient.

LocalDB technology is applied in the updated Prep-ME software. LocalDB is a new version of Microsoft SQL Server Express dedicated to developers to help them avoid a complex security configuration process and a full installation of SQL Server. It uses only a minimal set of files to start the SQL Server Database Engine. Therefore, developers can write and test their SQL codes without having to manage a full server instance of SQL Server.

Stability and Testing of Prep-ME

The OSU team had been rigorously testing the software internally on a regular basis to assess the final quality of the software in terms of its accuracy, completeness, reliability, efficiency, maintainability, compatibility and usability from two general aspects:

- Component Testing: to test each modified module for enhancement and improvement.
- System Testing: to evaluate their compliance with software specifications and requirements, such requirements based on the Traffic Monitoring Guide (TMG).

In addition, the OSU team interacted extensively with individual states to address their questions and newly discovered bugs via face-to-face meetings, emails and phone calls. Software debugging efforts and many improvements have been made in the final version of Prep-ME software.

Report and Documentation of Prep-ME

The updates and the technical documentation of the new functionalities completed in this project had been documented at a regular basis in terms of quarterly reports, bi-annual reports, annual reports, and a final report. Along with the final delivery of the Prep-ME software, detailed software User Manual with set up instructions and technical data samples was developed as part of the User's Guide.

Education and Training of Prep-ME

During the development of the Prep-ME software, the OSU team provided training to assist participating states implementing Prep-ME for Pavement ME Design, including:

- Three face-to-face meetings with attendees from participating states, other states, industry partners, and universities: The OSU team attended all the meetings and utilized these meetings as a valuable opportunity to provide training of the new Prep-ME software.
- A half-day TRB workshop on Prep-ME software in the 2014 TRB conference in January 16, 2014 in Washington D.C.
- A FHWA talking traffic webinar focusing on Prep-ME demonstration and implementation by participating states in February 2014 with more than 50 participants nationwide.
- A 1.5-day on-site training for KYTC pavement engineers and planning staff in Frankfort Kentucky from April 7 to April 8, 2014;
- A half day Prep-ME workshop at the 2014 North American Travel Monitoring Exposition and Conference (NATMEC) in Chicago in June 2014.

Utilize 1-mm 3D Laser Imaging Data for Pavement ME Design

In addition to input data such as those for traffic and climate, pavement surface distress information was critical for the local calibration of performance prediction models in Pavement ME Design. One of the FHWA requirements was conducting preliminary field work to assess the viability of using next-generation 1-mm 3D laser imaging data collection technology (PaveVision3D Ultra) for local calibration of Pavement ME Design. In working with the FHWA pavement performance office, PaveVision3D Ultra was used to collect field data at FHWA high-friction sites and LTPP sites in a number of states on a nationwide basis in 2012. It was demonstrated that cracking and other distress data extracted from the PaveVision3D Ultra survey data had the potential to be used as a basis for calibrating Pavement ME Design and application of other pavement related needs, particularly in PMS.

DISCUSSION OF RESULTS

The Pavement ME Design is a significant advancement in pavement design, but requires significantly more inputs from pavement designers. Many data sets need to be preprocessed before their use in the Pavement ME Design procedure, such as WIM traffic data. The developed Prep-ME software provides comprehensive database features to store and process climate, traffic and materials data. Specifically, Prep-ME is capable of pre-processing, importing, checking the quality of raw traffic data, and generating the required traffic inputs required in Pavement ME Design software by recognizing the differences in loading patterns or traffic groups. In summary, Prep-ME can assist state DOTs in the data preparation and improve the management and workflow of generating Pavement ME Design input data.

Besides input data such as those for traffic and climate, pavement surface distress information is critical for the local calibration of performance prediction models in Pavement ME Design. In working with the FHWA pavement performance office, PaveVision3D Ultra was used to collect field data at FHWA high-friction sites and LTPP sites on a nationwide basis in 2012. It is demonstrated that cracking and other distress data extracted from the PaveVision3D Ultra survey data have the potential to be used as basis for calibrating Pavement ME Design and application of other pavement related needs, particularly in PMS.

Overview of Prep-ME Software

General Overview

In Prep-ME 3.0, the database platform has been changed from Microsoft Access to SQL Server. As a result, the data storage capability has been increased from 2GB to 10 GB (for Express version of SQL Server) or 16 TB (for Standard version of SQL Server). The computation efficiency has been improved dramatically in the new Prep-ME by implementing several new programming algorithms.

As shown in Figure 1, Prep-ME 3.0 software includes four menus: Traffic, Climate, Materials, and Tools. For the traffic module, Prep-ME contains five main sub-modules: Import Traffic Data, Check Station Data, Check Weight Data, Check Classification Data, and Export Traffic Data. For the climate module, Prep-ME can import raw traffic data (Import Climate Data) and interpolate virtual climate files (Export Climate Data) for the Pavement ME Design software. In the material module, dynamic modulus (E*) for HMA (HMA E*), Coefficient of Thermal Expansion (CTE) for PCC (PCC CTE), soil map data (Soil Map), and FWD data (FWD) can be imported in Prep-ME and output data for Pavement ME Design. Prep-ME also provides tools to aid state DOTs in using the software.

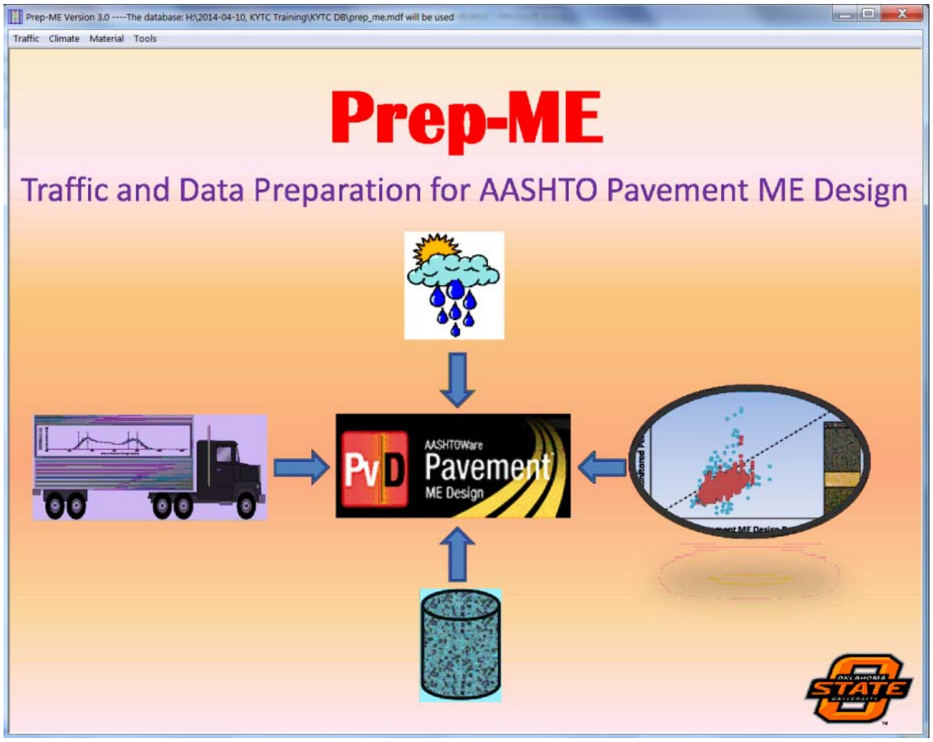


Figure 1

Prep-ME software main interface

Traffic Data Import

The Import Traffic Data sub-menu is able to:

- Import raw traffic data provided by state highway agencies. Regardless of traffic data collection techniques (such as Weigh-In-Motion, Automatic Vehicle Classification) and time coverage (such as permanent long term, short term counts), the traffic data can only be imported if the data files are saved strictly following the formats defined in the FHWA's Traffic Monitoring Guide (TMG), namely S-Card, C-Card, and W-Card.
- Conduct Travel Monitoring Analysis System (TMAS 2.0) data check for each line of raw data, and report errors into an error log file for each imported file. The TMAS 2.0 data check is documented in the 2013 version of Traffic Monitoring Guide, and provided in Appendix A. The data with critical errors are not imported into the Prep-ME database.
- Process the raw data which have passed the TMAS data check and save them in the Prep-ME database tables.

Traffic Data Check

The Traffic Data Check sub-menu is able to:

- Conduct QC check for both classification and weight data by direction and lane of traffic using data check algorithms defined in the TMG.
- Provide interfaces to review monthly, weekly and daily traffic data.
- Provide various manual, replacement, and sampling operations to analyze and utilize incomplete or failed data.

Traffic Data Export

The **Export Traffic Data** for traffic data is able to:

- Provide three levels of traffic outputs: Level 1 Site Specific, Level 2 Clustering Average, and Level 3 State Average. The Level 1 traffic inputs can be generated based on a WIM station or one direction of traffic. There are in total six clustering methods for Level 2 traffic inputs, including the NCDOT, Michigan DOT, KYTC, Truck Traffic Classification (TTC), and simplified TTC methods, or flexible clustering. State average values, LTPP-5(004) method, or Pavement ME Design defaults can be used for Level 3 inputs. Prep-ME allows the user to obtain outputs at different levels for the different traffic data types. For example, Level 1 is selected for Vehicle Class Distribution (VCD) data, while Level 3 data may be used for hourly adjustment factors.
- Implement independent C++ codes of Ward-based Hierarchical Agglomerative clustering algorithm, which is used in both NCDOT and MDOT clustering analysis, is implemented in Prep-ME. This algorithm will allow users to evaluate existing clusters and define new clusters if necessary.
- Generate 11 traffic input files in text file format for MEPDG and two XML traffic files for Pavement ME Design software.

Climate Module

The Climate Module in Prep-ME 3.0 is able to:

- Import Hourly Climate Data (HCD) files, including those from the Pavement ME Design software and new data sources provided by state DOTs, into Prep-ME database.
- Conduct preliminary data checks to the raw climate data.

- Interpolate ICM file and XML file that can be directly imported to MEPDG and the Pavement ME Design software.

Material Module

The Material Module in Prep-ME 3.0 is able to:

- Import raw FWD F25 data into Prep-ME database, output a summary report for back-calculation software, and generate an FWD XML file for Pavement ME Design.
- Retrieve dynamic modulus (E*) data for HMA materials from statewide material library for Pavement ME Design.
- Retrieve Coefficient of Thermal Expansion (CTE) data for PCC materials from a statewide material library for Pavement ME Design.
- Retrieve NCHRP 9-23A subgrade soil map data for Pavement ME Design.

Prep-ME Tools

Currently, Prep-ME 3.0 provides two tools to: (1) change traffic file names that don't comply with the Traffic Monitoring Guide name conventions; (2) calculate Annual Average Daily Truck Traffic (AADTT) and Vehicle Class Distribution (VCD) factors based on 24-hour or 48-hour short term traffic count data.

Traffic Data Import in Prep-ME

Traffic Data Formats and Naming Convention

The Prep-ME 3.0 software can only import traffic data that comply with the data formats recommended in the FHWA Traffic Monitoring Guide (TMG). Collected traffic data are classified into four types in TMG: station description data, traffic volume data, vehicle classification data, and truck weight data. Specific coding instructions and record layouts can be found in Chapter 6 of the 2001 Traffic Monitoring Guide. The recommended file naming conventions are “ssyy.STA,” “ssyy.CLA,” and “ssyy.WGT” for station, classification and weight data sets, where ss is state postal abbreviation and yy is the last two digits of the year. In case that state DOTs fail to follow the recommended name conventions to store traffic data, Prep-ME provides a tool to change the file names in a batch mode so that the data can be imported to the Prep-ME database.

The 2013 version of TMG guide also provides record layouts with minor changes. In addition to the four files above, the 2013 TMG guide requires collecting two more data files (speed data and the per vehicle data referred to as PVF). Each type of data has its own individualized record format.

TMAS 2.0 Data Check

TMAS stands for Travel Monitoring Analysis System. TMAS provides online data submitting capabilities to state traffic offices to submit data to FHWA. Access to TMAS is obtained through the FHWA Division office in the individual state. TMAS 2.0 provides a set of traffic data checks. All the TMAS checks are implemented in Prep-ME 3.0 during traffic data import.

Traffic Data Import Interface

After selecting your state and the file folder where WIM data are saved, clicking "**OK**" button, all classification, station description and weight files in this file folder and its sub-folder will be imported to the Prep-ME database. Figure 2 shows a screen shot of data import processing. This process reports the number of rows of data imported into the database, number of records (rows) that failed the TMAS check, failed rate in percentage, and number of rows (records) that are duplicate in the raw data sets etc.

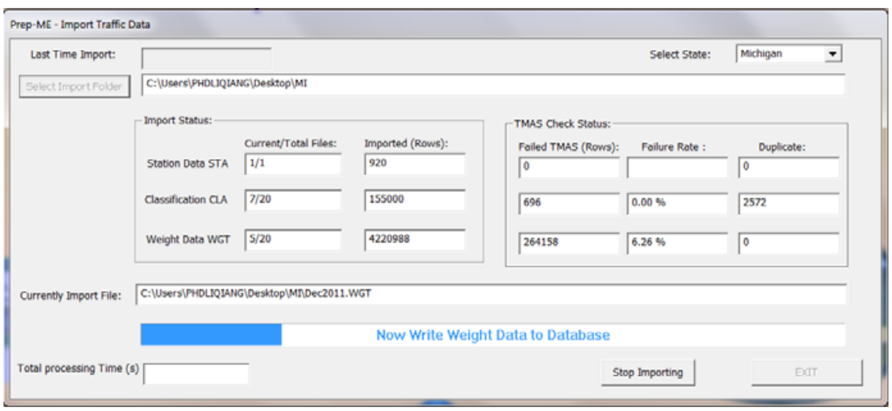


Figure 2

Traffic data import

A detailed TMAS checking error report file will be generated for each imported file and located in the same directory as the raw files that have been processed. Duplicate data and data lines with critical errors will not be imported by Prep-ME.

After data importing, the geo-referenced Google Map 3.0 is activated to show the geographical relationships among the design project, WIM stations, and the surrounding area.

This mapping utility has all major functions of Google Map 3.0, such as displaying satellite imagery. Users can click on the traffic station legend for more detailed information (Figure 3).

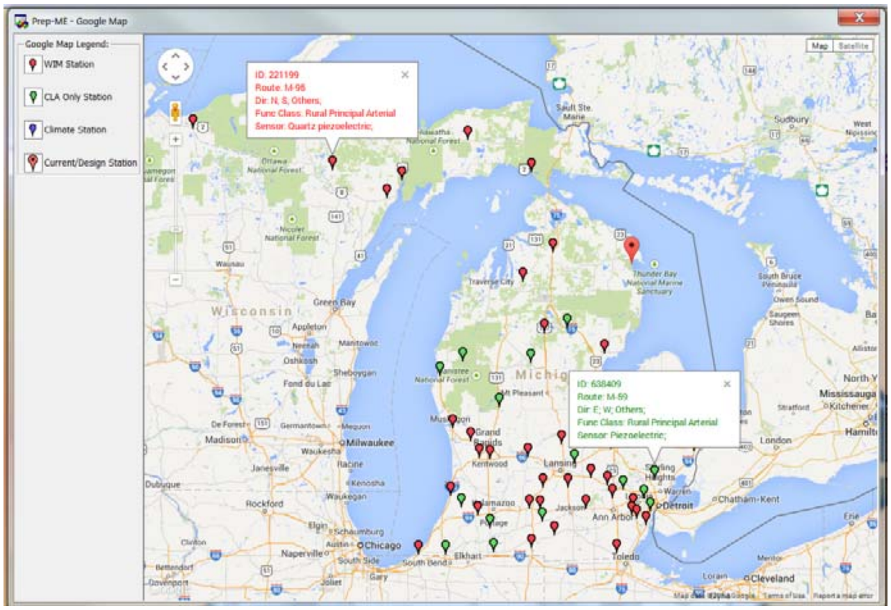


Figure 3

Google Map 3.0 utility

Traffic Data Check in Prep-ME

Automatic TMG Weight Data Check Algorithms

The algorithm used in the 2001 3rd Edition of TMG for the weight is adopted for weight data check. There are two basic steps to evaluate recorded vehicle weight data. First, check the front axle and drive tandem axle weights of Class 9 trucks. The front axle weight should be between 8,000 and 12,000 lb (10,000 ± 2,000 lb). The drive tandems of a fully loaded Class 9 truck should be between 30,000 and 36,000 lb (33,000 ± 3,000 lb). Second, check the gross vehicle weights of Class 9 trucks. The histogram plot should have two peaks for most sites. One represents unloaded Class 9 trucks and should be between 28,000 and 36,000 lb (32,000 ± 4,000 lb). The second peak represents the most common loaded vehicle condition with a weigh between 72,000 and 80,000 lb (76,000 ± 4,000 lb).

Figure 4 demonstrates the interface for weight data check. Default TMG QC Criteria are built into Prep-ME and the stations are automatically classified as “Accepted” and “Unaccepted.” Because a minimum of 12-month data within a year (from January to December) are required to prepare the loading spectra data inputs for the Pavement ME Design software, the Prep-

ME software will classify stations as "unaccepted" if they lack a minimum of 12-month data that pass the QC. Prep-ME also allows users to adjust those QC parameters based on their state's practices. In addition, users can opt not to apply one or all the QC criterion for weight data check by unselecting them.

For each station, the detailed traffic information can be reviewed by users. The corresponding histograms for each data check criterion can be checked by switching the radio buttons. The monthly QC check results can be viewed by WIM station, by direction of a station, and by direction and lane of a station.

For WIM stations that do not have a minimum of 12-month data, Prep-ME provides functionalities on how to use those incomplete traffic data sets for the Pavement ME Design software through various operations, such as manual, sampling and replacement operations.

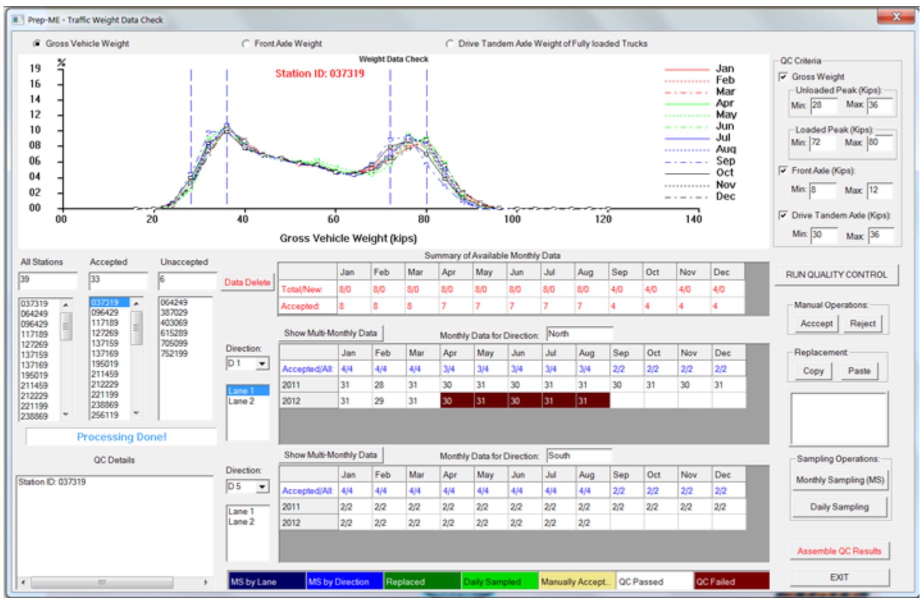


Figure 4

Weight data check by direction and by lane

Data Sampling and Replacement

Four sampling and repair options are provided in the Prep-ME: **Manual Operation** (**Accept** and **Reject**), **Replacement** (**Copy** and **Paste**), **and Sampling Operation** (**Daily Sampling** and **Monthly Sampling**). Prep-ME uses five different background colors to differentiate various QC checking status as shown in Figure 4.

Manual Operation (Accept/Reject) allows users to review and double check the automated QC results. If users confirm that the software has misclassified the data check status, users can manually accept or reject this month's data.

Daily check and sampling operation is useful in three situations:

- It can be used as a diagnostic tool to investigate the reason(s) for bad data that cannot pass automatic data check.
- When WIM sensors malfunction in the middle of a month, sampling operation can be used to prune failed daily data.
- When multiple day's data is missed in a month, sampled weekly data can be used as a substitute for that month.

Occasionally, multiple days of data are missing within a month for some WIM stations. In this case, users may want to sample the available data to represent this month. In addition, users may be interested in investigating the data trend for a specific Day of Week (for example, all 5 Mondays as shown in Figure 5). Therefore, the Prep-ME software has designed the function that allows user to select multiple days of data and show the results in the **QC Plots** and **Daily Data Summary** figures.

Figure 5 demonstrates the comparisons of the Gross Vehicle Weight data for all five Mondays in the selected month. It is anticipated that the data be consistent among the five Mondays. However, it is seen that the data for the first Monday shows a different trend from others. Users may investigate the data and decide whether the data is reasonable.

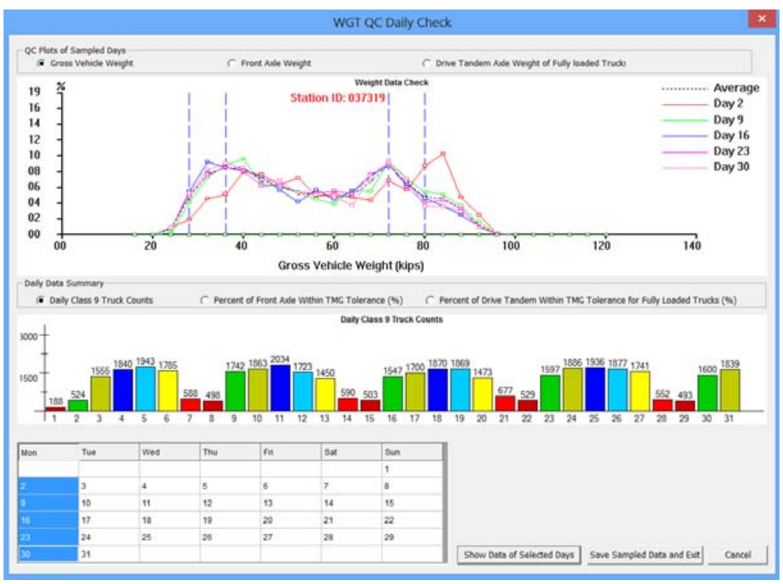


Figure 5

Daily check and sampling

When one month’s data is missing or fails to pass the data check algorithms, users can apply “**Copy**” and “**Paste**” operation by checking the similarity of the data in adjacent months, opposite direction, or different lane, same month but different year, and then identify a suitable month which can be used as the “source month” to substitute the failed or missing month (the “target month”).

Since WIM sites can collect many years of data, users may only be interested in using twelve consecutive months’ data right after a WIM system calibration or 12 selected months' data based on engineering judgment for pavement design. Prep-ME provides users with monthly sampling either by direction or by lane.

Traffic Classification Data Check

Classification data check follows the four-step algorithms defined in the TMG guide: (1) to compare the manual classification counts and the hourly vehicle classification data. The absolute difference should be less than five percent for each of the primary vehicle categories; (2) check the number of Class 1 (motorcycles). The evaluation procedure recommended that the number of Class 1 should be less than five percent unless their presence is noted; (3) check the reported number of unclassified vehicles. The number of unclassified vehicles should be less than five percent of the vehicles recorded; and (4) compare the current truck percentages by class with the corresponding historical percentages. No significant changes in the vehicle mix are anticipated. The first step is not used since no manually collected data are available. The second and third step can be checked with the imported vehicle classification data. In the fourth step, the TMAS2.0 consistency check is applied. By default, MADT from same month previous year should be within 30%.

The Prep-ME software provides a similar software interface (Figure 6), which is able to perform an automatic data check, daily check, replacement, sampling operations for classification data. Daily sampling function is illustrated in Figure 7.

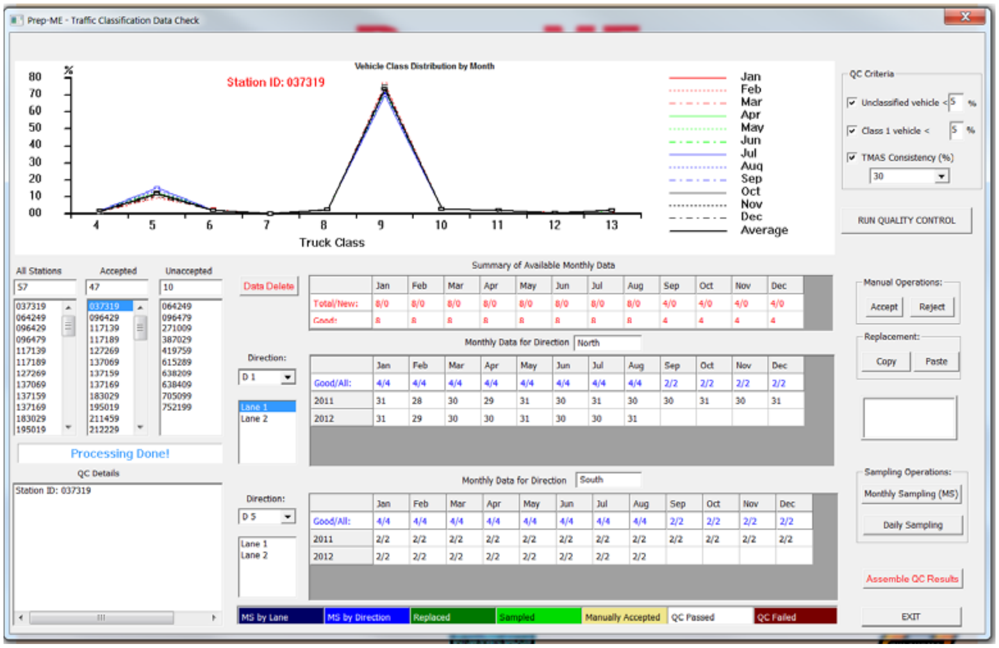


Figure 6

Classification data check by direction and by lane

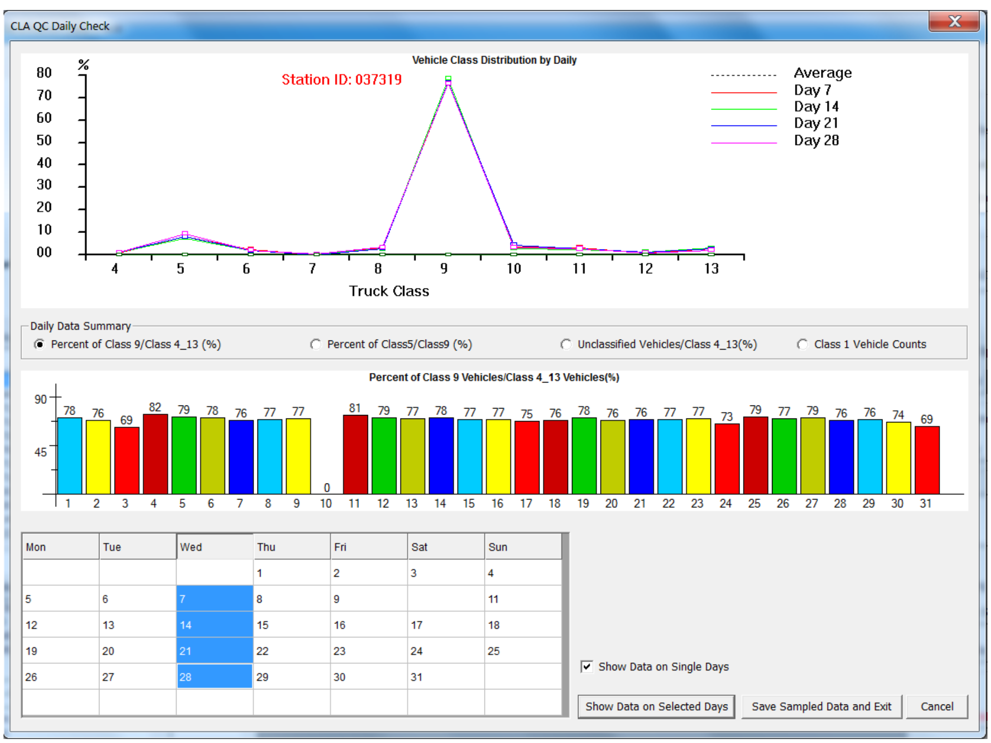


Figure 7

Classification daily data check

Traffic Data Export in Prep-ME

Traffic Data Export Levels

Due to the various levels of data availability and the criticality of a project, Pavement ME Design introduces a three-level hierarchical approach of design inputs. Level 1 inputs generally require site-specific data, which provide for the highest level of accuracy and would have the lowest level of uncertainty or error. Level 2 inputs typically would be user-selected and estimated through correlations or equations, possibly based on a limited testing program, an agency's database, additional research efforts to develop the estimation etc. Level 3 inputs provide the lowest level of accuracy, and typically average values for the region.

For traffic data inputs, ideally, Level 1 traffic inputs for Pavement ME Design can be obtained from a WIM system operating continuously at the design site over extended periods of time. In practice, however, when new pavements are designed, no prior Level 1 traffic WIM data are available. In such case, Level 2 traffic inputs are considered for design by combining existing site-specific data from WIM systems located on sites that exhibit similar traffic characteristics. This process is known as clustering analysis for traffic data, which has been researched by several state DOTs.

As shown in Figure 8, there are three level traffic outputs in Prep-ME: Output Level 1 site-specific, Output Level 2 cluster average, and Output Level 3 state average. Prep-ME 3.0 integrates six clustering approaches to generating Level 2 traffic inputs for Pavement ME Design in a production environment, including the discriminant analysis based method developed in Michigan, the decision tree based method in North Carolina, the Kentucky Transportation Cabinet (KYTC) method, the Truck Traffic Classification (TTC) Clustering method, the simplified TTC Clustering method, and the Flexible Clustering method. The first three methods were developed specifically for three state DOTs under separate research efforts. The fourth and fifth methods can meet the needs for state DOTs that do not have a comprehensive clustering approach or sufficient WIM data. Prep-ME also allows users to manually select existing WIM stations for each parameter based on local engineering knowledge. The data from the selected WIM station will be used to generate traffic data outputs. This capability is implemented in the "**Flexible Clustering**" button. The Prep-ME software offers state agencies the flexibility of generating loading spectra inputs for Pavement ME Design based on the availability of traffic data, which can substantially reduce state DOT's efforts in calibrating and implementing Pavement ME Design. In addition, three Level 3 methods: **State Average**, **LTPP-5(004)** and **Pavement ME Default** were developed.

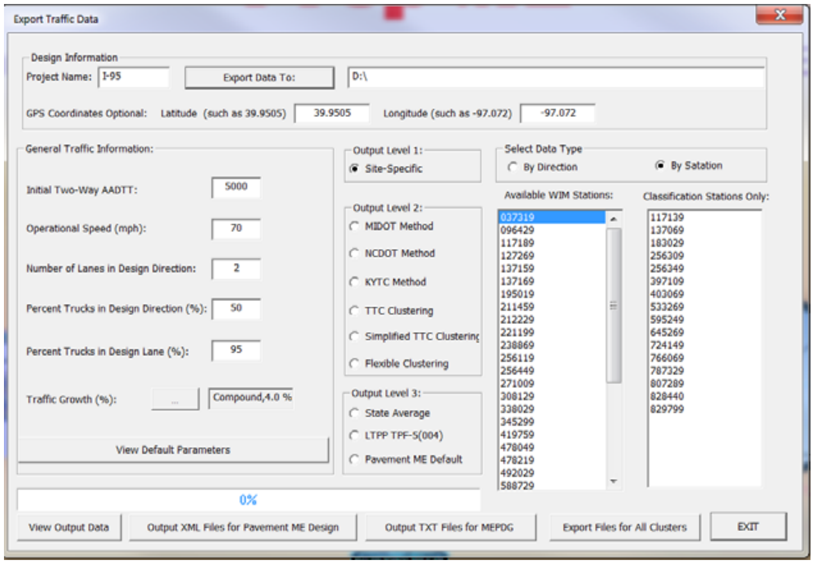


Figure 8

Three-Level traffic outputs for Pavement ME Design

Users need to input site-specific traffic values at the design location under "**General Traffic Information.**" Vehicle configuration related inputs are housed in the "View Default Parameters", where Pavement ME Design defaults are used. In Prep-ME 3.0, state average of **Number Axles/Truck** is developed based on the WIM data imported into the database (Figure 9).

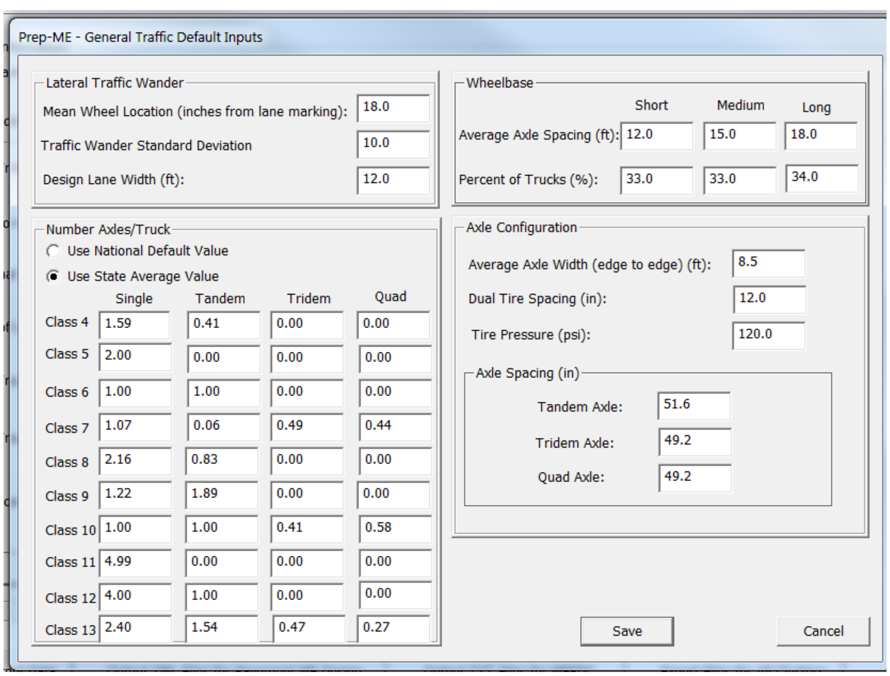


Figure 9

State average for number axles/truck

Output Level 1- Site-Specific

To export Level 1 site-specific output (As shown in Figure 8), Prep-ME allows users to export site-specific traffic data "**By Direction**" or "**By Station.**" The data shown by station contains the average data for all directions whereas the data shown by direction is only for a particular direction. The "**Available WIM stations**" list contains weight data and may (or may not) contain classification data. The "**Classification Stations Only**" list only contains classification data which does not contain weight data.

Output Level 2 -Michigan DOT Clustering

MDOT Methodology. The state of Michigan has developed a process for characterizing traffic inputs in support of the Pavement ME Design. Axle weight and vehicle classification data were obtained from 44 WIM stations located throughout Michigan to develop Level 1 traffic inputs. For pavement analysis and design, site-specific data should be used wherever available. For projects where site-specific data are not available, sensitivity of the various traffic inputs to the predicted pavement performance is used to identify critical input level for particular traffic characteristics for design. If predicted pavement performance is insensitive to a particular traffic input, Level 3 statewide or Pavement ME Design defaults should be used. Otherwise, Level 2 inputs at a minimum should be developed.

Cluster analyses using Squared Euclidean Distance with Ward's Method are conducted to group sites with similar characteristics for development of Level 2 inputs. After iterations of Pavement ME Designs using various traffic inputs, the input levels for traffic characteristics were recommended based on sensitivity analysis results, as shown in Table 1.

For the traffic inputs that require cluster averages (TTC, HDF, and tandem axle load spectra), discriminant analysis is employed to develop a set of linear regression equations to select the appropriate traffic input cluster group for a particular pavement design site. An example of such a linear equation is shown in Equation (1).

$$y = b_1 x_1 + b_2 x_2 + ... + b_n x_n + c \qquad (1)$$

The dependent variable (y) is a cluster for a given traffic characterization (i.e., TTC, MDF, Tandem axle load spectra) and the predictor variables (xi) are known traffic properties of the site for which traffic characterization is to be determined. The predictor variables selected for use in Michigan in the discriminant analysis include: vehicle freight commodity truck percentage for the following commodities, road class, geographic region, AADTT, percentage of Vehicle Class 5 (VC5%), percentage of Vehicle Class 9 (VC9%), functional class (rural/urban), and roadway annual tonnage. Subsequently, the discriminant scores (called classification scores) are calculated from the linear discriminant functions for all the clusters for a given traffic characterization. The site is then assigned to the cluster whose corresponding function produces the highest discriminant score.

Table 1

Traffic input level for rigid pavements (recommendations for the Michigan DOT)

Traffic characteristics	Recommended traffic input level
AADTT	Site-specific count data (Level 1)
Truck traffic classification (TTC)	Cluster averages (Level 2) (3 clusters)
Monthly distribution factors (MDF)	Statewide average (Level 3)
Hourly distribution factors (HDF)	Cluster averages (Level 2) (3 clusters)
Average groups per vehicle (AGPV)	Statewide average (Level 3)
Single axle load spectra	Statewide average (Level 3)
Tandem axle load spectra	Cluster averages (Level 2) (5 clusters)
Tridem axle load spectra	Statewide average (Level 3)
Quad axle load spectra	Statewide average (Level 3)

Setup MDOT Clusters. Select “Michigan DOT Method” in Figure 8, and the interface of “Prep-ME Michigan Clustering Parameters” will show up (Figure 10).

After importing new data or conducting new QC operations, the desired traffic clusters that are required for the Michigan discriminant analysis may not have been correctly set up. To find out whether the clusters are properly assigned, users should compare the numbers in the columns of “Desired” and “User Setup” in the “Traffic Patterns” section. The values in the “Desired” column represent the number of clusters for each indicator that are required in the Michigan discriminant analysis, while the values in the “User Setup” column are the number of the clusters that are set up in the database. It is required that these two sets of numbers are identical before any discriminant analysis can be conducted. If the numbers don't match, the “Identify traffic pattern” button will be disabled and users cannot proceed to the next step. In that case, users need to hit “Setup Michigan Traffic Patterns” to set up clusters until the two numbers match (Figure 11).

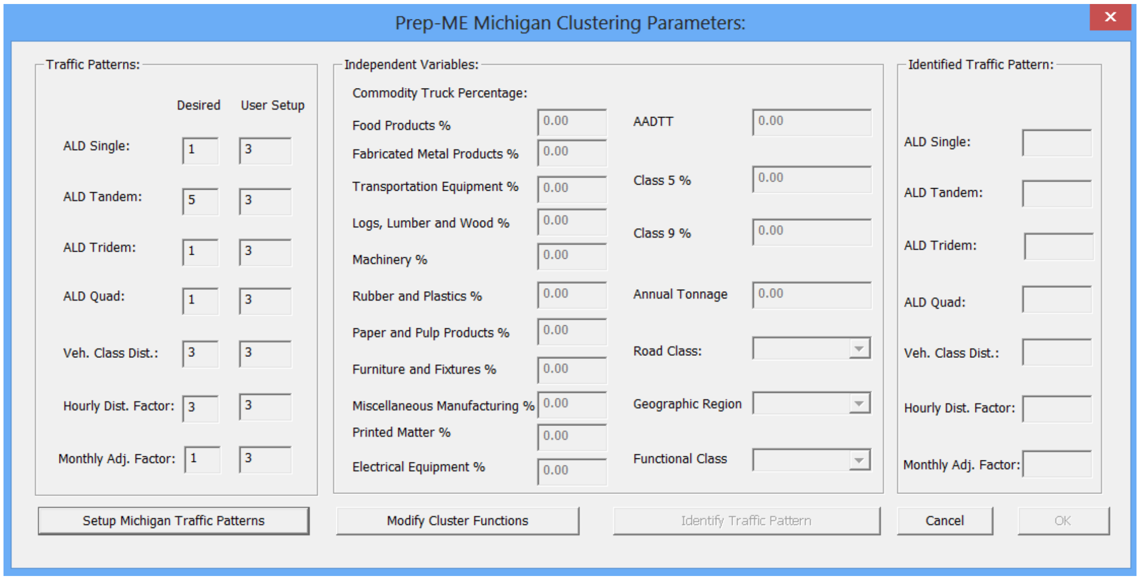


Figure 10

Output Level 2 – Michigan DOT method

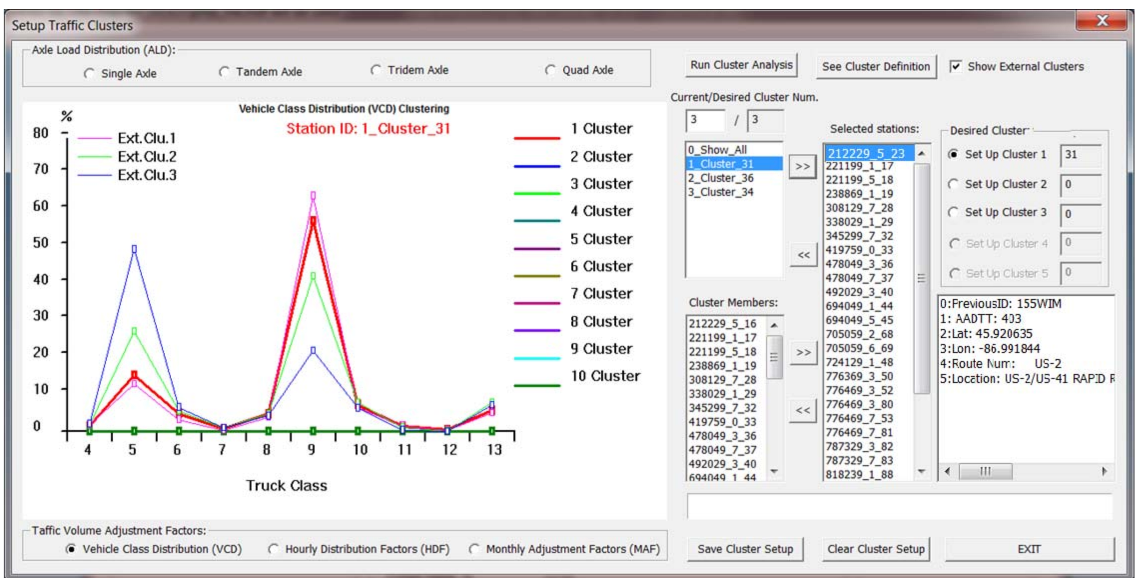


Figure 11

Set up Michigan DOT clusters

As shown in Figure 11, to set up Michigan clusters so that the developed discriminant equations can be used, users need to correctly set up the clusters for all the seven traffic parameters: **Single Axle; Tandem Axle; Tridem Axle; Quad Axle; Vehicle Class distribution (VCD); Hourly Distribution Factors (HDF); Monthly Adjustment Factors (MAF)**.

An example is provided to demonstrate this process to assign the clusters for “**Vehicle Class Distribution (VCD)**” factors, as shown in Figure 11. The following steps must be executed in order:

- Select the radio button for “**Vehicle Class Distribution (VCD)**” factors;
- Since the “**Desired Cluster Num.**” is 3 (what Michigan research recommends), input 3 for the “**Current**” setup of clusters;
- Click “**Run Cluster Analysis**” and the area below the “**Current/ Desired Cluster Num.”** column will be populated with four lines of texts: “**0_Show_All**”, “**1_Cluster_31**”, “**2_Cluster_36**”, “**1_Cluster_34**”. The Prep-ME software has automatically classified the data sets into three clusters. There are 31, 36, and 34 members for Clusters 1, 2, and 3. Select “**0_Show_All**” and the histogram on the left will show the plots of all three classified clusters, while selecting “**1_Cluster_31**” will only plot the VCD data for identified Cluster 1. In addition, the cluster members are listed under “**Cluster Members.**” Select any member and the histogram on the left will show the plot of the selected WIM site.
- This step shows how to assign the Prep-ME classified Cluster 1 to “**Desired Cluster**”. Select “**1_Cluster_31**”, the VCD for Cluster 1 is plotted on the histogram. Check the “**Show External Clusters,**” and all the three external clusters defined in Final report #RC-1537 are also added to the histogram. Now users can compare the Prep-ME classified Cluster 1 VCD to the external clusters. It can be seen that the Prep-ME classified Cluster 1 VCD can be well represented by “**Ext. Clu. 1**”. Therefore, “**1_Cluster_31**” can be assigned to the desired Cluster 1. The next step will show how to make the assignment.
- Select “**1_Cluster_31**”, then check the radio button of “**Setup Cluster 1**”, and click the “>>” button to assign the 31 cluster members to the desired Michigan traffic pattern “**Cluster 1**”. It is noted that the number of “**Setup Cluster 1**” has increased from 0 to 31, and the “**Selected Stations**” column are tied to the “**Setup Cluster 1**” to show its cluster members.
- Follow the same step to “**Setup Cluster 2**” and “**Setup Cluster 3**”. Repeat this process until all the pre-defined clusters are assigned. Prep-ME allow users to remove the cluster setup by clicking the “<<” button. It also allow users to assign individual WIM station to a cluster using the lower “>>” button by the “**Cluster Members**” column. Similarly, users can remove an individual WIM station from a cluster using the lower “<<” button by the “**Cluster Members**” column. This function provides

state DOTs with a very helpful tool to manually or semi-automatically setup clusters for further discriminant analysis.

- Click the "**Save Cluster Setup**" button. Users need to save the setup results for each traffic indicator individually.

For the definition of each pre-designed traffic pattern (cluster) defined in Michigan, users can click the "**See Cluster Definition**" button for brief help information from the Michigan Final Report # RC-1537.

Run Discriminant Analysis. After all the traffic patterns of the seven indicators are properly set up and saved, users should observe that: (1) the numbers of "Desired" and "User Setup" clusters are identical, (2) the "Independent Variables" input is enabled and users can input required project parameters to "Identify Traffic Patterns" (Figure 12). These independent parameters are then used for discriminant analysis to determine the desired clusters that each traffic indicator belongs to. With the input values, click "Identify Traffic Pattern" and Prep-ME will run the discriminant equations and identify the desired cluster number for each indicator. Hit "OK" to return to "Export Traffic Data" opening interface for data review and output.

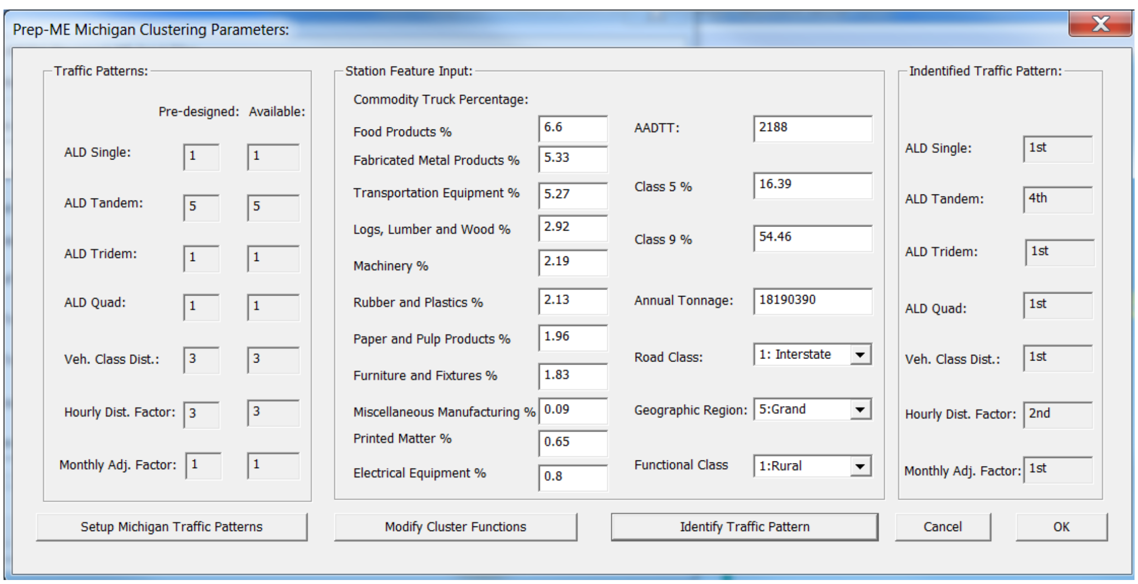


Figure 12

Identifying traffic pattern using Michigan method

Output Level 2 - NCDOT Clustering

NCDOT Methodology. Key results of the NCDOT research project (Sayyady et al 2010) are (1) the relative insensitivity of pavement performance to Hourly Distribution

Factor (HDF), (2) the use of 48-h classification counts to estimate Vehicle Class Distribution (VCD) inputs, and (3) a decision tree and table to help pavement designers select the proper Axle Loading Distribution Factor (ALDF) clusters and subsequently their inputs.

Initially, the WIM volume and weight data are reviewed with respect to completeness and anomalies using a quality control procedure. The cleaned data are then processed using computer programming to generate traffic factors including ALDF, MAF, HDF, and VCD for each WIM station.

Secondly, MEPDG damage-based sensitivity analysis is performed to identify sensitive factors that affect pavement performance and non-sensitive factors that do not. The analysis shows that pavement performance is sensitive to ALDFs, MAFs, and VCDs, but insensitive to HDF. To develop VCD factors, the 48-h site-specific classification counts are processed based on the seasonal factoring procedure as recommended in the Traffic Monitoring Guide (FHWA, 2001) to account for day-of-week and seasonal variations within a year. State average input are used for HDF input in North Carolina.

Thirdly, hierarchical clustering analysis based on North Carolina ALDFs and MAFs develops representative seasonal traffic patterns for different regions of the state. Among the four axle types (single, tandem, tridem, and quad), the tandem axle type is the most important one because it has the highest volume. Therefore, the clustering analysis is initially done based on tandem axles. The identified clusters are later modified based on the single and tridem axle types.

Consequently, a simplified decision tree and a related table help the pavement designer select the proper representative patterns of ALDF and MAF. Qualitative and quantitative explanatory parameters for the selection of traffic clusters include annual average daily truck traffic (AADTT), truck percentage (AADTT/AADT %), the ratio of Class 5 to Class 9 vehicles (5/9), and the ratio of single-unit (SU) trucks to multi-unit (MU) trucks [the ratio of Class 4–7 vehicles to Class 8–13 vehicles (SU/MU)] (Sayyady et al 2010). This decision tree has been fully implemented in Prep-ME.

A detailed NCDOT clustering approach is in the Appendix of the 2013 version of Traffic Monitoring Guide.

Prep-ME Interface. As shown in Figure 8, select “NCDOT Method” to enter the interface of NC-Clustering (Figure 13).

- Users need to input “**Project VCD**” data for vehicle classes 4 to 13. The total summation of the factors should be 100%. Click “**Save Input**” and the VCD figure will be updated with the newly input VCD data sets.

- The current Prep-ME software provides two options to set up the Axle Loading Distribution Factor (ALDF) groups. "**Upload External Groups**" allows the user to upload and directly use existing research clustering results for Prep-ME. NCDOT developed external ALDF groups and corresponding input files for MEPDG through NCDOT project HWY-2008-11. The data for the external groups should be prepared in ALDF data format that can be imported by Pavement ME Design software. The second option is to "**Set up Clusters**" using data from the Prep-ME database and build-in cluster analysis algorithms.
- In order to "**Run Decision Tree,**" "**Project Data**" should be provided, including "**AADTT,**" "**Class 5 %,**" "**Class 9 %,**" and "**Route Type.**" AADTT come from the input in the **Export Traffic Data** opening interface (Figure 8). "**Class 5 %**" and "**Class 9 %**" data are calculated from the users' input "**Project VCD**" data. "**Route Type**" is selected by users based on the location of the design.
- For rigid pavement design, statewide ALDF data is used and the "**Run Decision Tree**" button is not activated. For flexible pavement, users need to select ALDF groups. Click the "**Run Decision Tree**" button and the software will automatically generate the recommended ALDF cluster for pavement designers to consider. The algorithm for recommending an ALDF is summarized in Table 2.
- There are four ALDF groups for NCDOT method. Generally speaking, from Group 1 to Group 4, more multiple-unit (MU) vehicles and heavier loading are expected. ALDF Group 4 is more suitable for major roads while Group 1 for minor roads.
- Users have the option to "**Use Uploaded Clusters**" or "**Use Database Clusters**". The uploaded clusters are based on external results, while the database clusters are based on the user's setup from the Prep-ME database.
- The Prep-ME software provides a recommendation of ALDF Group for pavement designers. Pavement designers can investigate the ALDF group recommendation by reviewing the following data plots: (1) VCD plot (Figure 13): compare the project VCD with the vehicle class distributions of the four ALDF groups; (2) class comparison plot (Figure 14): compare the % Class 5 and % Class 9 trucks between project data and the ALDF grouping data; (3) Load plot (Figure 15): demonstrate the single and tandem loading distribution of the four ALDF groups; and (4) station summary (Figure 16): view the clusters for each traffic parameter and the members of this cluster.

Figure 13

NCDOT method

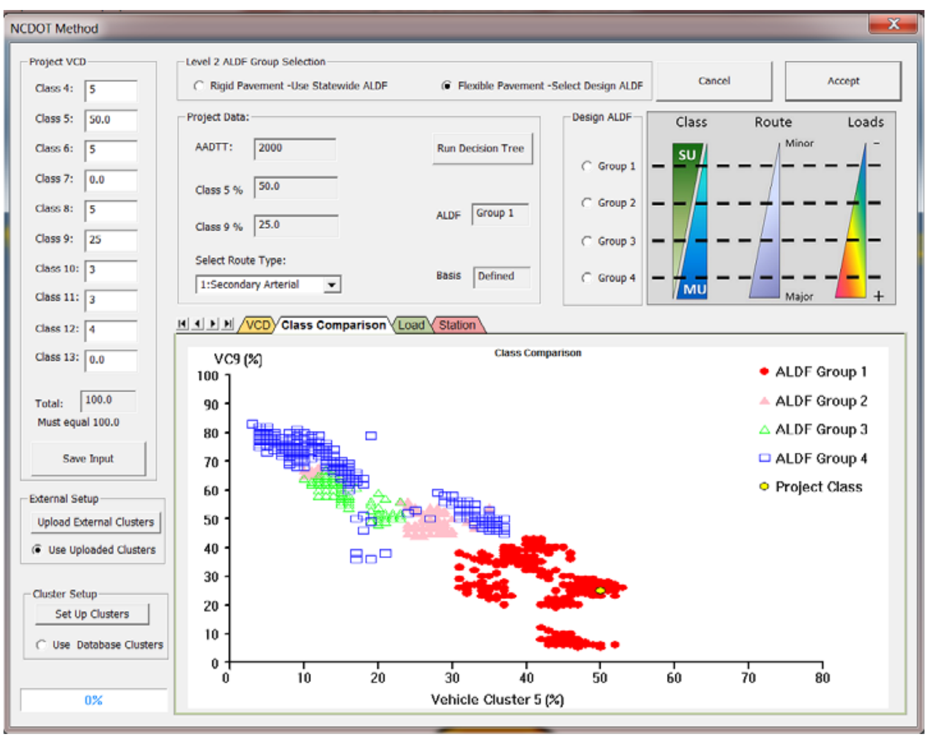


Figure 14

Traffic output by class comparison

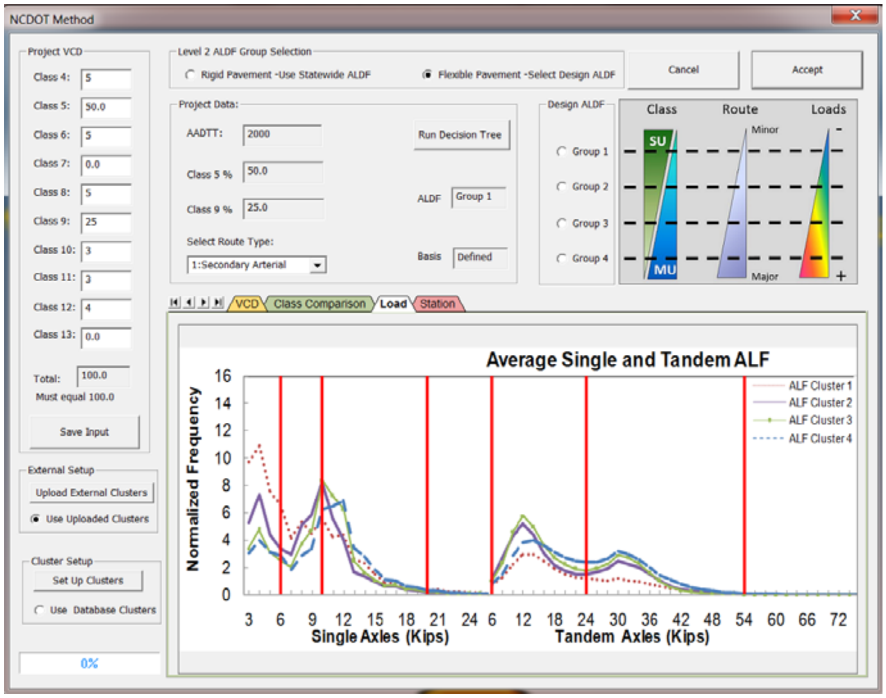


Figure 15

Traffic output by load

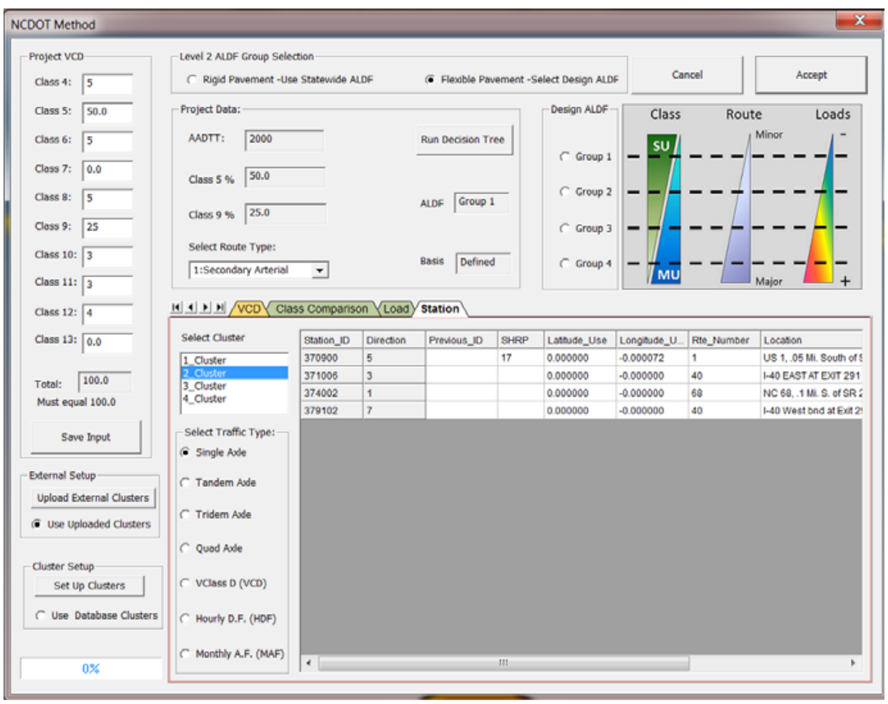


Figure 16

Traffic output by station information

Table 2

Algorithm for recommending an ALDF group for NCDOT

Step	Category	Criteria	Result
1	Pavement Type	If Pavement Type = Rigid	Recommended ALDF = Statewide And Recommended Basis = Defined
		If Pavement Type = Flexible	Go To Step 2
2	Class Distribution Only	If Class 9% >= 68 And Class 9% < 85 And Class 5% >= 3 And Class 5% < 18	Recommended ALDF = 4 And Recommended Basis = Defined
		If Class 9% >= 4 And Class 9% < 44 And Class 5% >= 30 And Class 5% < 54	Recommended ALDF = 1 And Recommended Basis = Defined
		If Class 9% >= 68 Or Class 5% < 18	Recommended ALDF = 4 And Recommended Basis = Assumed
		If Class 9% < 44 Or Class 5% >= 30	Recommended ALDF = 1 And Recommended Basis = Assumed
		If Recommended ALDF is not assigned a group	Go To Step 3
3	Class Distribution and Route Type	If Class 9% >= 44 And Class 9% < 68 And Class 5% >= 10 And Class 5% < 37 And Route Type = Primary Arterial	Recommended ALDF = 4 And Recommended Basis = Defined
		If Class 9% >= 44 And Class 9% < 68 And Class 5% >= 10 And Class 5% < 37 And Route Type = Collector	Recommended ALDF = 2 And Recommended Basis = Defined
		If Class 9% >= 44 And Class 9% < 68 And Class 5% >= 10 And Class 5% < 24 And Route Type = Secondary Arterial	Recommended ALDF = 2 And Recommended Basis = Defined
		If Recommended ALDF is not assigned a group	Recommended ALDF = None And Recommended Basis = Manual

Based on the review results, pavement designers will make the decision which ALDF Group the design would belong to. Subsequently, (1) designers can select the identified ALDF Group and click “Accept” to take the ALDF group; (2) return to the Export Traffic Data opening interface to review and output traffic data.

To set up clusters using the Prep-ME database data, click “Set Up Clusters” to launch the software interface. It is desired to have: (1) four clusters for Single Axle and Tandem Axle loading factors; (2) one cluster for Tridem Axle, Quad Axle loading factors, Hourly Distribution Factor (HDF), and Monthly Adjustment Factor (MAF); and (3) Vehicle Class Distribution (VCD) data based on user input site-specific project VCD data. Similarly, the numbers of set-up clusters and pre-designed clusters (Current/Desired Cluster Num.) should be identical when the clustering set-up process is successful. The clustering set up procedure is similar to that for the Michigan DOT method.

Output Level 2 - KYTC Method

The Kentucky Transportation Cabinet (KYTC) has been implementing aggregate classes for traffic data preparation. The definition of aggregate class is shown in Table 3.

The Prep-ME interface for KYTC method is shown as in Figure 17.

- Select “**KYTC Method**” and click the “**Assemble Aggregate Class**” button to show available aggregate classes in the database.
- Users can review the setup KYTC clusters by clicking the button of “**Review Aggregate Class.**”
- Select the functional class of the pavement under design; the corresponding KYTC Aggregate Class will be used to generate the output for the particular design.
- Click “OK” and return to the **Traffic Data Export** opening interface to review and output traffic data for a particular design.

Table 3

Aggregation class of roadway in Kentucky

Aggregate Class	Functional Class
Class I	Rural Interstate (FC1)
Class II	Rural Principal Arterial (FC2)
	Rural Minor Arterial (FC6)
Class III	Rural Major Collector (FC7)
	Rural Minor Collector (FC8)
	Rural Local (FC9)
Class IV	Urban Interstate (FC11)
Class V	Urban Other Freeway and Expressway (FC12)
	Urban Other Principal Arterial (FC14)
Class VI	Urban Minor Arterial (FC16)
	Urban Collector (FC17)
	Urban Local (FC19)

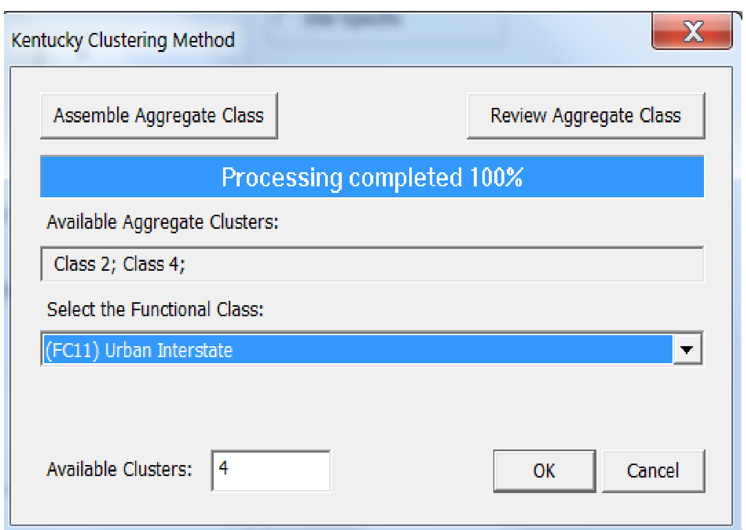


Figure 17

KYTC method

Output Level 2 - TTC Method

TTC Methodology. Even though various clustering approaches have been proposed, one of the key challenges is that these approaches are computationally extensive that require significant mathematical and statistical knowledge to conduct such analyses. Pavement ME Design itself has proposed a relatively straightforward grouping approach based on Truck Traffic Classification (TTC). Seventeen TTC groups are developed in Pavement ME Design to represent commonly encountered vehicle distribution spectra and are developed primarily around vehicle classes 5, 9, and 13. Default truck distribution values for these 17 TTCs are developed in Pavement ME Design based on the data from the LTPP program, as shown in Figure 18.

When designing a pavement section, pavement engineers can obtain the truck traffic composition on that section from short-term traffic count and identify the TTC group. Using this approach, the traffic inputs required in Pavement ME Design can be generated from historical database based on identified TTC group.

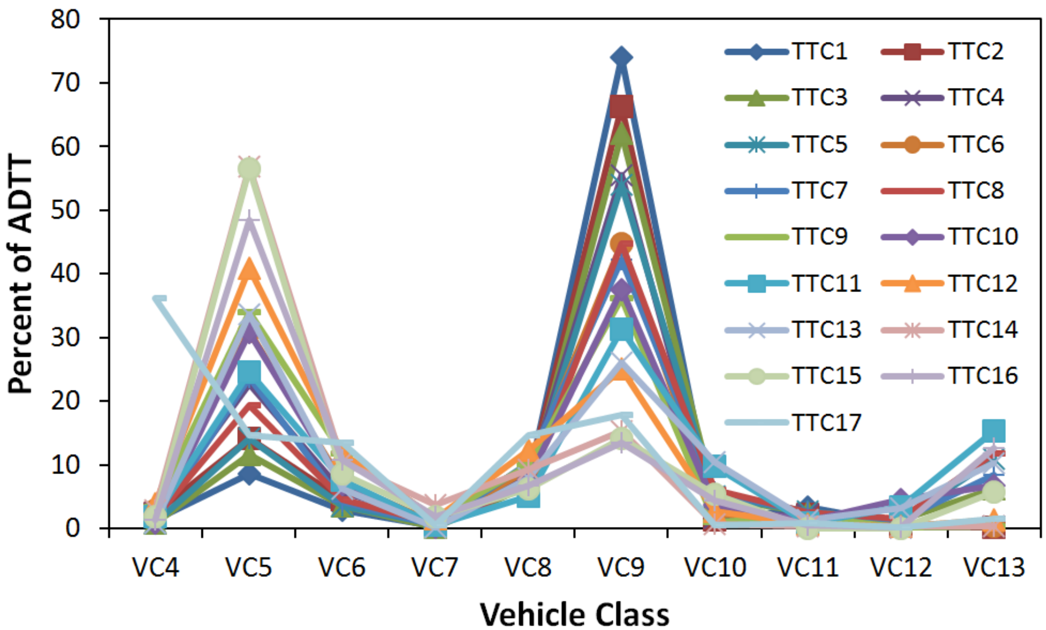


Figure 18

Pavement ME design TTC values

TTC Software Interface. The procedure of using the TTC cluster method for generating level 2 outputs is shown in Figure 18. This TTC approach can be used by states without a developed clustering approach to prepare axle loading spectra data for Pavement ME Design.

- Select "**TTC Clustering**" and the interface is shown in Figure 19.

- Click the "**Setup TTC Clusters**" button and the "**Available TTC Clusters**" will be populated with available TTCs that are available in the Prep-ME database after the progress bar is completed 100%.
- Users can review the setup TTC results by clicking the button of "**Review TTC Clusters**". The interface is demonstrated in Figure 20.
- Input short term truck count data at the design location, including counts for Class 4, Class 5, Class 9, and Class 13, and the total truck counts from Class 4 to Class 13,
- Click the button of "**Calculate TTC**" to "**Calculate TTC**" Cluster. The data for the WIM stations that belong to this TTC cluster are used to generate the output for the particular design. However, the TTC dentitions proposed in Pavement ME Design do not include all the truck class distributions. In many cases, the software will return with "Invalid TTC" because no TTC class can be identified based on users' short-term traffic input. By clicking "**Check TTC Plots**", The Prep-ME software provides users with TTC plots to compare site-specific distribution with those for Pavement ME TTC classes, and make a selection based on engineering judgment (Figure 21).
- Finally, click "OK" and return to the **Traffic Data Export** opening interface. Users can now review and output traffic data for this particular design.

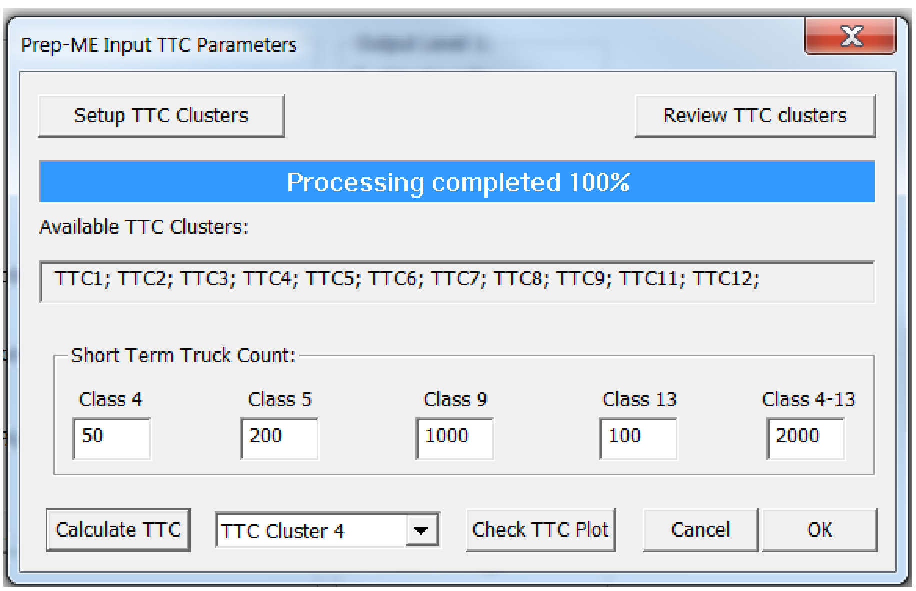


Figure 19

TTC clustering method

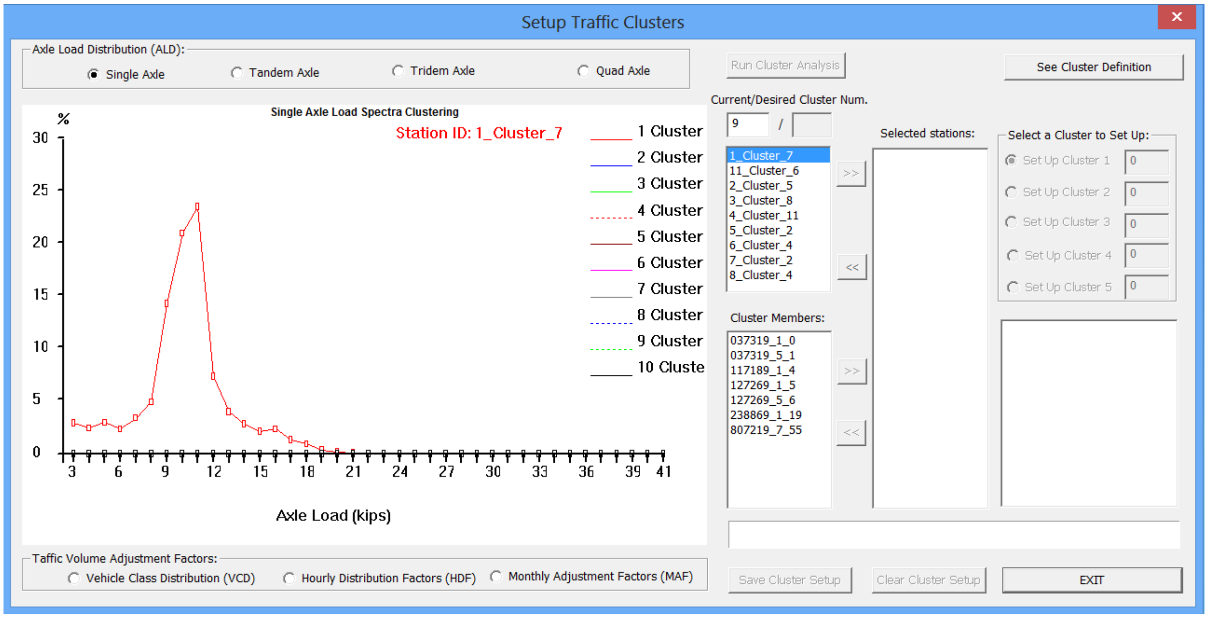


Figure 20

Review TTC Clusters

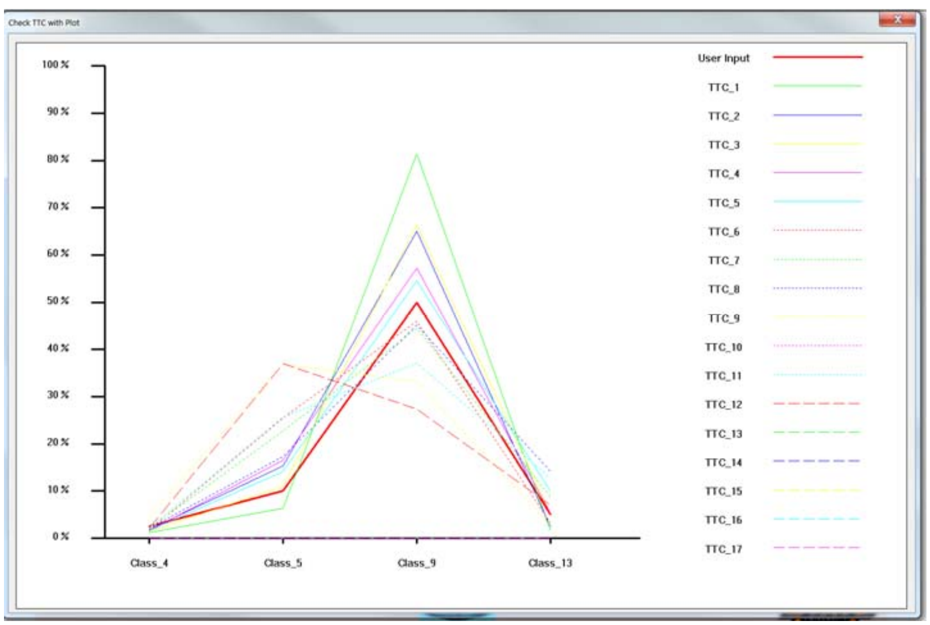


Figure 21

Check TTC plots

Output Level 2 - Simplified TTC Clustering

Methodology. It can be seen in Figure 18 that the differences of some TTC groupings are not significant. In many cases, site-specific short-term data couldn't be collected before a pavement actually opens to traffic. As a result, it is challenging to determine the TTC group that most closely describes the design traffic stream for a roadway under design. Li and Wang (2012) have developed a simplified TTC grouping approach so that highway agencies and practitioners can adopt it easily for their routine pavement design when short-term site-specific traffic counts are limited. The simplified four clusters developed to characterize truck traffic are illustrated in Figure 22. It is illustrated that the simplified truck traffic patterns can be distinguished by the relative proportion of Class 4, Class 5, and Class 9 trucks:

- Cluster 1 - Single-Unit Dominant Route (local haul trucking - Class 5)
- Cluster 2 - Multi-Trailer Dominant Route (long haul trucking - Class 9)
- Cluster 3 - Mixed Truck Route
- Cluster 4 - Bus Route (Class 4)

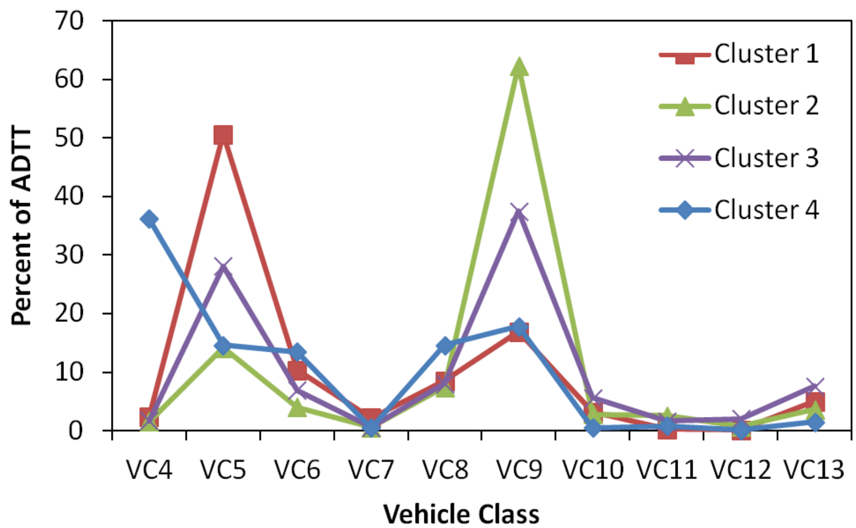


Figure 22

Simplified TTC approach (Li et al. 2012)

With the developed simplified TTC clusters, pavement designers can make Level 2 traffic inputs using existing WIM data based on prior engineering knowledge of the truck traffic spectra for major truck types. Even though this approach cannot provide traffic data as robust as Level 1 site-specific traffic data, this simplified approach will generate better traffic data than state average Level 3 input for the designs of less important pavements.

Software Interface. The TTC approach needs short term traffic data. If no data is available on the pavement under design, users can adopt the simplified TTC clustering procedure to prepare traffic data, generally for low-volume secondary road design. The procedure is similar to that for the "TTC Clustering" method.

- Click the "**Simplified TTC Clustering**" button on the **Traffic Data Export** opening interface, as shown in Figure 23.
- Click the "**Setup Simplified TTC Traffic Patterns**" button to get the result of available clusters.
- "**Select Route Type**" for the design based on local engineering knowledge.
- Click the "OK" button to return to the opening Export Traffic Data interface to review and output traffic results.

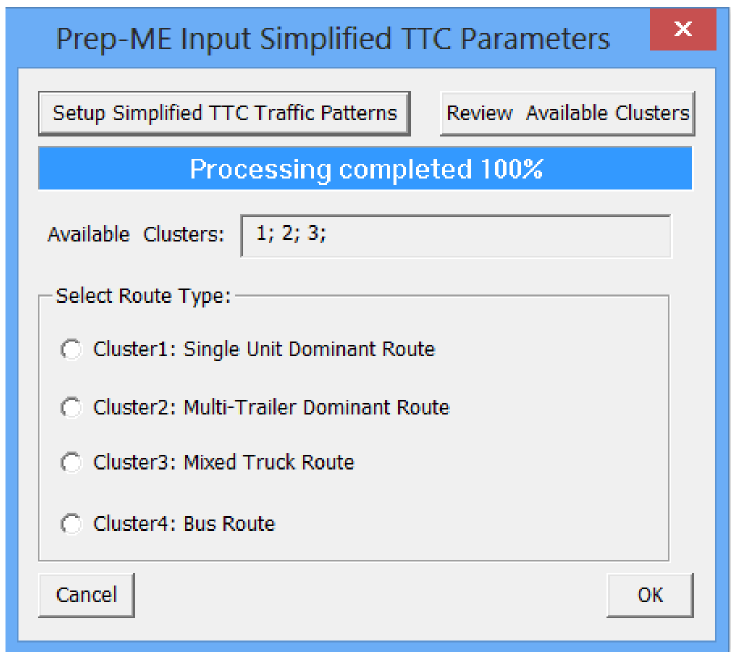


Figure 23

Simplified TTC clustering method

Output Level 2 - Flexible Clustering

In many cases, traffic engineers are familiar with the traffic patterns on the highway segments where WIM stations are located. Based on local engineering judgment, the traffic engineer may decide to use the data from all the WIM stations on Interstate 94 for a major arterial pavement design in the same area. The "**Flexible Clustering**" method allows user to apply local engineering judgment and select WIM sites with similar traffic patterns for the traffic data preparation for Pavement ME Design. The interface for "**Flexible Clustering**" is shown in Figure 24. Since "**Flexible Clustering**" doesn't use any statistical methodology, the desired number of clusters for each parameter is one. Users only need to manually select relevant WIM stations for traffic data export for the traffic parameters. The example in Figure 24 uses all the WIM stations on I-94 to generate Single Axle Load Distribution factors.

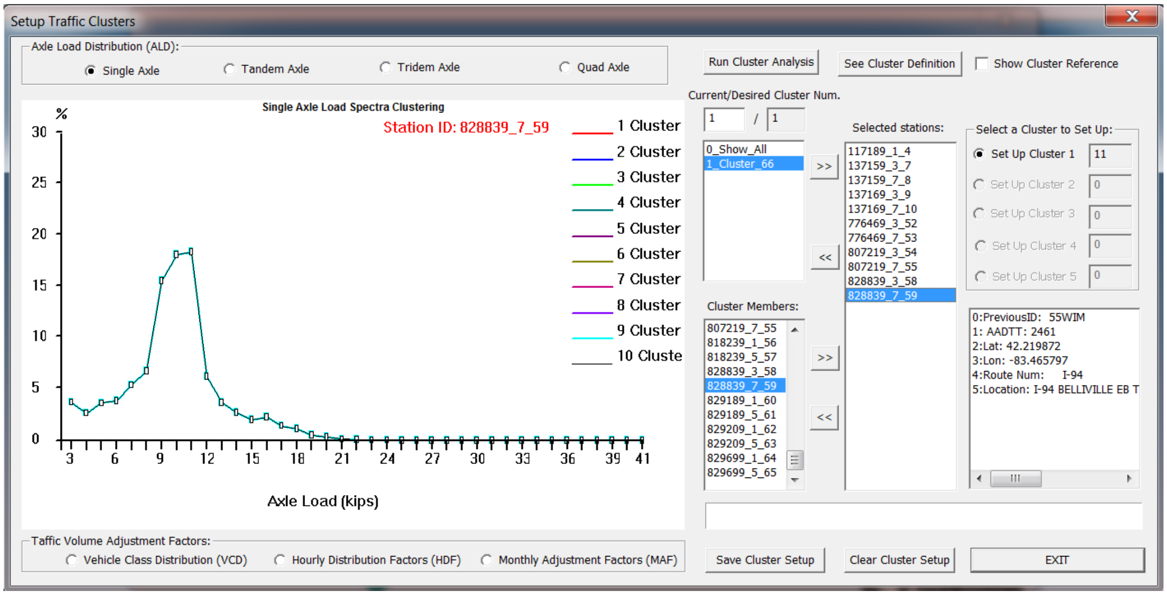


Figure 24

Flexible clustering method

Output Level 3

If insufficient data is available for Level 1 and Level 2 output or a traffic parameter is insignificant to pavement performance prediction, Level 3 state average values can be used for pavement design.

Output Level 3 can be selected by clicking one of these check boxes under "**Output Level 3**" (as shown in Figure 8). The current version of Prep-ME can prepare Level 3 output using "**State Average,**" "**LTPP-5(004)**" and "**Pavement ME Default.**" Users can review or export Level 3 results.

The Prep-ME software includes a preliminary function to implement the LTPP TPF-5(004) loading group method: *Long-Term Pavement Performance (LTPP) Specific Pavement Study (SPS) Traffic Data Collection*. The preliminary function allows users to export the results developed from this study in two tiers of loading groups: "Tier 1 – Global" and "Tier 2 – Typical" (Figure 25).

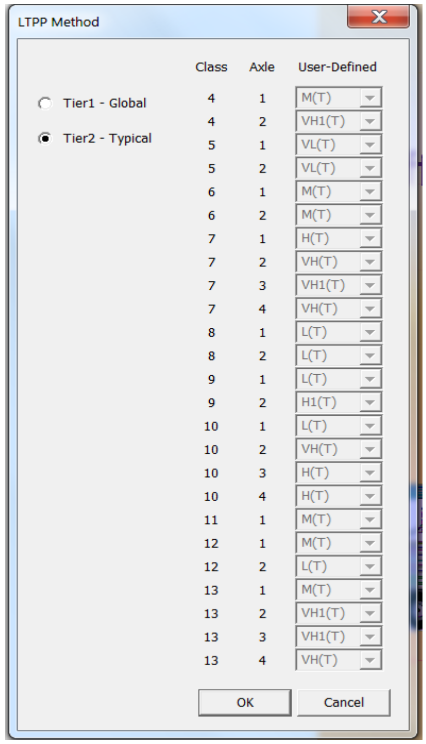


Figure 25

LTPP TPF-5(004) method

Review Output Data

Before exporting xml files or text files, users can review traffic data and make modifications on traffic input data or output levels. After clicking the "**View Output Data**" button, a data review interface will appear (Figure 26.)

As shown in Figure 26, users can review four types of traffic data: Vehicle Class Distribution (VCD), Hourly Distribution Factors (HDF), Monthly Adjustment Factors (MAF), Axle Load Distribution Factors (ALDF) including those for single, tandem, tridem, and quad axles. Users can switch viewing of these four type traffic data by clicking their tabs.

For specific type traffic data, such as VCD, users may opt to change the output level from Level 1 to Level 3 (or vice versa) by clicking the check boxes, and then click the button of "**Save Change to Output Level.**" In addition, Prep-ME also allows users to manually modify the software generated values with site-specific data if available. The changes can be saved by clicking "**Save Modification**" for traffic data output.

This mixed output setting is useful when only classification or WIM data is available for a specific site. After set-up of the levels of output, click the button of "OK" to return to the interface of "**Export Traffic Data.**"

Figure 26

Displaying output data

Climate Module in Prep-ME

Climate Data Import

The Climate Import function (Figure 27) in Prep-ME is used to:

- Import HCD (Hourly Climate Data) files from the Pavement-ME Design software, or/and additional climate data files from individual state DOTs following the same data formats required by Pavement ME Design.
- Conduct preliminary data check. The software can be customized for individual DOTs and comprehensive data check can be implemented to obtain high quality climate data sets.

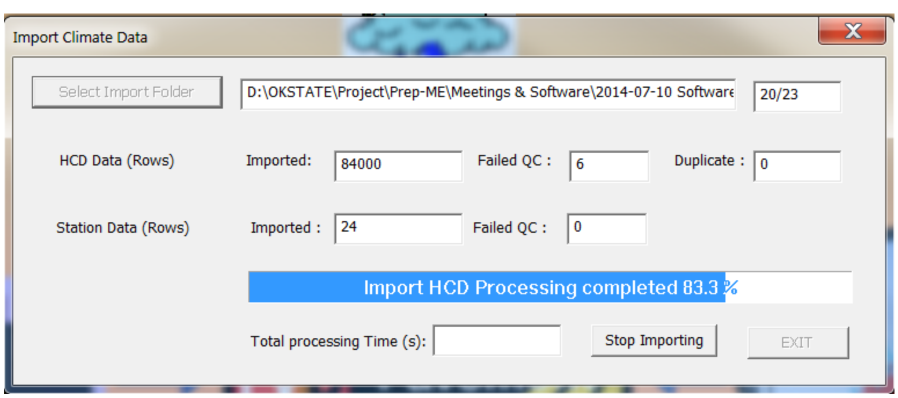


Figure 27

Importing climate files

After climate data are imported, Google Map 3.0 utility is launched to demonstrate the locations of the climate stations (Figure 28).

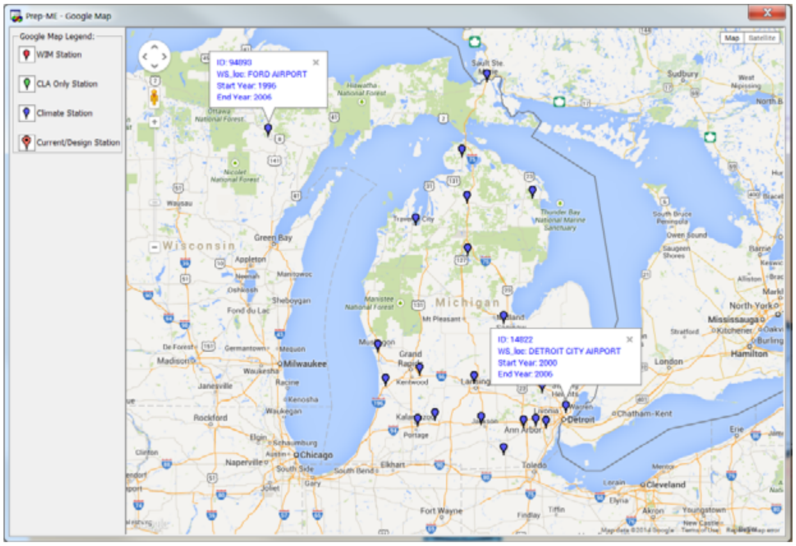


Figure 28

Google Map 3.0 utility for climate data

Export Climate Data

The Climate Export function (Figure 29) in Prep-ME is used to interpolate ICM files based on the imported data in the database. The software requires latitude, longitude, elevation, water depth table and time zone of the station that the user wants to set up for interpolation. The software can generate a virtual weather station file (ICM file) based on up to six existing adjacent stations from the database for users to select. The selected climate stations will be demonstrated in Google Map (Figure 30). The generated ICM file can be directly imported to MEPDG and Pavement-ME Design software.

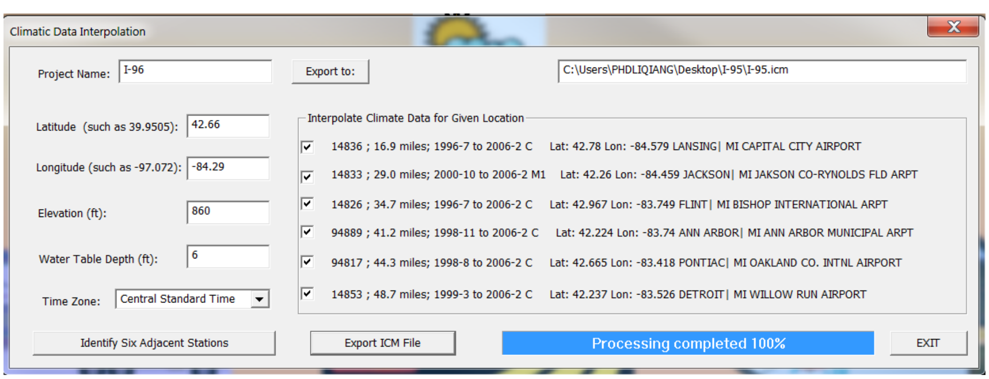


Figure 29

Interpolating climate files

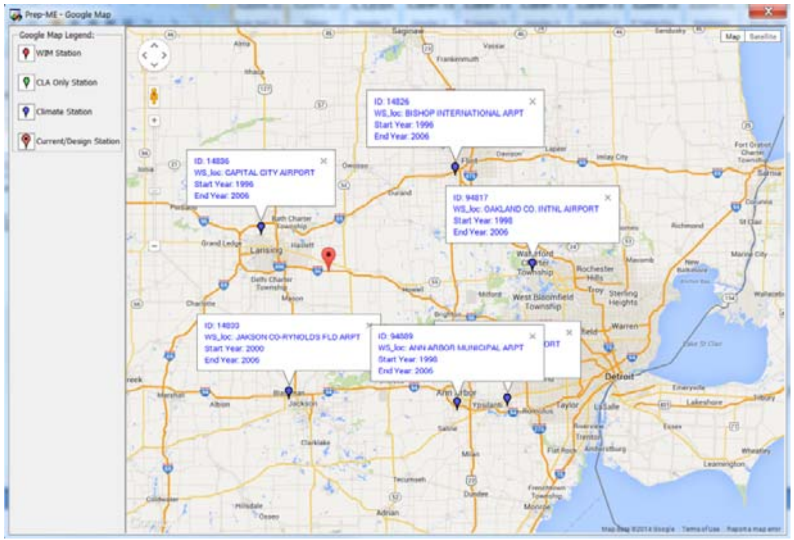


Figure 30

Selected climate stations on Google Map

Material Module in Prep-ME

In the material module, Dynamic Modulus (E*) for asphalt concrete, Coefficient of Thermal Expansion (CTE) for PCC pavement, and subgrade related parameters based on soil maps developed from NCHRP 9-23 project, can be retrieved based on the testing results from previous lab testing and NCHRP 9-23A research project. In addition, preliminary FWD functions are developed in Prep-ME to assist users utilizing FWD data for pavement evaluation and Pavement ME rehabilitation design.

Dynamic Modulus (E*) for HMA

The dynamic modulus (E*) of hot-mix asphalt (HMA) is one of the key parameters used to evaluate both rutting and fatigue cracking distresses in the MEPDG. The dynamic modulus represents the stiffness of the asphalt material when tested in a compressive-type, repeated load test. The Pavement ME Design software provides general default parameters for the dynamic modulus (i.e., Level 2 and 3 inputs). However, caution has already been raised by researchers as to the appropriateness of these parameters for regional areas. As a result, many state agencies have conducted comprehensive dynamic modulus laboratory testing based on state local materials and mix design specifications by varying factors such as aggregate type, nominal maximum aggregate sizes, PG binder grade, and air-void level.

Example data sets are populated into the Prep-ME database. The Prep-ME software can retrieve dynamic modulus data based on binder grade, nominal maximum aggregate size, air void level, coarse aggregate type (Figure 31). Users can not only view the retrieved testing data for dynamic modulus, asphalt binder properties, and mix design, but also export the data for Pavement ME Design to import.

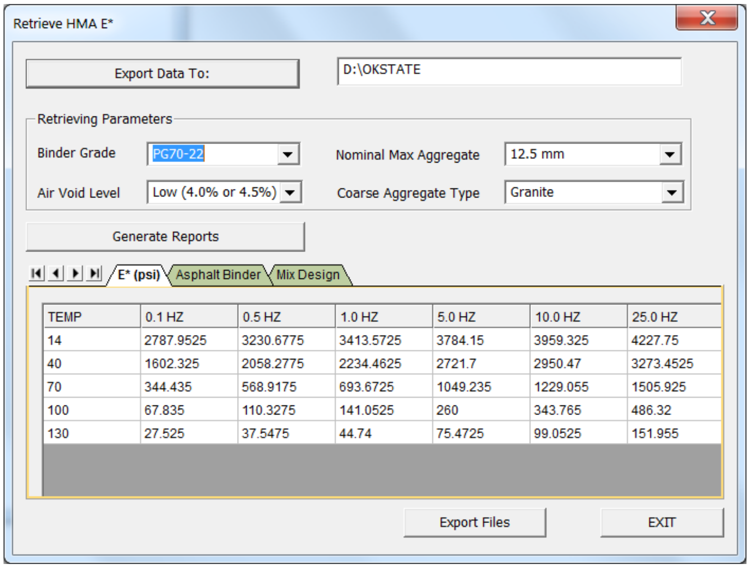


Figure 31

Retrieving Dynamic Modulus (E*) data

Coefficient of Thermal Expansion (CTE) for PCC

CTE of concrete materials has been identified as a very sensitive parameter affecting rigid pavement distress predictions within the Pavement ME Design software. However, many state agencies did not routinely determine the CTE of concrete materials in the past. With the needs of implementing Pavement ME Design, state agencies started testing CTE to develop typical CTE inputs in accordance with the AASHTO TP 60 protocol. A testing plan typically includes typical aggregates and cement types used for concrete mixtures. In addition, the PCC strength properties for the PCC mixtures are also tested at various aging conditions.

In Prep-ME, example data sets are populated into the database. The Prep-ME software can retrieve CTE data based on coarse aggregate type, cementitious paste, and mixture age (Figure 32). Users can not only view the retrieved testing data for CTE of PCC mix and cement paste, PCC mix properties, mixture time series strength and Poisson's ratio, but also export these data for Pavement ME Design.

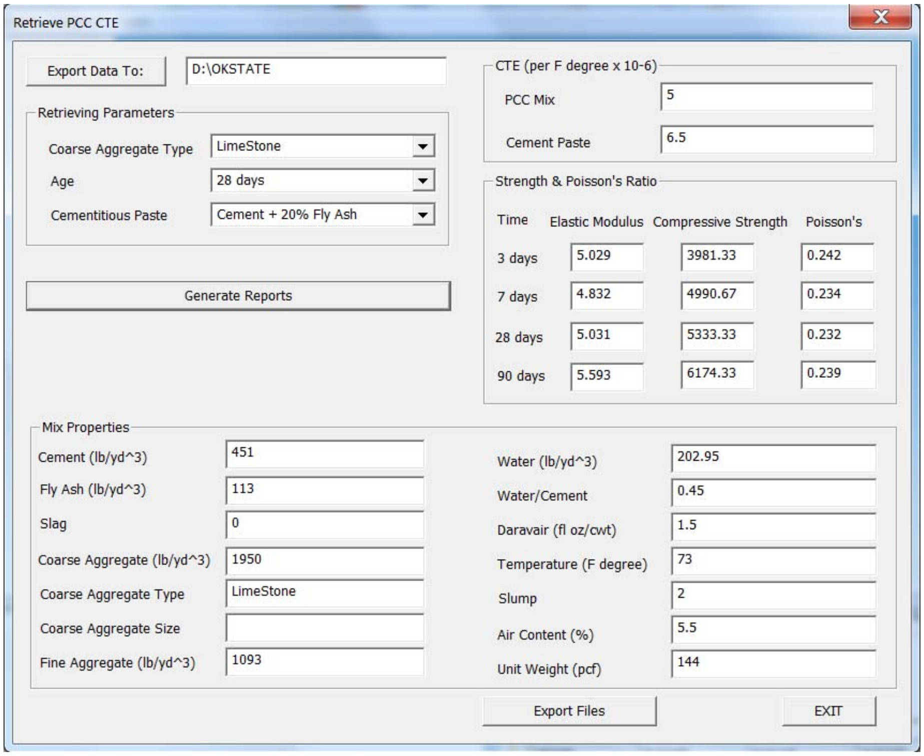


Figure 32

Retrieving CTE data

Soil Map for Subgrade

The NCHRP Project 9-23A project: *Implementing a National Catalog of Subgrade Soil-Water Characteristic Curve (SWCC) Default Inputs for Use with the MEPDG*, has created a national database of pedologic soil families that contains the soil properties for subgrade materials needed as input to the MEPDG. The database includes the parameters describing the soil-water characteristic curves (SWCC), which are key parameters in the implementation of MEPDG Level 1 environmental analysis, but also includes measured soil index properties needed by the EICM in all three hierarchical levels of pavement design. 814 soil maps covering the entire US are created from this project with an Excel based interface. Users can utilize this interface to facilitate searching for specific locations within a state.

The national database provides transportation agencies with a tool to design a pavement through the use of the measured materials properties rather than empirical equations. This database can assist pavement designers using the MEPDG. This database can also allow further analyses to estimate better default parameters for Level 3 designs. Parameters such as the group index, the complete soil gradation, and the Atterberg limits can be used to further subdivide soil classifications and improve the default parameters used as MEPDG inputs.

In Prep-ME, the soil maps and related soil property data are programmed in the software. The steps required to extract the desired subgrade SWCC and soil properties at a selected site using the Prep-ME interface:

- By inputting the latitude and longitude of a design location, the associated Soil Map image will be loaded into the software interface with a cross marking demonstrating the design location (Figure 33).
- Users can manually input the “Map Char” code on the soil map at the design location to the Prep-ME software interface (Figure 33).
- A soil report with all the required soil parameters in Pavement ME Design will be generated for users to view (Figure 34). Users can also import the soil parameters in a txt file report (Figure 35).

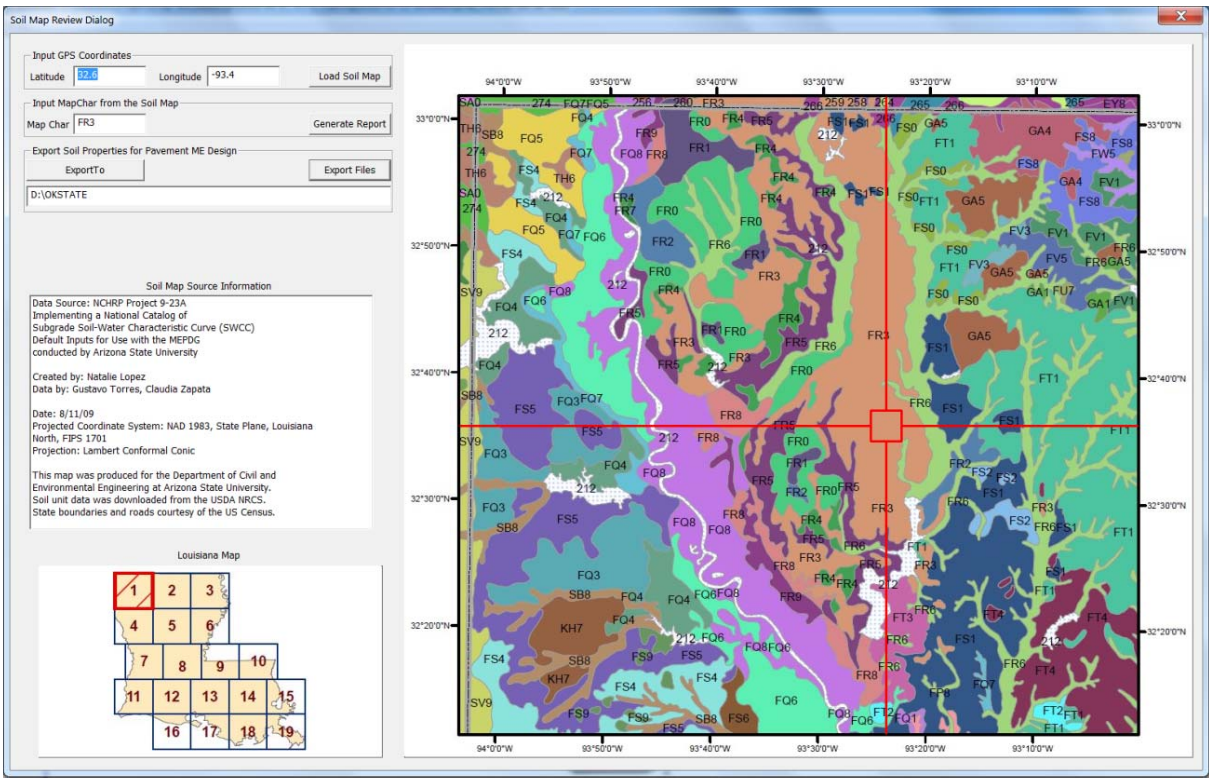
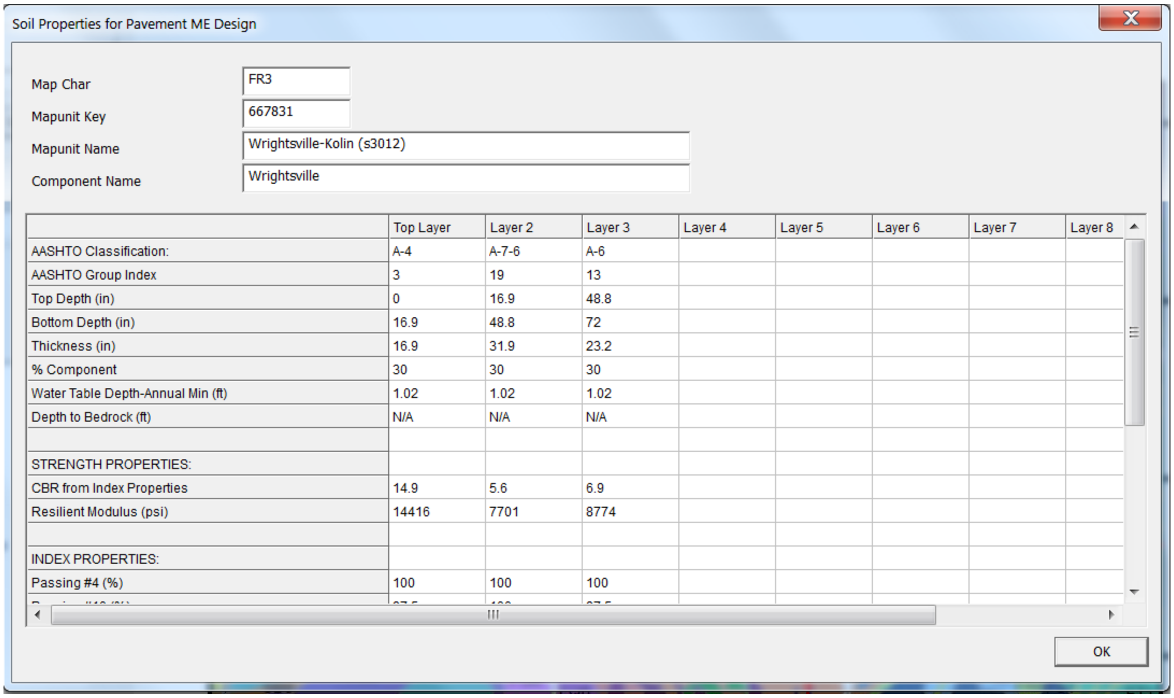


Figure 33

Soil Map Module in Prep-ME


Soil Properties for Pennement ME Design

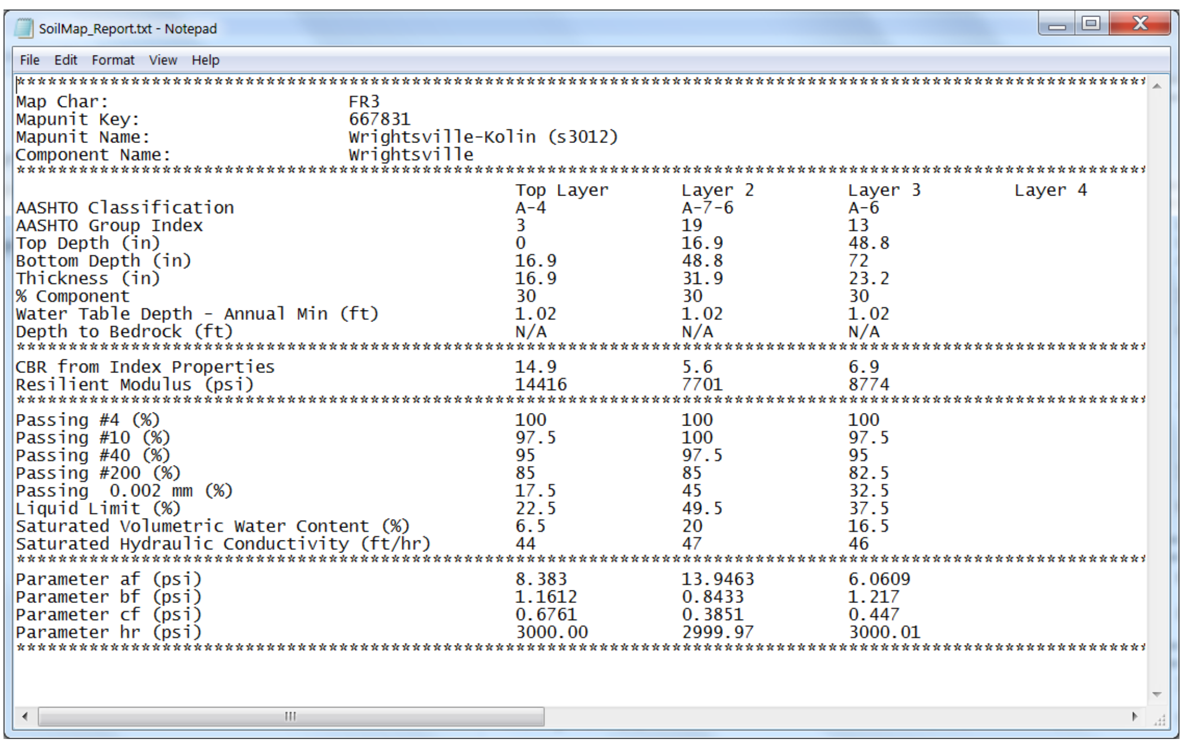
Map Char	FR3
Mapunit Key	667831
Mapunit Name	Wrightsville-Kolin (s3012)
Component Name	Wrightsville

	Top Layer	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8
AASHTO Classification:	A-4	A-7-6	A-6					
AASHTO Group Index	3	19	13					
Top Depth (in)	0	16.9	48.8					
Bottom Depth (in)	16.9	48.8	72					
Thickness (in)	16.9	31.9	23.2					
% Component	30	30	30					
Water Table Depth-Annual Min (ft)	1.02	1.02	1.02					
Depth to Bedrock (ft)	N/A	N/A	N/A					
STRENGTH PROPERTIES:								
CBR from Index Properties	14.9	5.6	6.9					
Resilient Modulus (psi)	14416	7701	8774					
INDEX PROPERTIES:								
Passing #4 (%)	100	100	100					

OK

Figure 34

Retrieved Soil Properties


SoilMap_Report.txt - Notepad

File Edit Format View Help

Map Char:	FR3			
Mapunit Key:	667831			
Mapunit Name:	Wrightsville-Kolin (s3012)			
Component Name:	Wrightsville			

	Top Layer	Layer 2	Layer 3	Layer 4
AASHTO Classification	A-4	A-7-6	A-6	
AASHTO Group Index	3	19	13	
Top Depth (in)	0	16.9	48.8	
Bottom Depth (in)	16.9	48.8	72	
Thickness (in)	16.9	31.9	23.2	
% Component	30	30	30	
Water Table Depth - Annual Min (ft)	1.02	1.02	1.02	
Depth to Bedrock (ft)	N/A	N/A	N/A	
CBR from Index Properties	14.9	5.6	6.9	
Resilient Modulus (psi)	14416	7701	8774	
Passing #4 (%)	100	100	100	
Passing #10 (%)	97.5	100	97.5	
Passing #40 (%)	95	97.5	95	
Passing #200 (%)	85	85	82.5	
Passing 0.002 mm (%)	17.5	45	32.5	
Liquid Limit (%)	22.5	49.5	37.5	
Saturated Volumetric Water Content (%)	6.5	20	16.5	
Saturated Hydraulic Conductivity (ft/hr)	44	47	46	
Parameter af (psi)	8.383	13.9463	6.0609	
Parameter bf (psi)	1.1612	0.8433	1.217	
Parameter cf (psi)	0.6761	0.3851	0.447	
Parameter hr (psi)	3000.00	2999.97	3000.01	

Figure 35

Generated soil property file for Pavement ME Design

Preliminary FWD Functions

Falling Weight Deflectometer (FWD) testing has grown in popularity, becoming one of the most effective tools in the evaluation and characterization of existing pavement structures for rehabilitation purposes and for constructing new pavements. In Pavement ME Design, it is recommended that FWD data and subsequent data analysis results be used as an input to determine rehabilitation strategies for existing pavement structures. In Prep-ME, a preliminary FWD module has been developed, which can:

- Import raw FWD F25 data into Prep-ME database (Figure 36): currently only F25 FWD files can be imported into the Prep-ME database. Deflection data, temperature data, and general FWD information are saved into Prep-ME database;
- Input pavement structure data into Prep-ME database (Figure 36): users need to manually input pavement structure data where FWD testing is performed;
- Output a summary report for back-calculation software: Prep-ME outputs a summary report including pavement structure data along with the deflection data for use in back-calculation process (Figure 37); and
- Generate FWD XML file for Pavement ME Design (Figure 38): after the back-calculation analysis is completed using a third party software, user can manually input the back-calculated modulus at multiple stations for each pavement layer through Prep-ME. Prep-ME can output FWD XML file that can be read by Pavement ME Design.

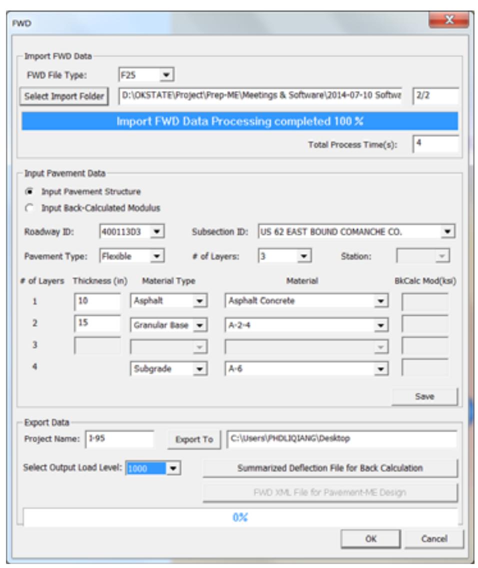
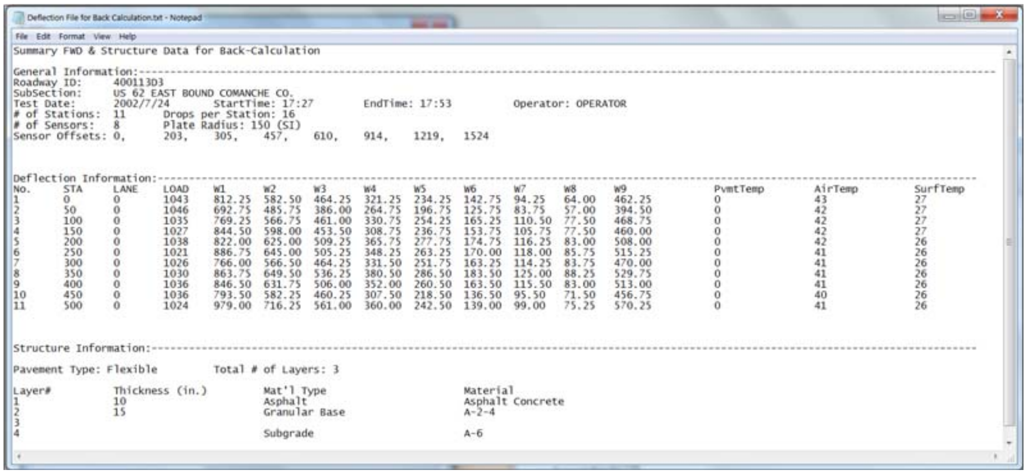


Figure 36

Import FWD data



Deflection File for Back Calculation.txt - Notepad

File Edit Format View Help

Summary FWD & Structure Data for Back-Calculation

General Information:
Roadway ID: 400113D3
SubSection: US 62 EAST BOUND COMANCHE CO.
Test Date: 2002/7/24 StartTime: 17:27 EndTime: 17:53 Operator: OPERATOR
# of Stations: 11 Drops per Station: 16
# of Sensors: 8 Plate Radius: 150 (SI)
Sensor Offsets: 0, 203, 305, 457, 610, 914, 1219, 1524

Deflection Information:

No.	STA	LANE	LOAD	W1	W2	W3	W4	W5	W6	W7	W8	W9	PvmtTemp	AirTemp	SurfTemp
1	0	0	1043	812.25	582.50	464.25	321.25	234.25	142.75	94.25	64.00	462.25	0	43	27
2	50	0	1046	692.75	485.75	386.00	264.75	196.75	125.75	83.75	57.00	394.50	0	42	27
3	100	0	1035	769.25	566.75	461.00	330.75	254.25	165.25	110.50	77.50	468.75	0	42	27
4	150	0	1027	844.50	598.00	453.50	308.75	236.75	153.75	105.75	77.50	460.00	0	42	27
5	200	0	1038	822.00	625.00	509.25	365.75	277.75	174.75	116.25	83.00	508.00	0	42	26
6	250	0	1021	886.75	645.00	505.25	348.25	263.25	170.00	118.00	85.75	515.25	0	41	26
7	300	0	1026	766.00	566.50	464.25	331.50	251.75	163.25	114.25	83.75	470.00	0	41	26
8	350	0	1030	863.75	649.50	536.25	380.50	286.50	183.50	125.00	88.25	529.75	0	41	26
9	400	0	1036	846.50	631.75	506.00	352.00	260.50	163.50	115.50	83.00	513.00	0	41	26
10	450	0	1036	793.50	582.25	460.25	307.50	218.50	136.50	95.50	71.50	456.75	0	40	26
11	500	0	1024	979.00	716.25	561.00	360.00	242.50	139.00	99.00	75.25	570.25	0	41	26

Structure Information:

Pavement Type: Flexible Total # of Layers: 3

Layer#	Thickness (in.)	Mat'l Type	Material
1	10	Asphalt	Asphalt Concrete
2	15	Granular Base	A-2-4
3			
4		Subgrade	A-6

Figure 37

Generate Report for FWD Back-Calculation

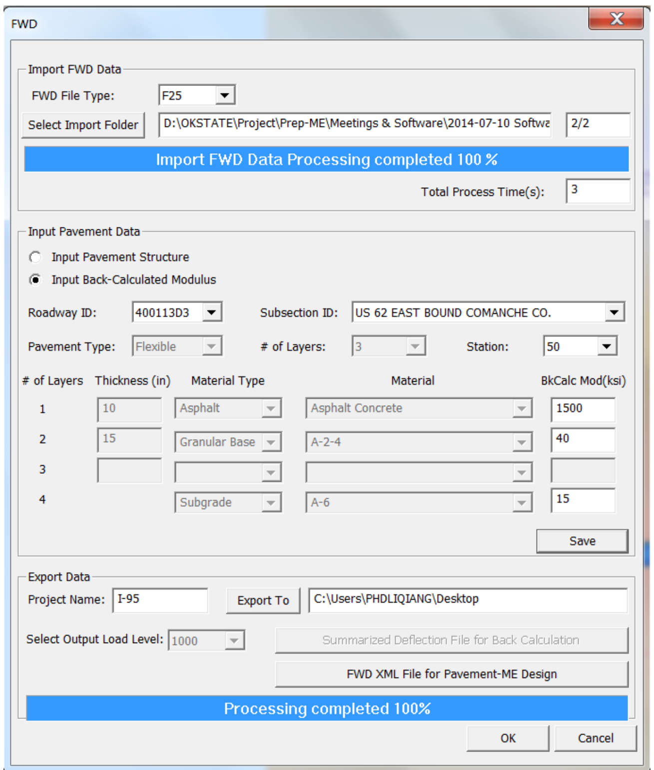


Figure 38

Output FWD XML file for Pavement ME Design

File Name Change

The current version of Prep-ME software can only read traffic data that comply with the TMG data file format. The file extensions of Station card, C-Card, and W-Card should be ".STA," ".CLA," and ".WGT" as recommended in TMG. If a state DOT uses other extensions for station, classification or weight data the files cannot be imported into the Prep-ME software. As an example, Michigan DOT uses .WIM, .STA and .CLA extensions for weight, station and classification data. The weight data files are not .WGT extension and cannot be imported into Prep-ME. Therefore, file extension change is desired. Users can change the extension manually, or using the "Change File Names" function provided in Prep-ME in batch mode. If the number of files is small, manual changing the file extension is preferred.

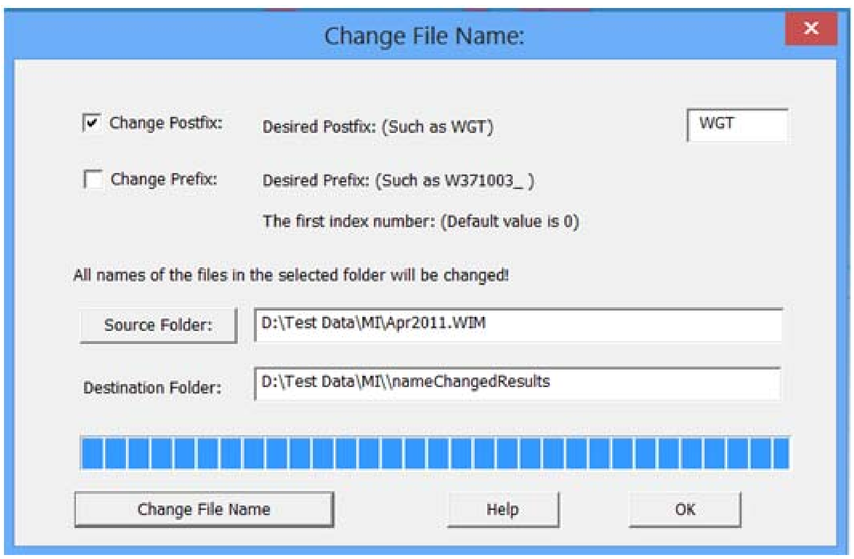


Figure 39

Change file name interface

AADTT Calculation Based on Short Term Traffic Counts

The Average Annual Daily Truck Traffic Prediction function calculates the VCD for vehicle class 4-13 based on short term traffic count (24 hours or 48 hours). The interface is shown in Figure 40.

- Users have to input the first 24 hours and second 24 hours traffic data, including the month of year (1-12) and day of week (1-7) for which the data is reported. The day of week will be Monday and Sunday if the inputs are 1 and 7. The total traffic count and number of Class 4-13 vehicles in the total count has to be reported for the first and second 24 hours.

- Click on the button "**Estimate Annual Average,**" the Annual Average Daily Truck Traffic (AADTT) and the annual average daily traffic for Class 4-13 vehicles are predicted based on the AASHTO formulation for AADT. This formula computes an average day of week for each month, and then computes an annual average value from those monthly averages, before finally computing a single annual average daily value. This process effectively removes most biases that result from missing days of data, especially when those missing days are unequally distributed across months or days of the week.

Based on the AADT of the ten classes of trucks, vehicle class distribution factors are calculated for vehicle class 4-13, which can be directly input into the Pavement ME Design software.

Figure 40

AADTT prediction based on short term traffic count

1-mm PaveVision3D Laser Imaging Technology for Pavement ME Design

The Digital Highway Data Vehicle (DHDV), developed by the WayLink Systems Corporation with collaborations from the University of Arkansas and the Oklahoma State University, has evolved into a sophisticated system to conduct full lane data collection on roadways at highway speed up to 60 mph (about 100 km/h). With the latest PaveVision3D Ultra (3D Ultra in short), the resolution of surface texture data in the vertical direction is about 0.3 mm and in the longitudinal direction is approximately 1 mm at 60MPH data collection speed. Figure 41(a) shows the exterior appearance of the DHDV equipped with the 3D Ultra technology. With the high power line laser projection system and custom optic filters, DHDV can work at highway speed during daytime and nighttime and maintain image quality and consistency. 3D Ultra is the latest imaging sensor technology that is able to acquire both 2D and 3D laser imaging data from pavement surface through two separate left and right sensors. Each sensor in the rear of the vehicle consists of two lasers and five special-function cameras. For the two lasers, one is for providing 2D visual illumination and the other one for 3D data illumination. For the five cameras, four cameras are for capturing 3D laser illumination and the other one is for capturing 2D laser illumination. The camera and laser working principle is shown in Figure 41(b).

Figure 41

DHDV equipped with Pavevision3D

Data Collection

The OSU research team conducted field data collection using the PaveVision3D Ultra system at FHWA Long Term Pavement Performance (LTPP) sites including those with Weigh-In-Motion (WIM) systems and high-friction sites on nationwide basis. The data collection trip took 17 days for a three-person team to drive through 15 states and covered a total distance of about 5800 miles. During this trip, the team planned and visited 13 LTPP General Pavement Sections (GPS), 9 Specific Pavement Sections (SPS) with 46 segments, 4 Weigh-In-Motion (WIM) sites, and 14 FHWA High Friction Surface Treatment (HFST) sites, which are illustrated in Figure 42. The data was collected at normal highway speed under different weather conditions, such as sunny, cloudy, partly cloudy and light rain, for both flexible and concrete pavements. Because some sites are under construction, or have been overlayed, or it was raining when the sites were visited, not all the data are collected on the sites that were planned. In addition, the team also collected data for the 6.5-mile surface texture test section including Next Generation Concrete Surface (NGCS) from the Niles interchange to the Solomon Bridge interchange on Interstate 70 eastbound in Kansas.

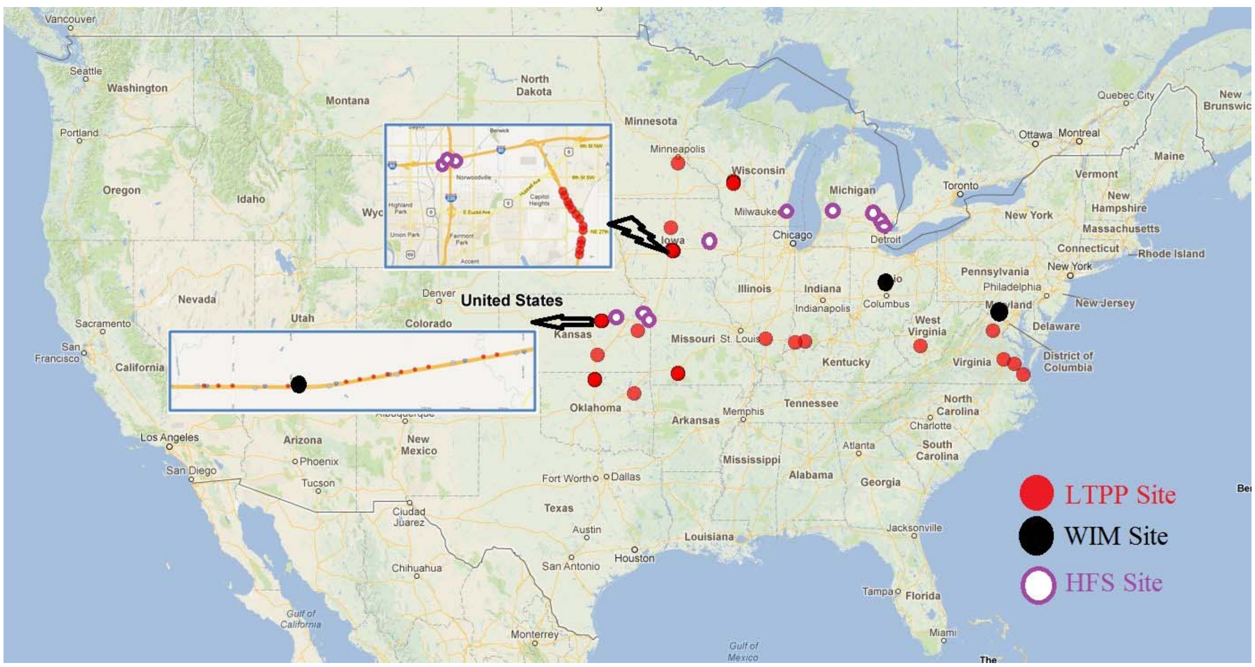


Figure 42

Data collection sites

LTPP Sites. Among the 13 planned and visited GPS sites, site 5453 in Illinois on Interstate 64 was under construction. Due to a route change, three sites that were planned (3055 in Iowa, 4037 in Minnesota, and 1005 in Kansas) were not on the revised routes and were excluded from the data collection. In addition, even though the data were collected for the two Indiana GPS sites (site 6012 and site 1028) it was observed that the sites have been overlayed and no markings could be identified on the pavement surface. As a result, only data for 7 GPS sites was delivered to FHWA.

Within each SPS segment, multiple test sites were constructed. For example, the SPS 19-0200 segment on US65 in Des Moines included 13 test sites (Figure 43). For the SPS segments, the two segments in Ohio were under construction when the team visited the locations. It was raining on the morning of September 16 for the data collection of 29-0800 in Missouri. The data were collected for that site, but due to the remaining water on the pavement surface, the data could not be used. Data were collected for site 55-0900 in Wisconsin and 40-0600 in Oklahoma. However, because these two SPS segments have been heavily treated, maintained, or overlayed, the markings for each test sites were missing with two exceptions: site 40-0601 and site 40-0602. As a result, the team had difficulty in identifying the locations of the test sites and excluded those sites without marking from the delivery.

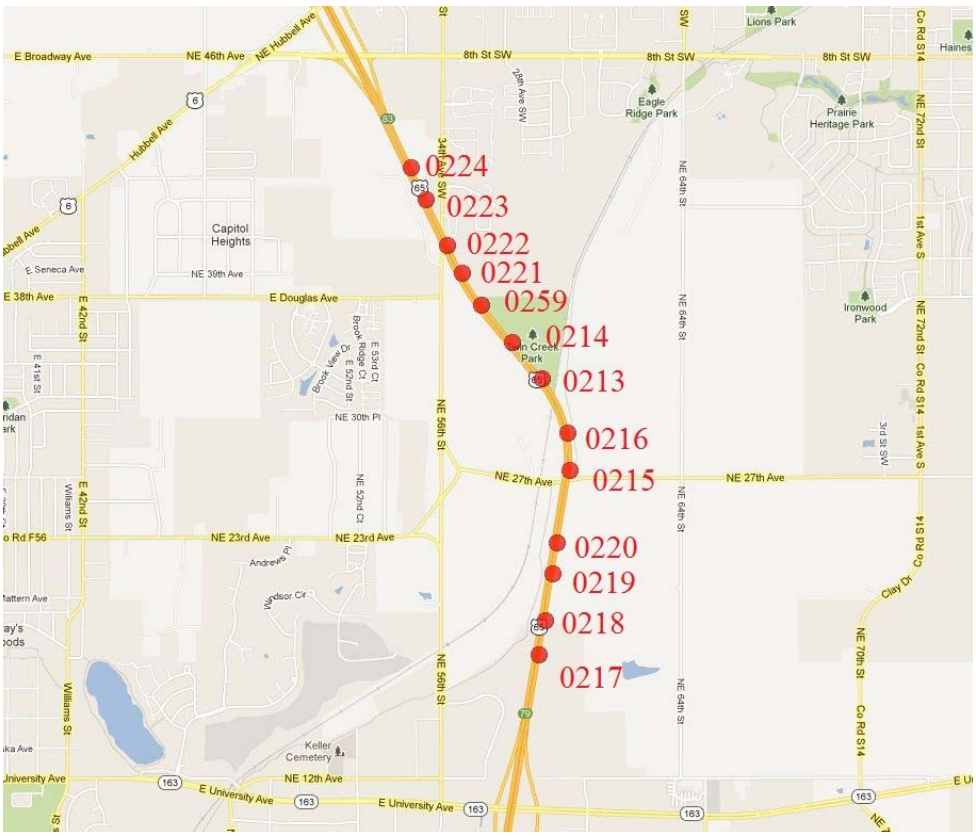


Figure 43

LTPP SPS 19-0200 segment with 13 test sites

Weigh-In-Motion (WIM) Sites. The team identified four WIM sites along the planned route from the LTPP's SPS WIM Pooled Fund Study. The two WIM sites in Ohio SPS1 and SPS2 were under construction during the visit, and thus this trip only collected pavement 3D data for two WIM sites.

High Friction Surface Treatment (HFST) Sites. Highway agencies periodically monitor pavement surface properties, such as friction and texture to reduce roadway highway accidents. In this context, high friction surface treatments (HFST) are becoming an appealing alternative since these systems are able to increase friction and improve texture immediately after placement without significantly affecting other pavement qualities such as noise or durability. The HFST consists of high polished stone value (PSV) aggregates mixed with some type of resin to hold the aggregate particles together and bond them to the existing pavement surface.

The FHWA has implemented a nation-wide High Friction Roads program (http://www.highfrictionroads.com/). In working with FHWA and TransTech group, 14 HFST along the data collection trip were planned. Further exploration of the collected data reveals that no HFST treatment seems to be applied on the ramp of northbound I-75 to northbound Baldwin Road on Exit 84A. The HFST site on K5 south of Eisenhower Road in Leavenworth, Kansas was removed from the program and thus the data were not collected. As a result, the data collection for 11 HFST sites was delivered.

It should be noted that HFST is applied at areas where high friction or anti-skidding properties are desired, such as horizontal curves and ramps, intersections/intersection approaches, steep grades etc. Figure 44 illustrate an example HFST sites in Milwaukee, Wisconsin.

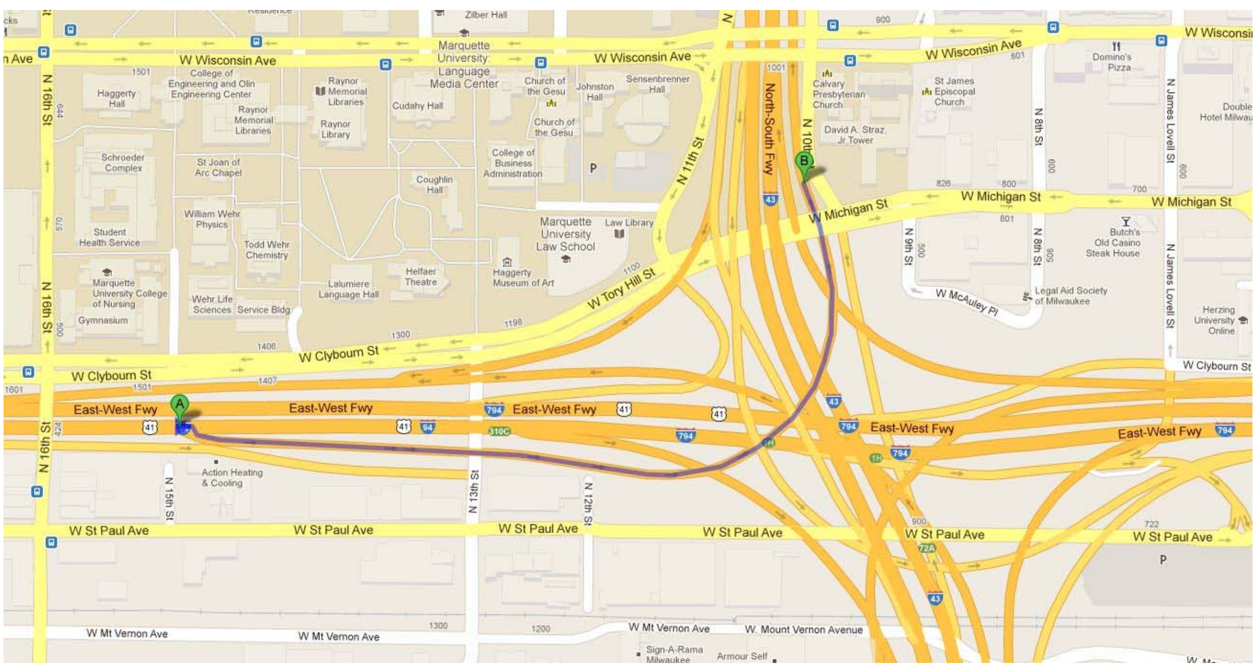


Figure 44

HFST in Milwaukee, Wisconsin

Other Sites. During this visit, the team also surveyed the Next Generation Concrete Surface (NGCS) on Interstate 70 eastbound from Niles interchange to Solomon Bridge interchange.

Data Deliverables

In total, the data for 48 testing sites were delivered to FHWA, including 7 GPS sites, 28 SPS sites, 2 WIM sites, and 11 HFST sites. The data for each site are stored in one folder. Inside of each folder for one test site, the same data structures used include the following files:

- Sub-file folder “3DData\00000000”: used for 3-D images storage;
- Sub-file folder “PvmtImg\00000000”: used for 2-D images storage;
- Sub-file folder “ROWImg\00000000”: used for 2-D Right-Of-Way images storage;
- “Alignment.seq”: the alignment file used for camera alignment;
- “Calibration.cal”: used for camera calibration; and
- “WisInfoIdx”: the access database file which contains the data collection information. This database file will be used for the data viewing software MHIS.

PaveVision3D Ultra surface data including 1-mm 3D data, 2D intensity data and right of way (ROW) data are collected at highway speed for the bridge decks and adjacent pavement sections in both directions. The Multimedia based Highway Information System Deluxe (MHIS-3D Deluxe) software is designed to view and analyze the collected data.

1-mm 3D Surface Data Sets

MHIS-3D Deluxe. MHIS-3D Deluxe provides the user with 2D and 3D graphical representation of all the data sets collected using the DHDV vehicle. These data sets, which are accessed and organized by MHIS-3D Deluxe, include Pavement Vision 3D images, Right-of-Way images, DMI and GPS readings. Figure 45 shows the overall user interface of MHIS-3D Deluxe. The 2D image frame is shown on the left, the 1-mm 3D height data frame on the top right, ROW in the middle of the bottom portion, and information frame on the bottom right. The 1-mm 3D frame can be rotated along x, y, and z directions for the user to investigate an object from various directions. The information frame provides speed information, GPS location information collected by an Inertial Measuring Unit (IMU) in DHDV. It is noted that the data were collected at 55.0 mph.

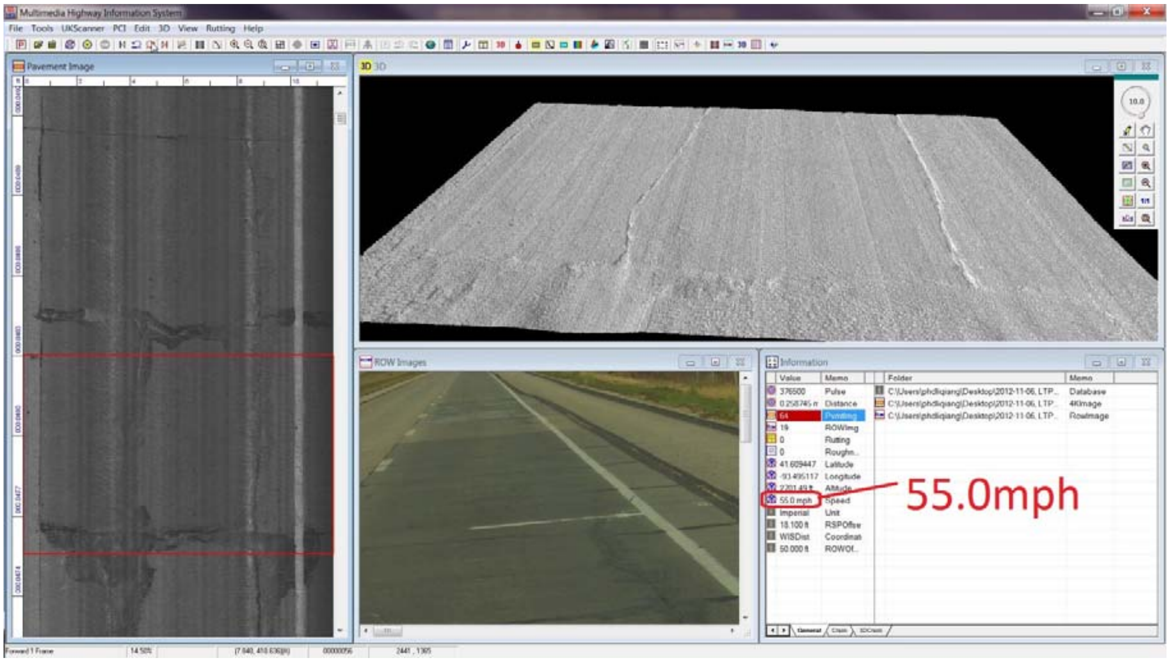


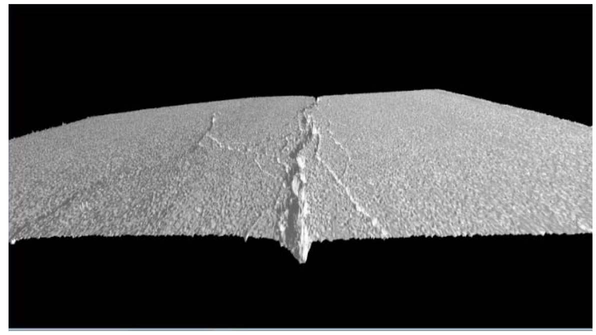
Figure 45

Example data at LTPP 200217

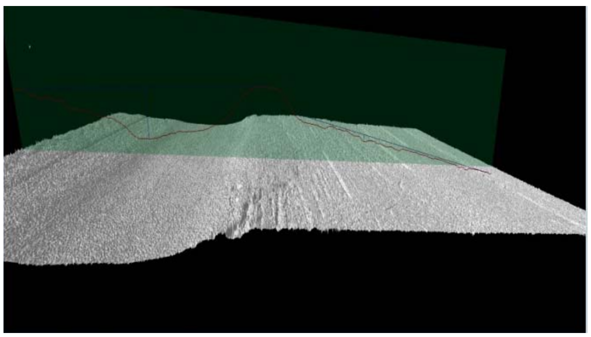
Example Data Sets. Several example data sets are shown in Figure 46. The PaveVision3D Ultra data with various key features are presented. These distinctive features with high resolution 3D height information are unprecedented compared to those from traditional 2D based imaging technology for pavement cracking.

As an addition to the **PaveVision3D** subsystem, a dedicated crack identification and categorization software called ***Automated Distress Analyzer 3D (ADA-3D)*** was developed. ***ADA-3D*** is designed to detect longitudinal, transverse, block, and alligator cracks and to calculate their lengths, widths, and other general information sets. Various post-processing features are also provided. The crack information from ***ADA-3D*** can be read by ***MHIS-3D,*** which generates crack maps and statistics using multiple crack survey protocols. In addition, ***ADA-3D*** is capable of conducting surveys of rutting and IRI. Figure 47 provides an example image with ADA3D detected cracks. ADA3D is able to define wheelpaths of a pavement, as illustrated in blue lines. Therefore various types of cracking can be reported in wheelpaths (such as fatigue cracking in MEPDG) and outside of wheelpaths (such as longitudinal cracking in MEPDG). Such capabilities will allow PaveVision3D collected data sets to be implemented for local calibration of MEPDG distress models. It is envisioned that the application of the PaveVision3D laser imaging technology for automated distress survey will provide a new and much more advanced platform for pavement engineers in both pavement design and management.

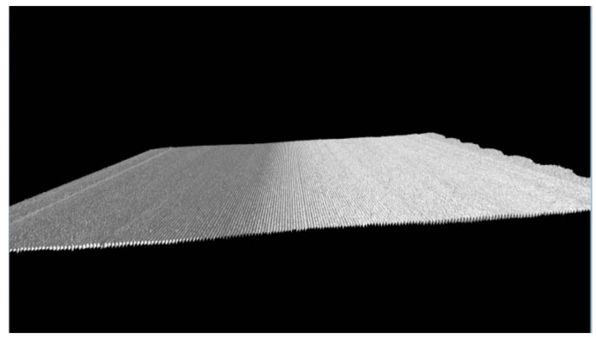
(1) Alligator Cracking



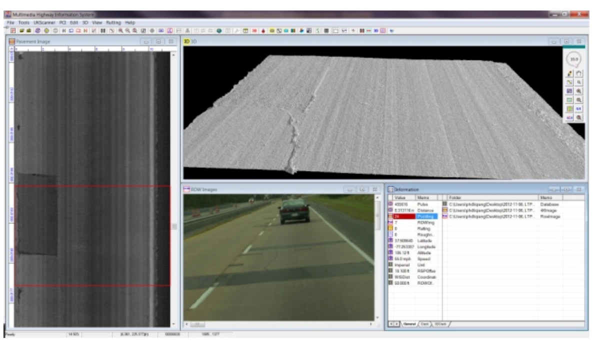
(2) 3D Crack Depth



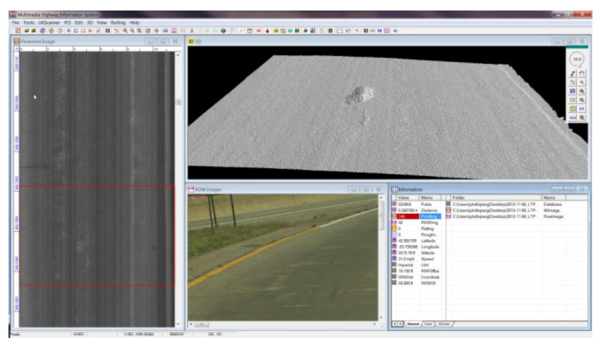
(3) Permanent Deformation



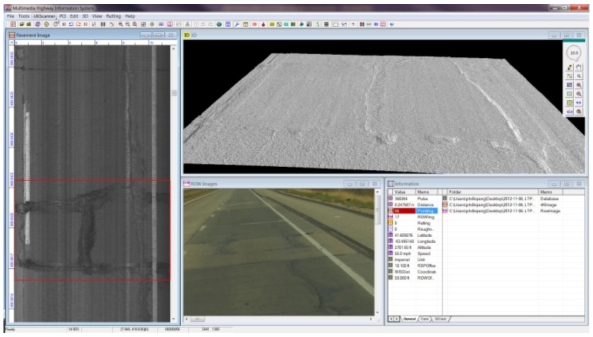
(4) Pavement Grooving



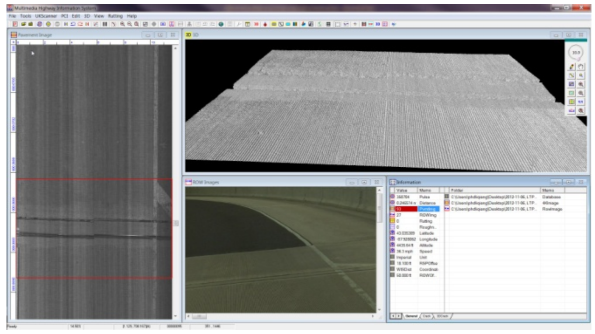
(5) Patching with Cracks



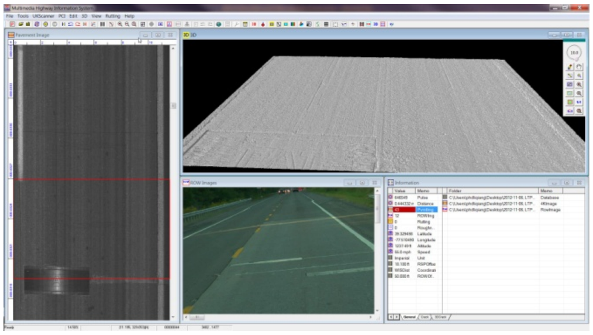
(6) Popout



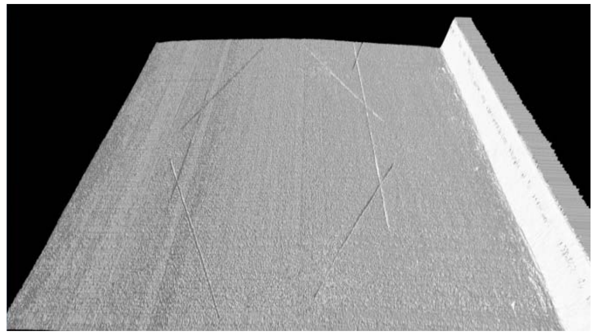
(7) Spalling, Patching with Cracks



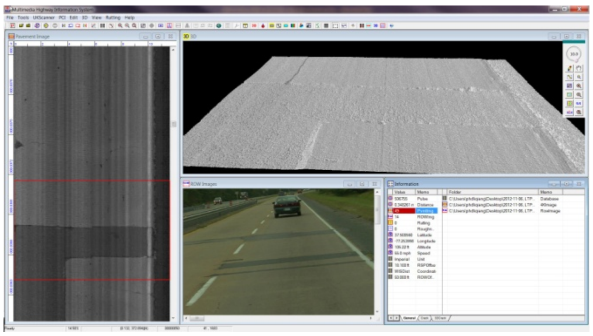
(8) Transition Area for HFST



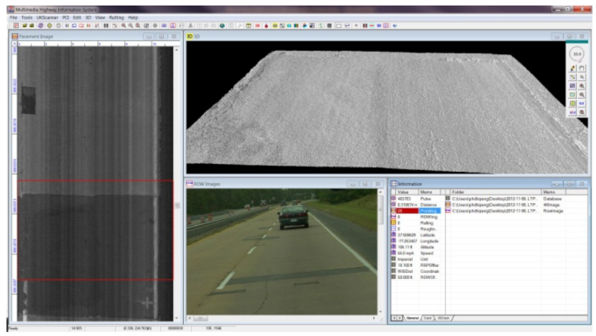
(9) WIM Plates and Its Logo



(10) WIM Site



(11) Patching with Height Difference



(12) Patching with Permanent Deformation

Figure 46

Example PaveVision3D data sets

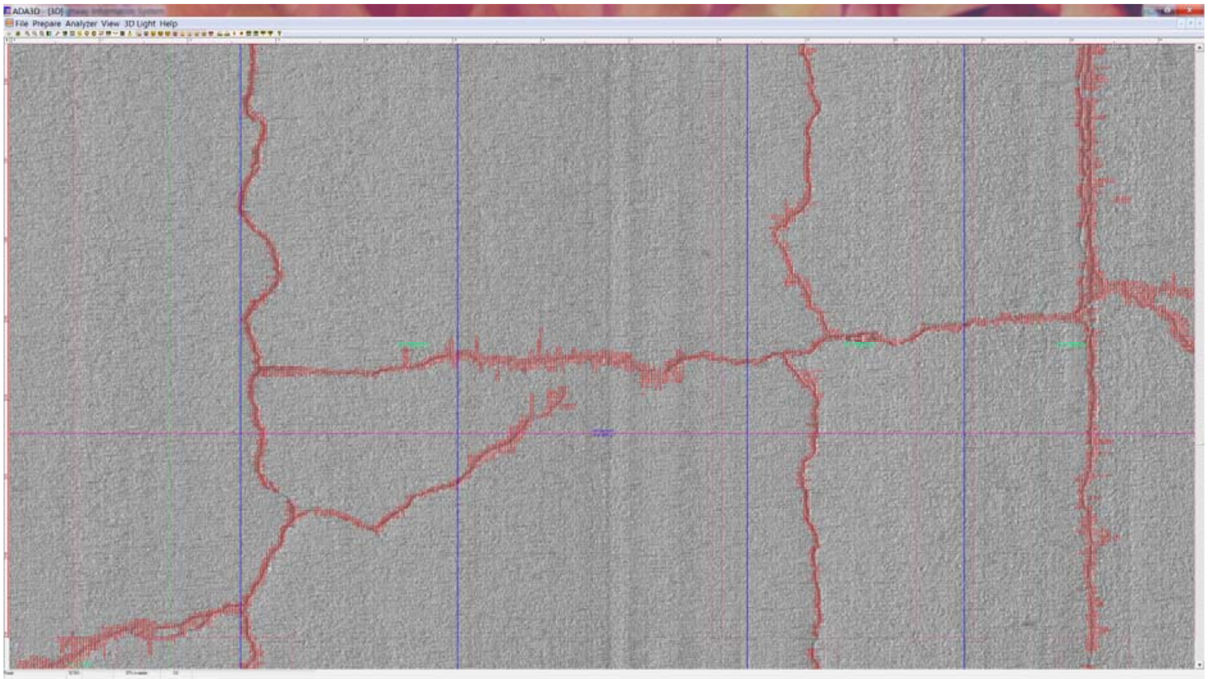


Figure 47

ADA3D for automated distress detection

CONCLUSIONS

The Prep-ME software has been enhanced in the pooled-fund study TPF-5(242). Prep-ME is able to assist state DOTs in the data preparation and improve the management and workflow of the Pavement ME Design input data. Prep-ME has comprehensive database features to store and process climate, traffic, materials, distress and performance data. The functionalities of the software interface based on the consensus of participating states are demonstrated. It is envisioned that through this pooled fund study, a possible nationwide platform for data preparation of Pavement ME Design can be established with guidelines and support provided to individual states for local calibration and implementation purposes.

The success of Prep-ME depends on its capability in detecting and filtering out various input errors of raw traffic data, considering millions of lines of raw input data. Prep-ME has investigated and developed effective error handling methods and codes. Specifically, TMAS 2.0 checking rules have been implemented into Prep-ME framework. QC checking codes have fully taken advantage of relational SQL database for efficiency.

The traffic QC check module is able to conduct a WIM traffic data check for each station by direction and lane independently. Algorithms adopted in the traffic monitoring guide are implemented in Prep-ME to automatically examine raw WIM data for quality. In addition, several data operations such as manually accept/reject, copy/paste, monthly and daily sampling are developed aiming to salvage incomplete WIM data or those who cannot pass automatic QC checks. These data operations can also be used as a diagnostic tool to identify poor traffic data.

Prep-ME provides the capability to generate three levels of traffic outputs for Pavement ME Design and offer state agencies with the flexibility of generating traffic loading spectra inputs for Pavement ME Design based on the availability of traffic data. Several clustering approaches have been integrated to generate Level 2 traffic inputs for Pavement ME Design in a production environment. The Prep-ME tool is capable of generating the required loading spectra data for Pavement ME Design, which can substantially reduce a state DOT's traffic data preparation efforts for calibration and implementation of the Pavement ME Design.

In addition, there are a number of other features in Prep-ME that may be useful to any highway agency, including: (1) importing raw climatic data and exporting XML climate files for Pavement ME Design; (2) populating and exporting material inputs including E* for HMA, CTE for PCC, and soil properties based on soil map for Pavement ME Design; and (3) importing FWD raw files and preparing FWD XML file for Pavement ME Design inputs.

RECOMMENDATIONS

The software functionalities in Prep-ME required by the project contract have been completed. Several state agencies currently plan to use Prep-ME for ME based pavement design and the local calibration of Pavement ME Design. The research team has also conducted extensive internal testing of the Prep-ME software. Many improvements and corrections have been made based on user comments during the three-year period of the project development. However, more testing by participating states is expected. Implementation and testing of the Prep-ME software is an integral and important phase for the software development life-cycle (SDLC). This process ensures that defects are recognized as soon as possible. Software training and support is as equally important, as software is only effective if it is used correctly and to its maximum capacity.

Even though the current Prep-ME software has many robust modules for data preparation of Pavement ME Design, there are several important functions that are either preliminary or missing. Based on comments and feedback from several participating states and FHWA, the following list of new features for Prep-ME are desired, which may assist participating states implementing Pavement ME Design by adding the new features into the Prep-ME. The new features include:

Develop Climate Data Input Files and Virtual Stations

The Pavement ME Design software identifies a limited number of weather stations from the National Climatic Data Center (NCDC) database that are not evenly distributed within a state. The weather stations included in the Pavement ME Design software only cover a limited number of years. For a typical twenty-year pavement analysis period, Pavement ME Design predicts future climate data by repeating the limited data in the Pavement ME Design climate input files to a much longer pavement design period.

A rigorous quality control check procedure has not yet come into being, mainly due to the lack of reputable software. A workable framework and related algorithms need to be developed and implemented in the Prep-ME software to perform a comprehensive data check for climate data. In addition, besides data from NCDC, a significant amount of other sources of climate data are available at both state and national levels, including NASA's most recent Modern-Era Retrospective Analysis for Research and Applications (MERRA). The effort to build climate data files for Pavement ME Design based on various data sources in this proposed task provides substantially more weather data over time for the existing MEPDG stations and expands geographic coverage of field weather data by creating new climatic stations.

In addition, many state highway agencies such as the Louisiana Transportation Research Center (LTRC) and Michigan DOT (MDOT) are conducting on-going climate studies for Pavement ME Design. The research results should be incorporated into Prep-ME for full production.

PMS Data for Local Calibration in Pavement ME Design

Pavement performance data are required for local calibration and validation of the Pavement ME Design procedure. The AASHTO Local Calibration Guide outlines a sophisticated local calibration procedure with 11 steps. Many of these steps require iterative calculations and can be coded in Prep-ME with automated calculations to aid the local calibration process for Pavement ME Design.

Develop Statewide Materials Library for Pavement ME Design

Many state highway agencies have performed comprehensive material testing for the Pavement ME Design methodology. A statewide pavement materials library can be developed in Prep-ME software customized for individual states. Software interface is to be developed to retrieve design values from the material library for a specific design project for input into Pavement ME Design without soliciting material data in a separate effort anymore.

Develop Portable Version of Prep-ME for Field Data Check and Other Usage

The current version of Prep-ME is capable of conducting comprehensive data checks for permanent WIM traffic data. Due to the high construction and maintenance costs of continuous count programs, portable WIM and short term count programs are widely used by state DOTs. Therefore, developing a portable version of Prep-ME that is capable of checking the traffic data in the field is of great importance. Data issues can be identified immediately and correction activities may be taken on-site. Such tools will assist traffic engineers in evaluating the quality of traffic data during the collection process. This effort will not only save participating states' costs, more importantly it will assure that state DOTs will collect high quality traffic data that can be used for Pavement ME Design and many others.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AADTT	Annual Average of Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
AGPV	Average Groups per Vehicle
AHTD	Arkansas Highway and Transportation Department
ALDF	Axle Loading Distribution Factor
CTE	Coefficient of Thermal Expansion
DHDV	Digital Highway Data Vehicle
DOT	Department of Transportation
EICM	Enhanced Integrated Climatic Module
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
GPS	General Pavement Sections
GUI	Graphic User Interface
HCD	Hourly Climate Data
HDF	Hourly distribution factors
HFC	Highway Functional Classification
HFST	High Friction Surface Treatment
HMA	Hot Mix Asphalt
HPMS	Highway Performance Monitoring System
IMU	Inertial Measuring Unit
KYTC	Kentucky Transportation Cabinet
LTPP	Long Term Pavement Performance
LTRC	Louisiana Transportation Research Center
MDF	Monthly Distribution Factors
MEPDG	Mechanistic-Empirical Pavement Design Guide (MEPDG)
MERRA	Modern-Era Retrospective Analysis for Research and Applications
MU	Multiple-Unit
NCDC	National Climatic Data Center
NATMEC	North American Travel Monitoring Exposition and Conference
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
NGCS	Next Generation Concrete Surface
PSV	Polished Stone Value

SDLC	Software Development Life-Cycle
SPS	Specific Pavement Study
SU	Single-Unit
SWCC	Soil Water Characteristic Curves
TMAS	Travel Monitoring Analysis System
TMG	Traffic Monitoring Guide
TTC	Truck Traffic Classification
VCD	Vehicle Class Distribution
WIM	Weigh-In-Motion

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