TRC1203

# Data Preparation for Implementing Pavement-ME Design™ (DARWin-ME / MEPDG)

Kevin D. Hall, Kelvin C. P. Wang, Joshua Q. Li

Final Report

2015

**FINAL REPORT**

**TRC-1203**

# Data Preparation for Implementing Pavement-ME Design™ (DARWin-ME / MEPDG)

By

Kevin D. Hall, Ph.D., P.E.
University of Arkansas

Kelvin C. P. Wang, Ph.D., P.E.
Joshua Q. Li, Ph.D.
Oklahoma State University

Conducted by

Department of Civil Engineering
University of Arkansas

Department of Civil and Environmental Engineering
Oklahoma State University

In Cooperation with

Arkansas State Highway and Transportation Department

U.S. Department of Transportation
Federal Highway Adminstration

University of Arkansas
Fayetteville, AR 72701

May 2015

## TABLE OF CONTENTS


CHAPTER 1 INTRODUCTION ........ 8

1.1 Background ........ 8

1.2 Objectives and Tasks ........ 9

1.3 Report Outline ........ 10

CHAPTER 2 OVERVIEW OF PREP-ME 3.0 SOFTWARE ........ 12

2.1 General Overview ........ 12

2.2 Traffic Data Import ........ 13

2.3 Traffic Data Check ........ 14

2.4 Traffic Data Export ........ 14

2.5 Climate Module ........ 15

2.6 Material Module ........ 15

2.7 Preliminary FWD Module ........ 16

2.8 Prep-ME Tools ........ 16

CHAPTER 3 TRAFFIC DATA IMPORT ........ 17

3.1 Traffic Data Formats and Naming Convention ........ 17

3.2 Travel Monitoring Analysis System (TMAS 2.0) Data Check ........ 17

3.3 Prep-ME Software Interface ........ 18

CHAPTER 4 TRAFFIC DATA CHECK ........ 20

4.1 Weight Data Check ........ 20

4.1.1 Automatic TMG Data Check Algorithms ..................................... 20

4.1.2 Data Sampling and Replacement.................................................. 22

4.2 Traffic Classification Data Check .................................................. 24

CHAPTER 5 TRAFFIC DATA EXPORT ........................................................... 26

5.1 Traffic Data Export Levels ............................................................. 26

5.2 Output Level 1- Site-Specific .......................................................... 28

5.3 Output Level 2 -Michigan DOT Clustering .................................... 29

5.3.1 Methodology....................................................................................... 29

5.3.2 Prep-ME Interface - Setup Clusters................................................ 30

5.3.3 Prep-ME Interface - Run Discriminant Analysis ........................... 34

5.4 Output Level 2 -NCDOT Clustering ................................................ 35

5.4.1 Methodology....................................................................................... 35

5.4.2 Prep-ME Interface ............................................................................ 37

5.5 Output Level 2 - KYTC Method ..................................................... 42

5.6 Output Level 2 -TTC Clustering ..................................................... 45

5.6.1 Methodology....................................................................................... 45

5.6.2 Software Interface ............................................................................. 46

5.7 Output Level 2 -Simplified TTC Clustering ................................... 48

5.7.1 Methodology....................................................................................... 48

5.7.2 Software Interface ............................................................................. 50

5.8 Output Level 2 - Flexible Clustering................................................ 51

5.9 Output Level 3 ........ 52

5.10 Mixed Output Levels and Output Data Review ........ 52

CHAPTER 6 CLIMATE MODULE ........ 54
6.1 Climate Data Import ........ 54

6.2 Export Climate Data ........ 55

CHAPTER 7 MATERIAL MODULE ........ 57
7.1 Introduction ........ 57

7.2 Dynamic Modulus (E*) for HMA ........ 57

7.3 Coefficient of Thermal Expansion (CTE) for PCC ........ 58

7.4 Soil Map for Subgrade ........ 59

CHAPTER 8 Preliminary FWD Module ........ 63
8.1 Introduction ........ 63

8.2 FWD Capabilities ........ 63

CHAPTER 9 PREP-ME TOOLS ........ 66
9.1 File Name Change ........ 66

9.2 AADTT Calculation Based on Short Term Traffic Counts ........ 67

CHAPTER 10 CONCLUSIONS ........ 69
CHAPTER 11 REFERENCES ........ 71

LIST OF FIGURES

Figure 2.1 Prep-ME 3.0 Main Interface ........ 13

Figure 3.1  Interface of data import ........ 19

Figure 3.2 Google Map 3.0 Utility ........ 19

Figure 4.1 Detailed Traffic Information by Lane ........ 21

Figure 4.2 Daily Check and Sampling ........ 23

Figure 4.3 Classification Data Check by Direction and by Lane ........ 25

Figure 4.4 Classification Daily Data Check ........ 25

Figure 5.1 Three-Level Outputs ........ 28

Figure 5.2 State Average for Number Axles/Truck ........ 28

Figure 5.3 Output Level 2 – Michigan DOT Method ........ 31

Figure 5.4 Set Up Michigan DOT Clusters ........ 32

Figure 5.5 Identifying Traffic Pattern ........ 35

Figure 5.6 NCDOT Method ........ 39

Figure 5.7 Traffic Output by Class Comparison ........ 40

Figure 5.8 Traffic Output by Load ........ 40

Figure 5.9 Traffic Output by Station Information ........ 41

Figure 5.10 KYTC Method ........ 44

Figure 5.11 DARWin-ME TTC Values ........ 45

Figure 5.12 TTC Clustering Method ........ 47

Figure 5.13 Review TTC Clusters ........ 47

Figure 5.14 Check TTC Plots ........................................................................ 48

Figure 5.15 Simplified TTC Approach (Li et al, 2012) ................................................ 49

Figure 5.16 Simplified TTC Clustering Method .......................................................... 50

Figure 5.17 Flexible Clustering Method ...................................................................... 51

Figure 5.18 Displaying Output Data ............................................................................ 53

Figure 6.1 Importing Climate Files .............................................................................. 54

Figure 6.2 Google Map 3.0 Utility for Climate Data .................................................... 55

Figure 6.3 Interpolating Climate Files .......................................................................... 56

Figure 6.4 Selected Climate Stations on Google Map .................................................. 56

Figure 7.1 Retrieving Dynamic Modulus (E*) Data ..................................................... 58

Figure 7.2 Retrieving CTE Data .................................................................................... 59

Figure 7.3 Soil Map Module in Prep-ME ...................................................................... 61

Figure 7.4 Retrieved Soil Properties ............................................................................. 61

Figure 7.5 Generated Soil Property File for Pavement-ME Design™ ........................... 62

Figure 8.1 Import FWD Data ........................................................................................ 64

Figure 8.2 Generate Report for FWD Back-Calculation ................................................ 64

Figure 8.3 Output FWD XML File for Pavement-ME Design™ ................................... 65

Figure 9.1 Change File Name Interface ........................................................................ 66

Figure 9.2 AADTT Prediction Based on Short Term Traffic Count .............................. 68

LIST OF TABLES

Table 5.1  Traffic Input Level for Rigid Pavements (Haider et al 2011) ....................... 31

Table 5.2  Algorithm for Recommending an ALDF Group for NCDOT ...................... 41

Table 5.3 Aggregation Class of roadway in Kentucky................................................... 44

# CHAPTER 1 INTRODUCTION

## 1.1 Background

Pavement-ME Design™ (previously DARWin-ME; also known as the Mechanistic-Empirical Pavement Design Guide [MEPDG]) is a significant advancement in pavement design technology. In this report, the terms Pavement-ME Design™, DARWin-ME, and MEPDG are used interchangeably. AASHTO, FHWA, NCHRP, and many state highway agencies in the US have spent well over $50 million in the past decade on developing, refining, and calibrating the MEPDG procedure. Arkansas State Highway and Transportation Department (AHTD) as a leader in MEPDG studies started supporting MEPDG research early on. As the next-generation pavement design procedure, Pavement-ME Design™ is embraced by many state highway agencies. As it requires a magnitude more data inputs, some of which are not familiar to pavement designers and not systematically stored and archived, it is imperative to have a process in place for AHTD to collect, analyze, prepare, and use the input data sets for Pavement-ME Design™. Equally important, Pavement-ME Design™ will be also used as an analysis tool for pavement engineering due to its inclusion of many engineering principles, including prediction models, materials analysis, construction and as-built database, environment, and qualification of traffic data. This research project relies on know-how and experience from past AHTD sponsored projects on MEPDG development and establish a workflow in implementing Pavement-ME Design™ at AHTD with the long-term goal of establishing a supporting infrastructure for pavement engineering at AHTD using Pavement-ME Design™ as the core pavement design engine.

## 1.2 Objectives and Tasks

The primary objective of the proposed study is to establish a workflow for AHTD to start implementing DARWin-ME for production and develop relevant technologies so that positive impacts of DARWin-ME will be fully exploited in pavement design, management, materials, construction, and traffic data collection. The objectives of this project include:

- Develop a DARWin-ME Implementation Plan for AHTD.
- Develop necessary software tools and processes for integrating numerous AHTD data sets for multiple purposes such as design, management, construction activities etc.
- Develop statewide database of traffic and materials for the initial implementation of DARWin-ME.
- Develop new pavement design manuals for the implementation of DARWin-ME in the state of Arkansas.
- Conduct training and workshops for AHTD designers and industry representatives to use DARWin-ME.

More specifically, there are five tasks for this project:

- Task 1: Review of Literature and State of Practice
- Task 2: Software Development to Integrate Data from Different Divisions
- Task 3: Development of Statewide Database
- Task 4: Specifications and Design Document

- Task 5: Education, Training, and Final Report

The University of Arkansas functioned as the contractor on the project; however, a large portion of the work was performed under a subcontract to Oklahoma State University. It is noted that AHTD chose not to pursue Task 3 as originally proposed.  Task 2 – software development – is the primary work, and comprises the primary deliverable of the project.

### 1.3 Report Outline

This report documents the research, mainly focused on the development of the new version of the Prep-ME software. The capabilities of the updated Pre-ME version 3.0 software are introduced in the following chapters.

Chapter 2 provides an overview of the Prep-ME 3.0 software.

Chapter 3 illustrates the traffic data import functionalities in Prep-ME;

Chapter 4 provides a detailed documentation of traffic data checks for both weight and classification data. Automated data check algorithms in accordance with FHWA Traffic Monitoring Guide (TMG), but also various data operations such as manually process, daily sampling and monthly sampling are available in Prep-ME 3.0 for users to perform comprehensive WIM traffic data checks.

Chapter 5 emphasizes on how to export traffic data for Pavement-ME Design™ software for specific pavement design based on available WIM data. Several clustering methods are implemented in the software.

Chapter 6 demonstrates the capabilities of Prep-ME for climate module.

Chapter 7 demonstrates the material module in Prep-ME. Dynamic modulus (E*) for HMA materials and coefficient of thermal expansion (CTE) for PCC materials can be retrieved from the statewide material library. In addition, Prep-ME is able to retrieve soil maps and related soil property data describing the soil-water characteristic curves (SWCC) from the pedologic soil family national database developed by the NCHRP 9-23A project.

A preliminary Falling Weight Deflectometer (FWD) module and Prep-ME tools are included in Chapters 8 and 9, respectively.

# CHAPTER 2 OVERVIEW OF PREP-ME 3.0 SOFTWARE

## 2.1 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 2.1, Prep-ME 3.0 software includes four menus: Traffic, Climate, Materials, and Tools. For 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 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 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.

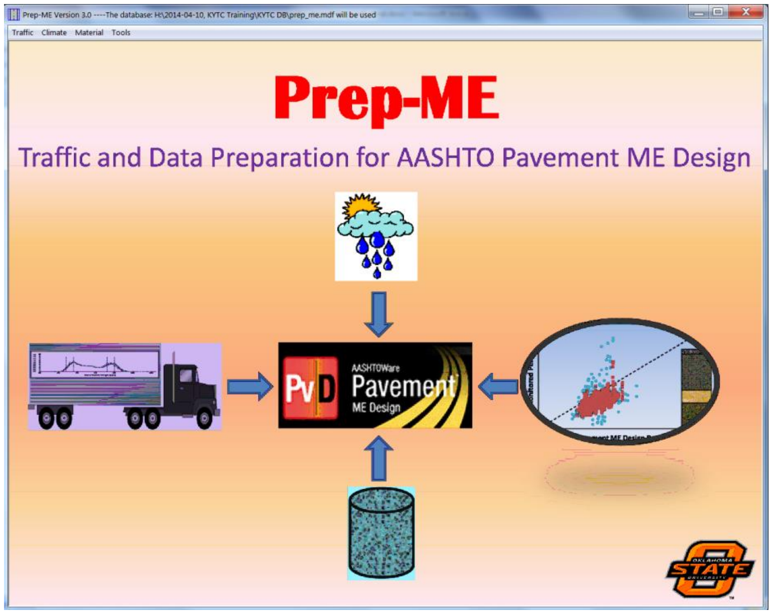



Figure 2.1 Prep-ME 3.0 Main Interface

## 2.2 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 cannot be imported ONLY 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.

## 2.3 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.

## 2.4 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 five clustering methods for Level 2 traffic inputs, including NCDOT method, Michigan DOT method, KYTC Method, Truck Traffic Classification (TTC) method, simplified TTC method, TPF-5(004) Method, Flexible Clustering. State average values or Pavement-ME Design™ defaults can be used for Level 3 inputs. Prep-ME allows each type of traffic data to select its own output level. 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.

## 2.5 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 for MEPDG and the Pavement-ME Design™ software.

## 2.6 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, generate 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 statewide material library for Pavement-ME Design™.

- Retrieve NCHRP 9-23A subgrade soil map data for Pavement-ME Design™.

### 2.7 Preliminary FWD Module

The FWD module in Prep-ME 3.0 is able to:

- Import raw FWD F25 data and pavement structure data into Prep-ME database;
- Output a summary report including pavement structure data along with the deflection data for use in back-calculation process;
- Generate FWD XML file for Pavement-ME Design™.

### 2.8 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.

# CHAPTER 3 TRAFFIC DATA IMPORT

## 3.1 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 in 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 don't 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.

## 3.2 Travel Monitoring Analysis System (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, as provided in Appendix A. All the TMAS checks are implemented in Prep-ME 3.0 during traffic data import.

### 3.3 Prep-ME Software Interface

After selecting a file folder and 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 3.1 shows a screen shot of data import processing.

- **Current/Total Files**: The index of current processing file verse total number of file selected to be imported;
- **Imported (Rows)**: number of rows of data imported into the database;
- **Failed TMAS (Rows)**: the number of records (rows) that failed the TMAS check;
- **Failed Rate**: the percentage of failed TMAS records to the total number of data imported;
- **Duplicate**: number of rows (records) that are duplicate in the raw data sets;
- **Currently Import File**: The path of current raw data file under import processing;
- **Total Processing Time**: the processing time of data importing in seconds;
- **Stop Importing**: user can stop importing the data being processed.

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. Data lines with critical errors will not be imported by Prep-ME.

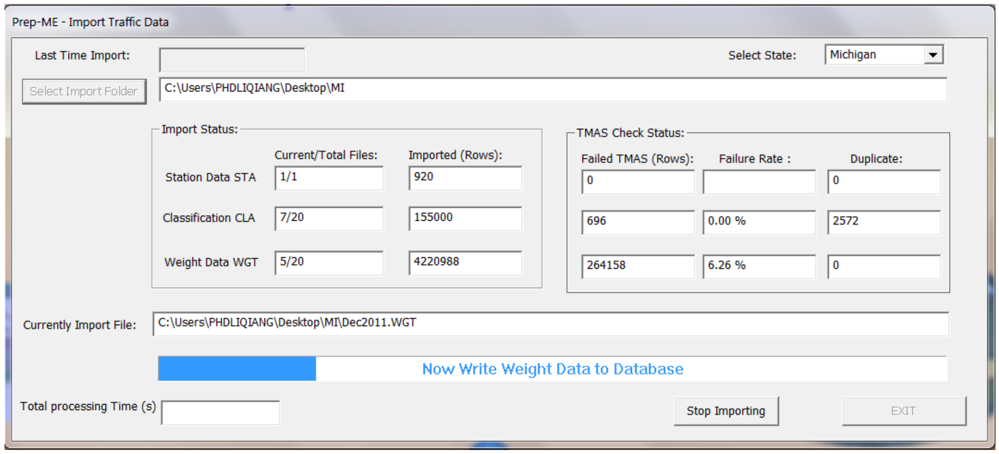



Figure 3.1 Interface of data import

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 the traffic station legend for more detailed information (Figure 3.2).

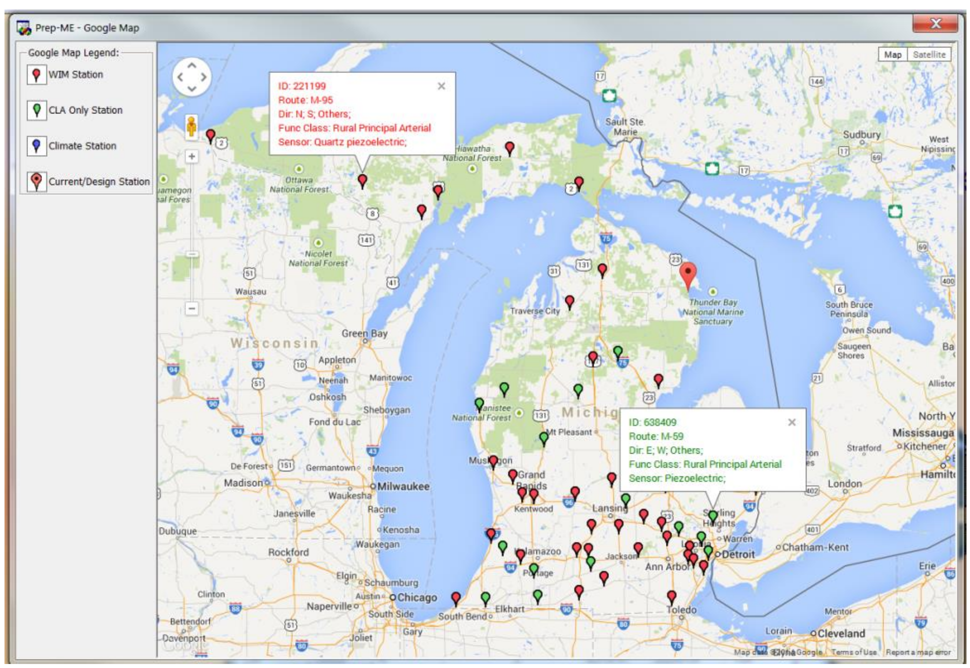



Figure 3.2 Google Map 3.0 Utility

# CHAPTER 4 TRAFFIC DATA CHECK

## 4.1 Weight Data Check

### *4.1.1 Automatic TMG Data Check Algorithms*

The algorithm used in the 2001 3rd Edition of TMG for weight is adopted for weight data check. There are two basic steps to evaluate recorded vehicle weight data. Firstly, to 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). Secondly, to 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 4.1 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 don't have a minimum of 12-month data that pass the QC. Prep-ME also allows users to adjust those parameters. 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 & lane of a station.

For WIM stations don't 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.

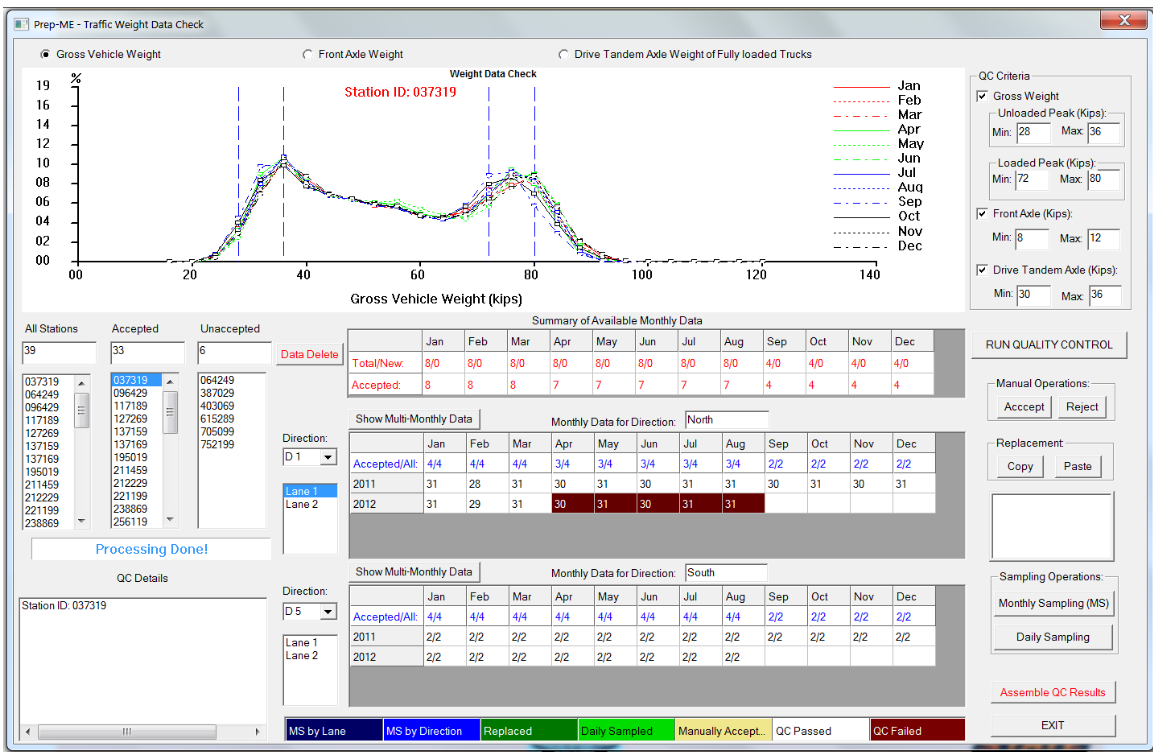


Figure 4.1 Detailed Traffic Information by Lane

### *4.1.2 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 4.1.

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 could 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 days’ 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 4.2). 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 4.2 demonstrates the comparisons of the Gross Vehicle Weight data for all the 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 different trend from those for the other Mondays. Users may investigate the data and decide whether the data is reasonable.


Figure 4.2 Daily Check and Sampling

When one month data is missing or fail 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.

## 4.2 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) To 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) To check the reported number of unclassified vehicles. The number of unclassified vehicles should be less than five percent of the vehicles recorded. (4) To 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 processed since no manually 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 similar software interface (Figure 4.3), which is able to perform automatic data check, daily check, replacement, sampling operations for classification data. Daily sampling function is illustrated in Figure 4.4.

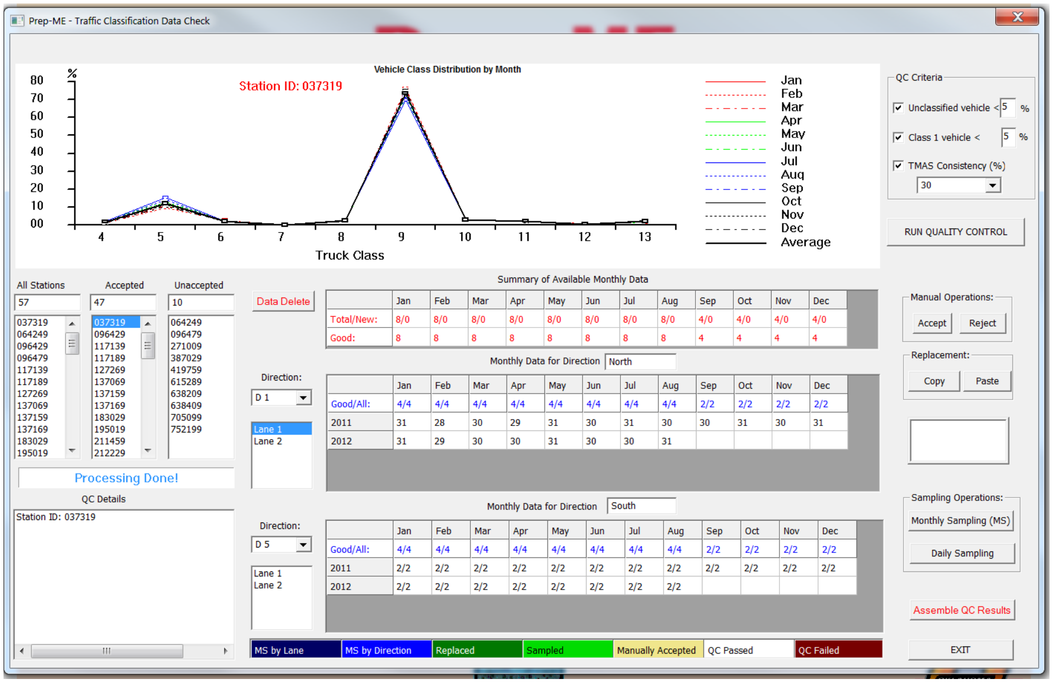



Figure 4.3 Classification Data Check by Direction and by Lane

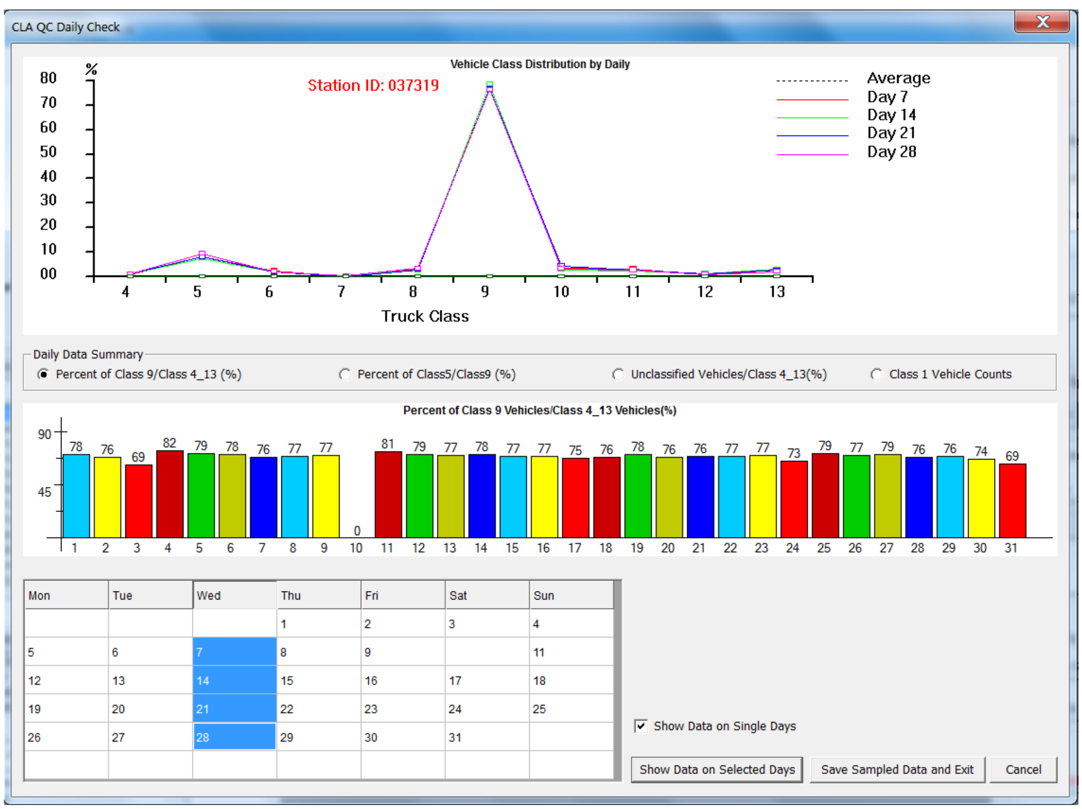



Figure 4.4 Classification Daily Data Check

# CHAPTER 5 TRAFFIC DATA EXPORT

## 5.1 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, Levels 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 5.1, 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.

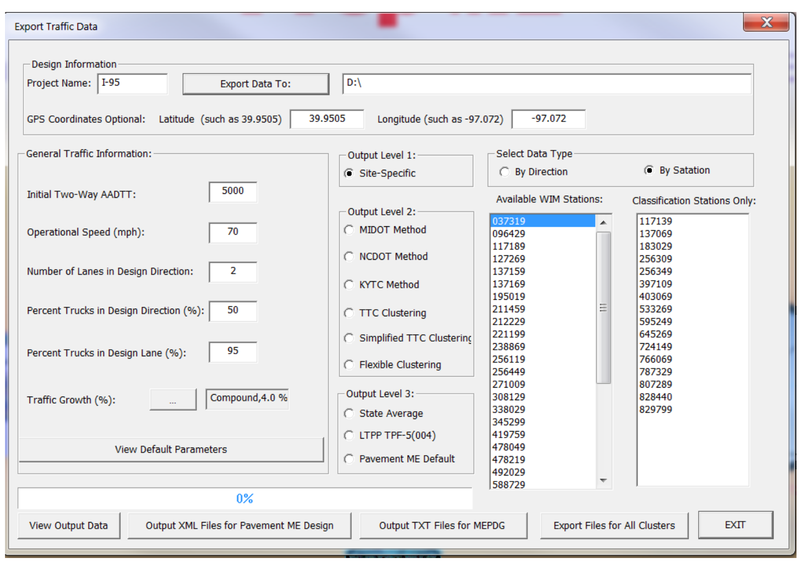


Figure 5.1 Three-Level Outputs

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 5.2).

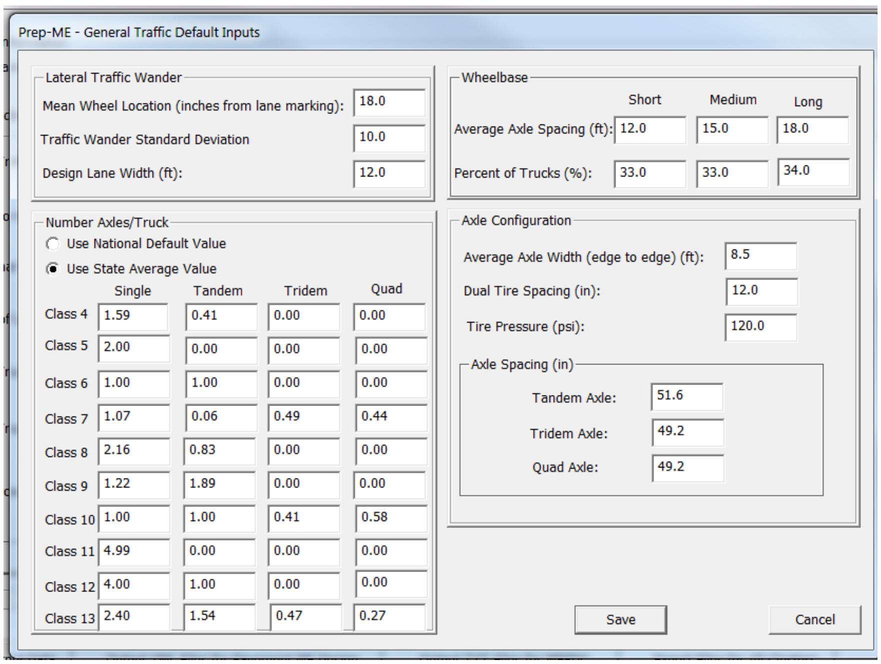


Figure 5.2 State Average for Number Axles/Truck

## 5.2 Output Level 1- Site-Specific

To export Level 1 site-specific output (As shown in Figure 5.1), 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 while do not contain weight data.

## 5.3 Output Level 2 -Michigan DOT Clustering

### *5.3.1 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 the predicted pavement performance is insensitive to a particular traffic input, Level 3 statewide values 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 Design™s using various traffic inputs, the input levels for traffic characteristics were recommended based on sensitivity analysis results, as shown in Table 5.1.

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 at a particular pavement design site. An example of such a linear equation is shown in Equation (5.1).

$$y = b_1 x_1 + b_2 x_2 + ... + b_n x_n + c \quad \text{.................................................(5.1)}$$

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, VC5%, VC9%, functional class (rural/urban), roadway annual tonnage (Haider et al 2011). 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.

### *5.3.2 Prep-ME Interface - Setup Clusters*

Select “**Michigan DOT Method**" in Figure 5.1”, and the interface of “Prep-ME Michigan Clustering Parameters” will show up (Figure 5.3).

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 are matched (Figure 5.4).

Table 5.1 Traffic Input Level for Rigid Pavements (Haider et al 2011)

| 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) |

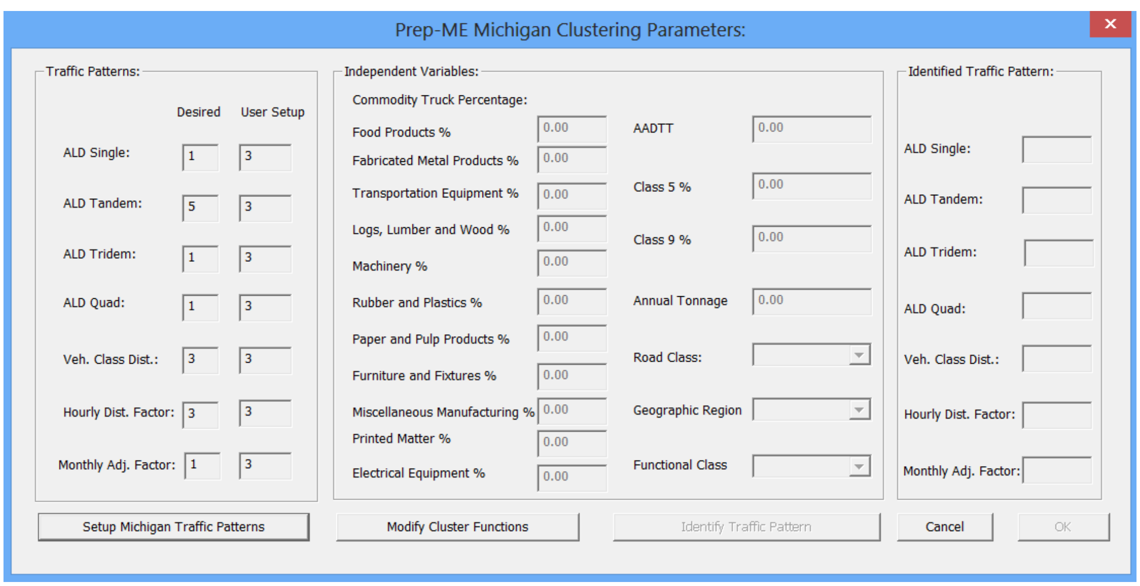



Figure 5.3 Output Level 2 – Michigan DOT Method

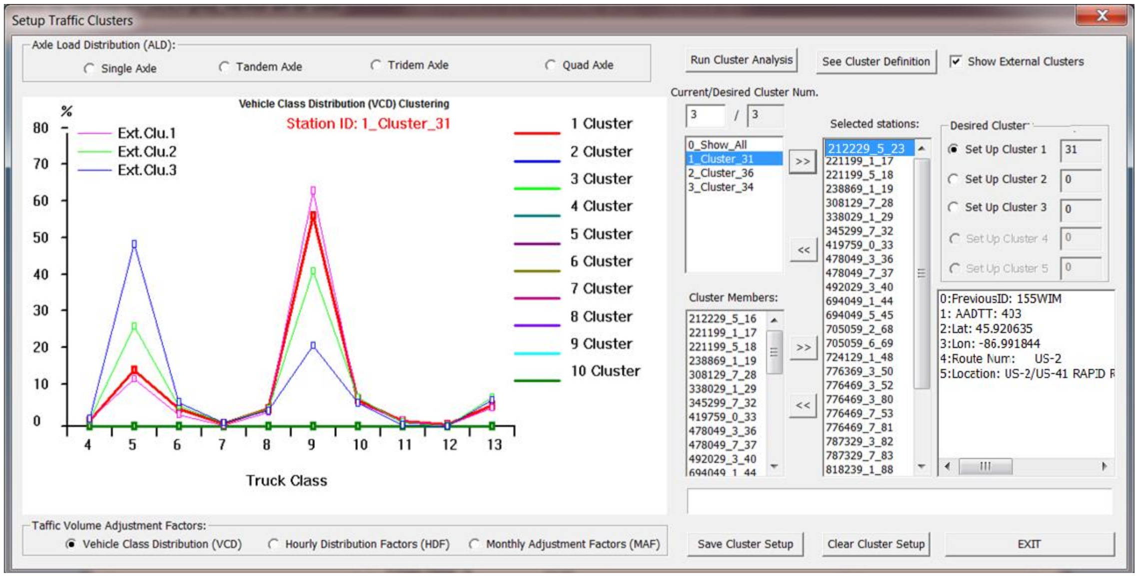



Figure 5.4 Set Up Michigan DOT Clusters

As show in Figure 5.4, 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 5.4. 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**" button 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, 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**", 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 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.

### *5.3.3 Prep-ME Interface - 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 5.5). 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.

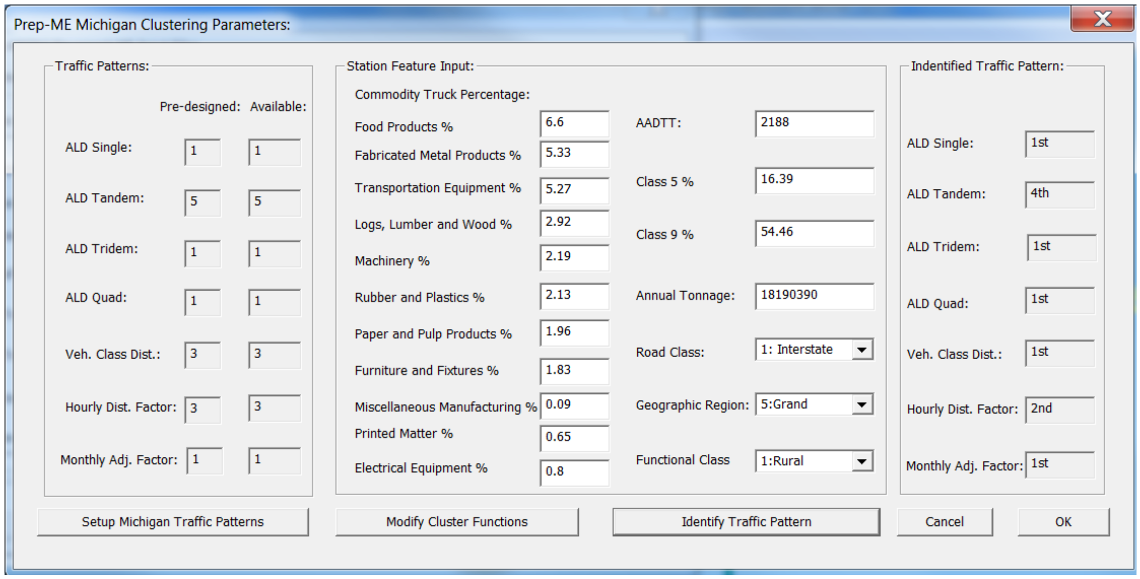



Figure 5.5 Identifying Traffic Pattern

## 5.4 Output Level 2 -NCDOT Clustering

### *5.4.1 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 Factor (ALF) 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 ALF, 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 ALFs, 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 ALFs 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 ALF 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 attached in the Appendix of the 2013 version of Traffic Monitoring Guide.

### *5.4.2 Prep-ME Interface*

As shown in Figure 5.1, select “NCDOT Method” to enter the interface of NC-Clustering (Figure 5.6).

- 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**", 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 user to upload and use existing research clustering results for Prep-ME. For NCDOT, the external cluster data come from the NCDOT final project report HWY-2008-11. The data for the external groups should be prepared in ALF 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 (Figure 5.6).
- 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 5.1). "**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, the software will automatically generate the recommended ALDF cluster for pavement designers to consider. The algorithm for recommending an ALDF is summarized in Table 5.2.
- 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 user's setup from the Prep-ME database.
- The Prep-ME software provides recommendation of ALDF Group for pavement designers. Pavement designers can investigate the ALDF Group recommendation by reviewing the following data plots.
    - ❖ **VCD** plot (Figure 5.6): compare the project VCD with the vehicle class distributions of the four ALDF Groups;
    - ❖ **Class Comparison** plot (Figure 5.7): compare the % Class 5 and % Class 9 trucks between project data and the ALDF Grouping data;
    - ❖ **Load** plot (Figure 5.8): demonstrate the single and tandem loading distribution of the four ALDF Groups;

❖ **Station** summary (Figure 5.9): view the clusters for each traffic parameter and the members of this cluster;

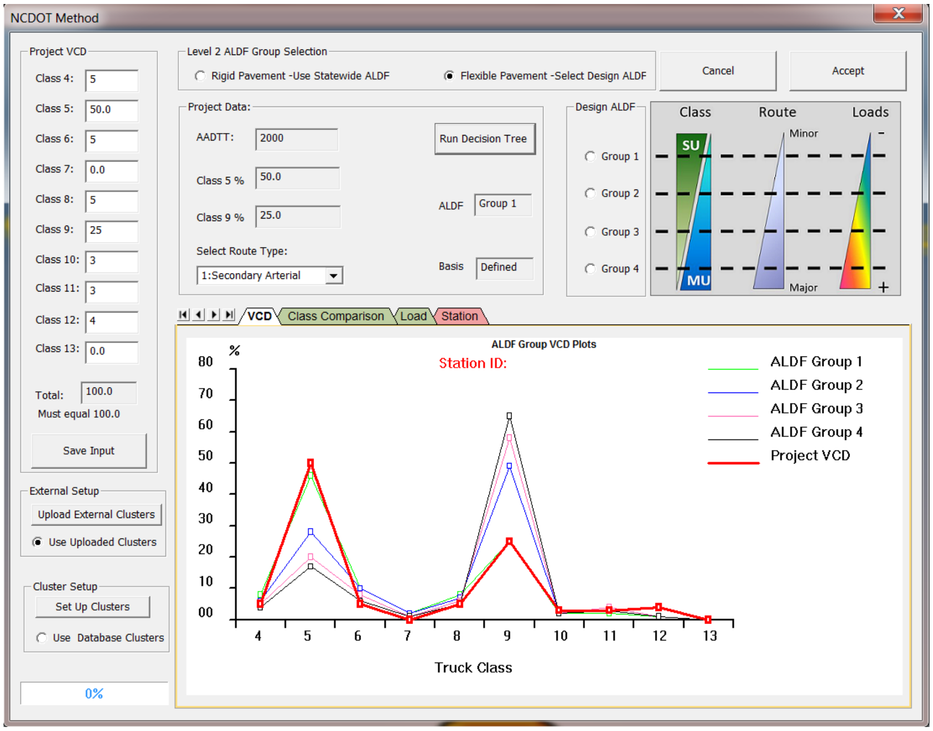



Figure 5.6 NCDOT Method

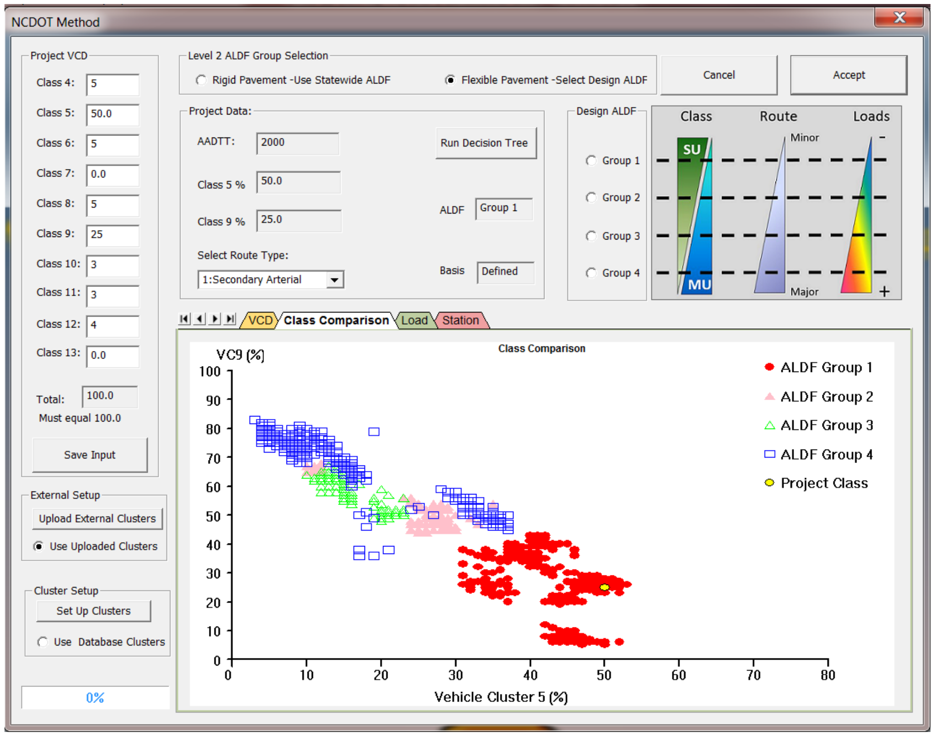



Figure 5.7 Traffic Output by Class Comparison

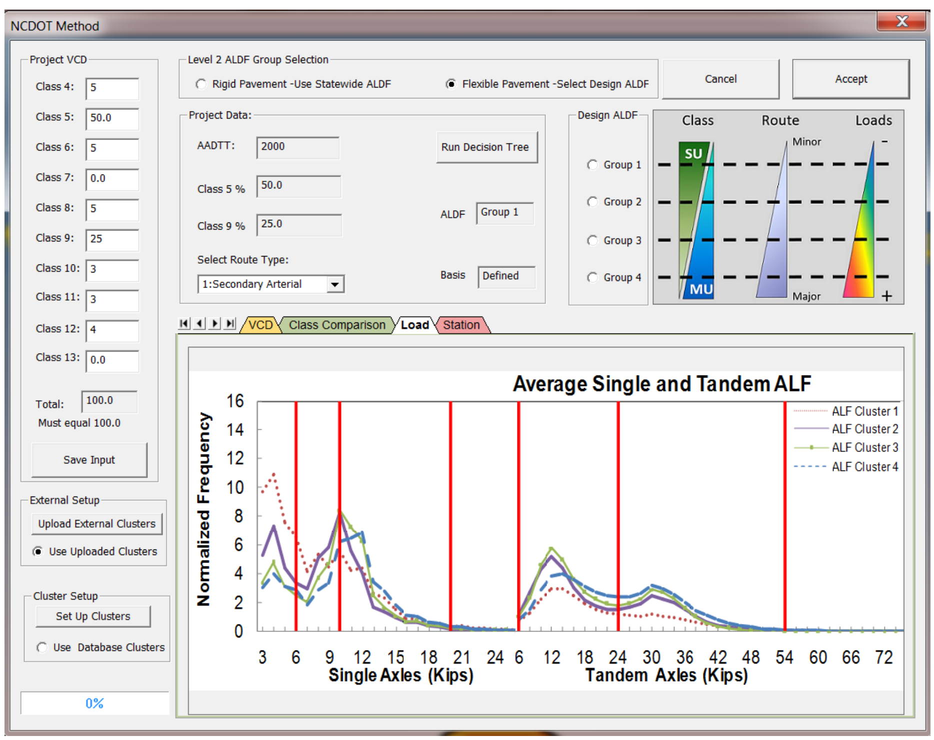



Figure 5.8 Traffic Output by Load

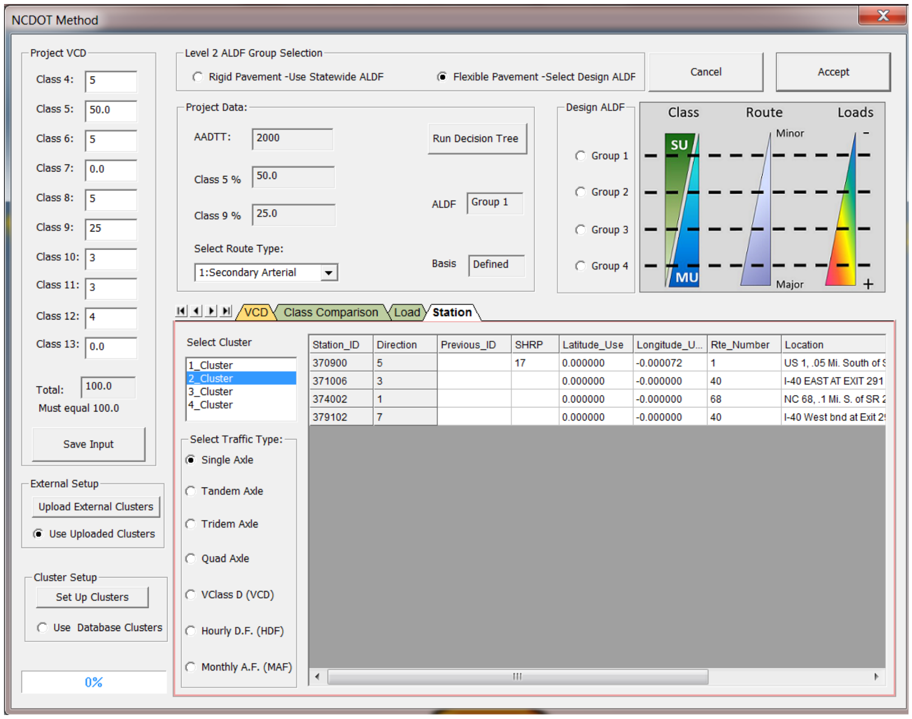



Figure 5.9 Traffic Output by Station Information

Table 5.2 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 |
| Note - Must be performed in Step order and Criteria order specified below; Once a criteria is met and a Recommended ALDF identified, the process stops. | | | |

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), Monthly Adjustment Factor (MAF); (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.

### 5.5 Output Level 2 - KYTC Method

Kentucky Transportation Cabinet (KYTC) has been implementing aggregate classes for traffic data preparation. The definition of aggregate class is shown in Table 5.3.

The Prep-ME interface for KYTC method is shown as in Figure 5.10.

- 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” button and return to the **Traffic Data Export** opening interface to review and output traffic data for a particular design.

Table 5.3 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) |

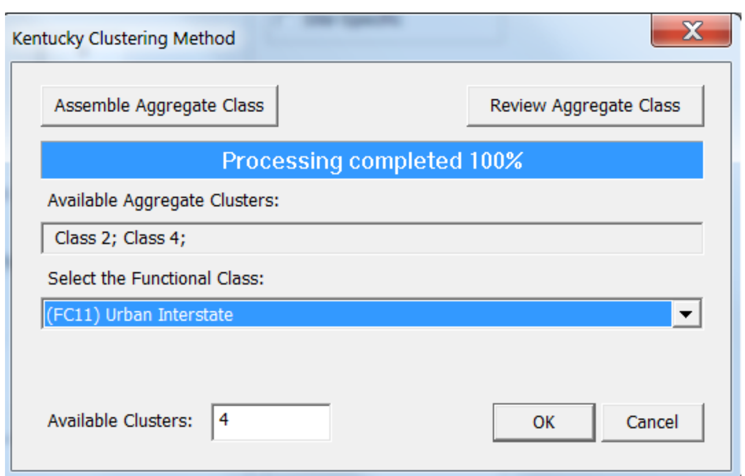



Figure 5.10 KYTC Method

## 5.6 Output Level 2 -TTC Clustering

### *5.6.1 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 (NCHRP 1-37A 2004). Default truck distribution values for these 17 TTCs are developed in DARWin-ME based on the data from the LTPP program, as shown in Figure 5.11.

When design 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.

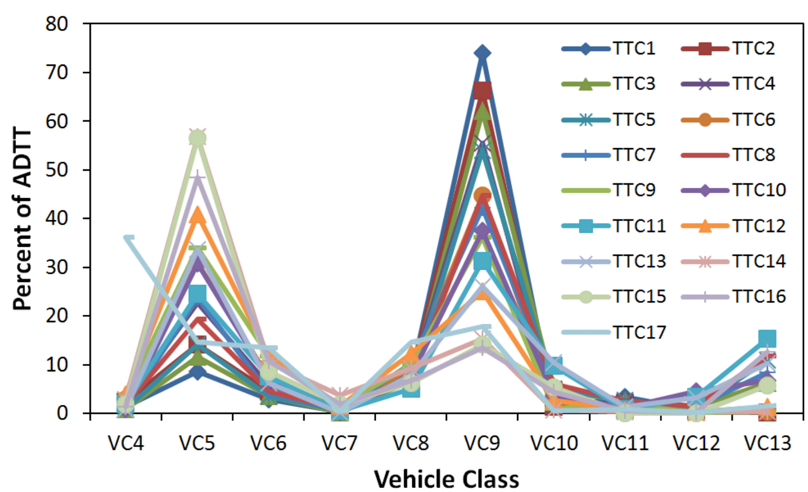



Figure 5.11 DARWin-ME TTC Values

### *5.6.2 Software Interface*

The procedure of using TTC cluster method for generating level 2 outputs is shown as in Figure 5.12. This TTC approach can be used by states that don't have a developed clustering approach to prepare axle loading spectra data for Pavement-ME Design™

- Select “**TTC Clustering**” and the interface is shown in Figure 5.12.
- Click the “**Setup TTC Clusters**” button, 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 5.13.
- 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 selection based on engineering judgments (Figure 5.14).

- Finally, click "OK" button and return to the **Traffic Data Export** opening interface. Users can now review and output traffic data for this particular design.

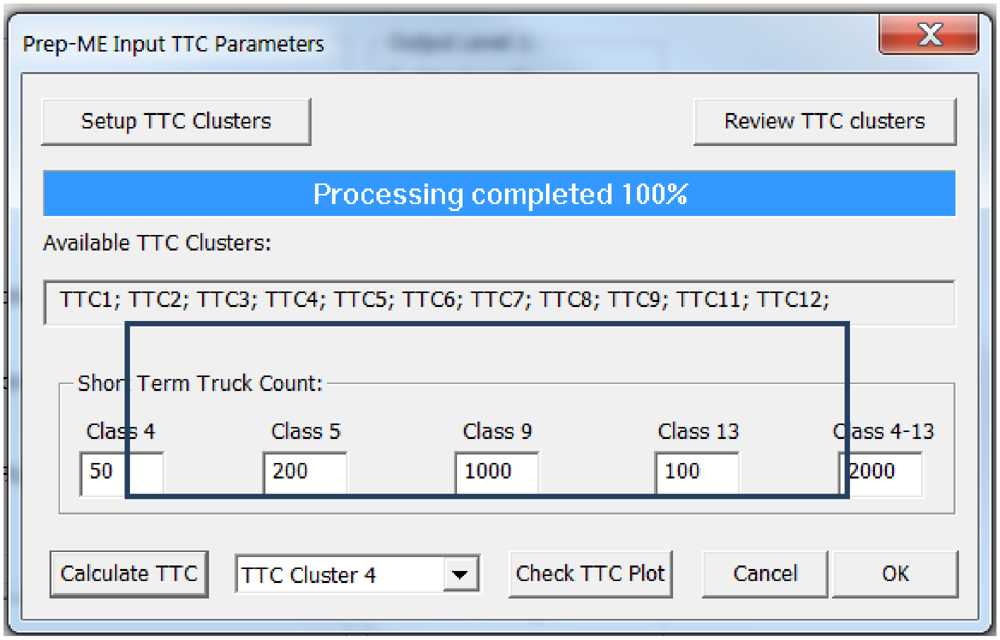



Figure 5.12 TTC Clustering Method


Figure 5.13 Review TTC Clusters

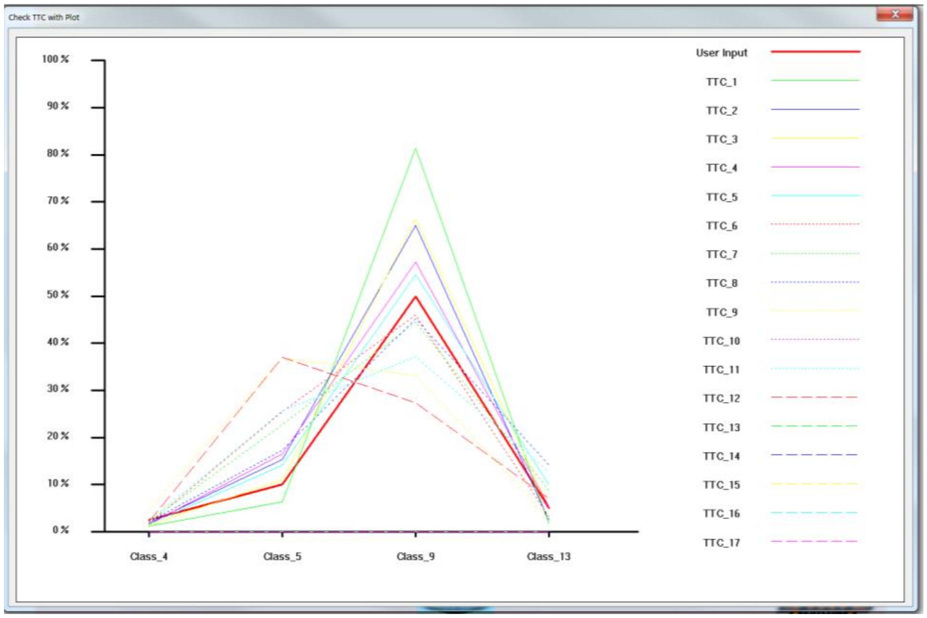



Figure 5.14 Check TTC Plots

## 5.7 Output Level 2 -Simplified TTC Clustering

### *5.7.1 Methodology*

It can be seen in Figure 5.11 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 is actually open to the 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 5.15. It is illustrated that the simplified truck traffic patterns can be distinguished by the relative proportion of Class 4, Class5, and Class 9 trucks:

- Cluster 1 - Bus (Class 4) Dominant Route
- Cluster 2 - Single-Unit (Class 5) Truck Dominant Route
- Cluster 3 - Multi-Unit (Class 9) Truck Dominant Route
- Cluster 4 - Mixed Truck Route

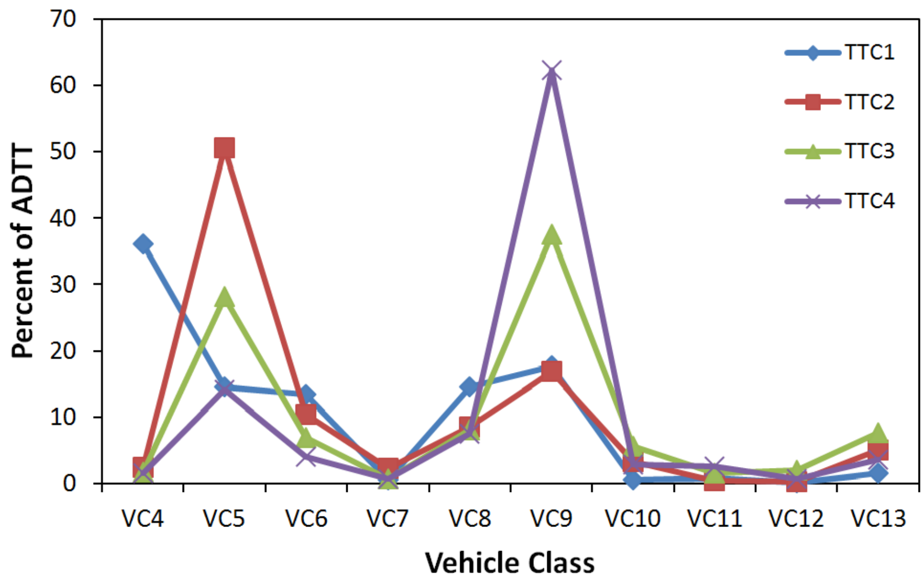



Figure 5.15 Simplified TTC Approach (Li et al, 2012)

Based on Figure 5.15, it demonstrates that reducing TTC groupings from seventeen to four extract the most representative traffic patterns with acceptable statistical confidence.

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.

### *5.7.2 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 and the interface is shown in Figure 5.16.
- 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.

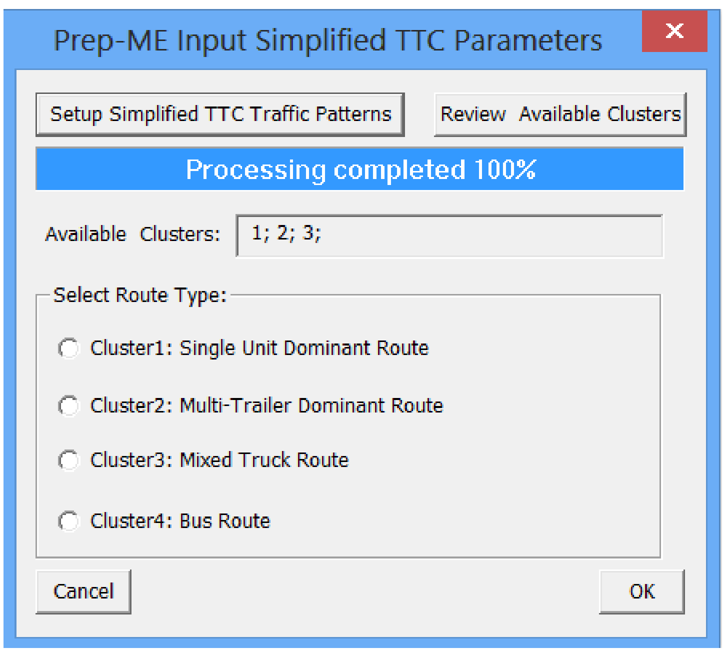



Figure 5.16 Simplified TTC Clustering Method

## 5.8 Output Level 2 - Flexible Clustering

In many cases, traffic engineers are familiar with the traffic patterns on the highway segments where WIM stations locate. Based on local engineering judgment, 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 5.17. 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 5.17 uses all the WIM stations on I-94 to generate Single Axle Load Distribution factors.

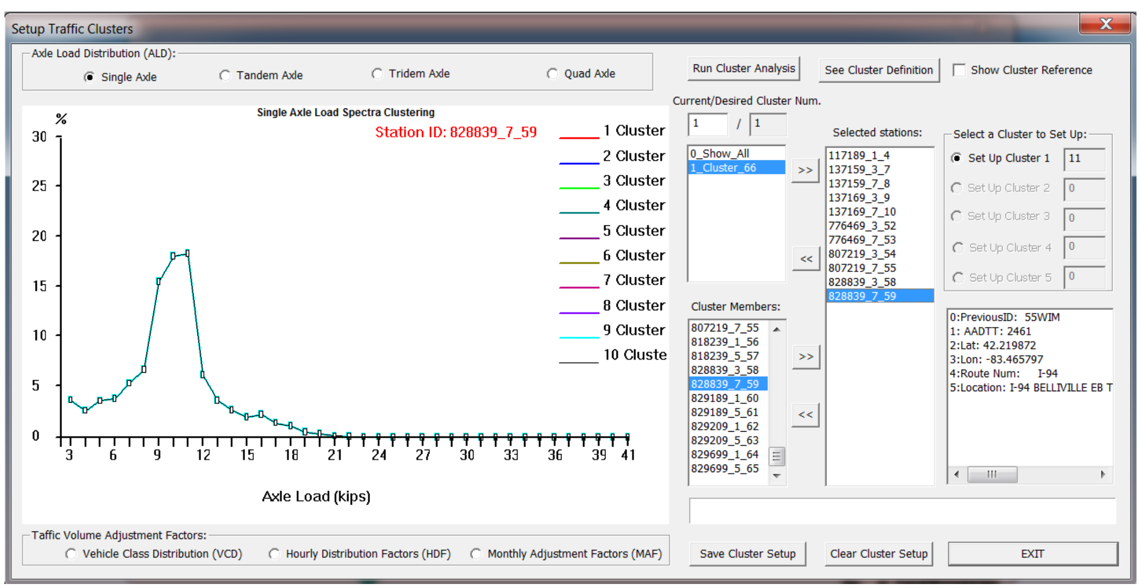



Figure 5.17 Flexible Clustering Method

## 5.9 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 5.1). 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.

## 5.10 Mixed Output Levels and Output Data Review

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 5.18.)

As shown in Figure 5.18, 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**".

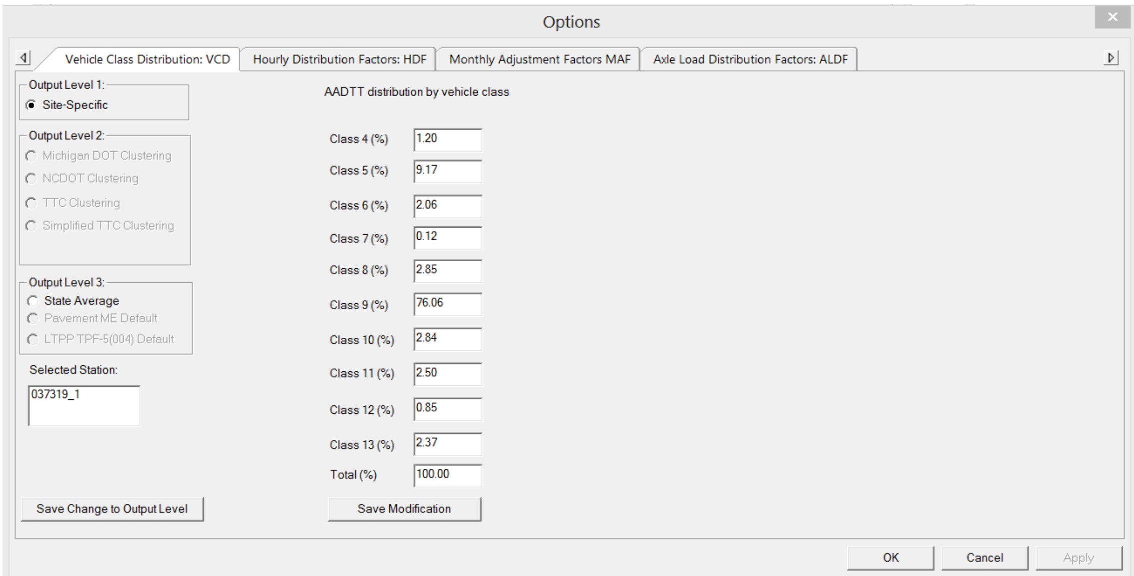



Figure 5.18 Displaying Output Data

# CHAPTER 6 CLIMATE MODULE

## 6.1 Climate Data Import

The Climate Import function (Figure 6.1) 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 on the imported data. The software can be customized for individual DOTs and comprehensive data check can be implemented to obtain high quality climate data sets.

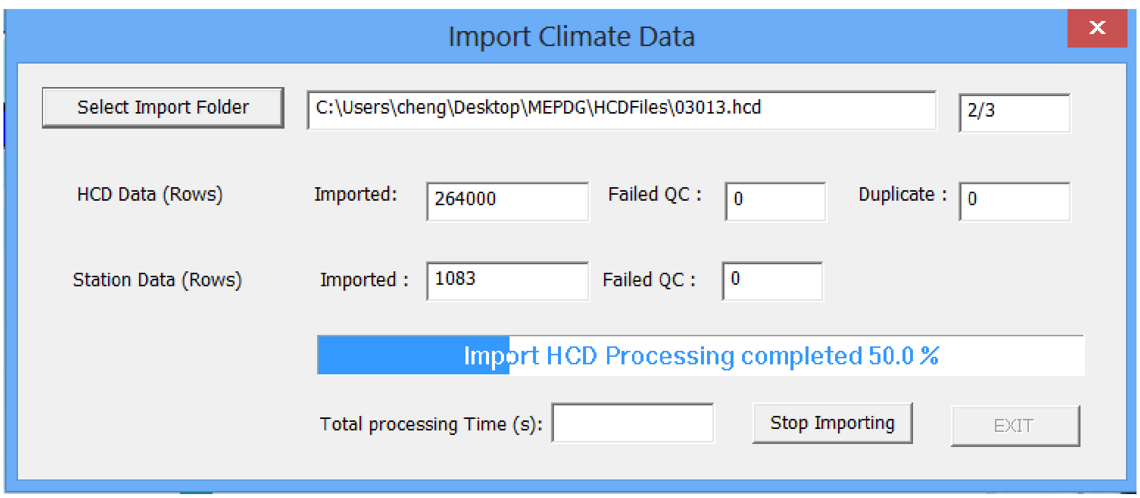



Figure 6.1 Importing Climate Files

After climate data are imported, Google Map 3.0 utility is launched to demonstrate the locations of the climate stations (Figure 6.2).

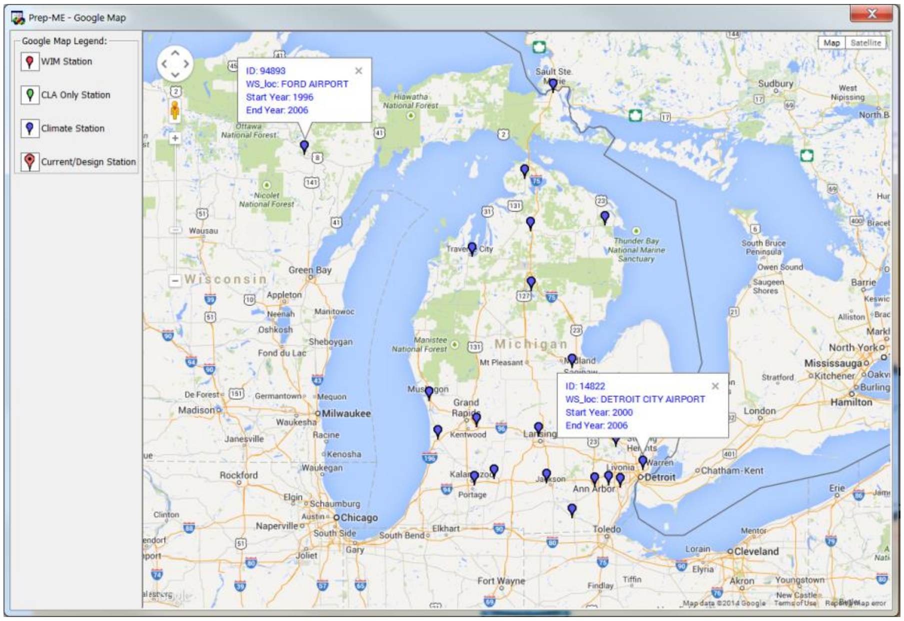


Figure 6.2 Google Map 3.0 Utility for Climate Data

## 6.2 Export Climate Data

The Climate Export function (Figure 6.3) 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. The selected climate stations will be demonstrated in Google Map (Figure 6.4). The generated ICM file can be directly imported to MEPDG and Pavement-ME Design™ software.

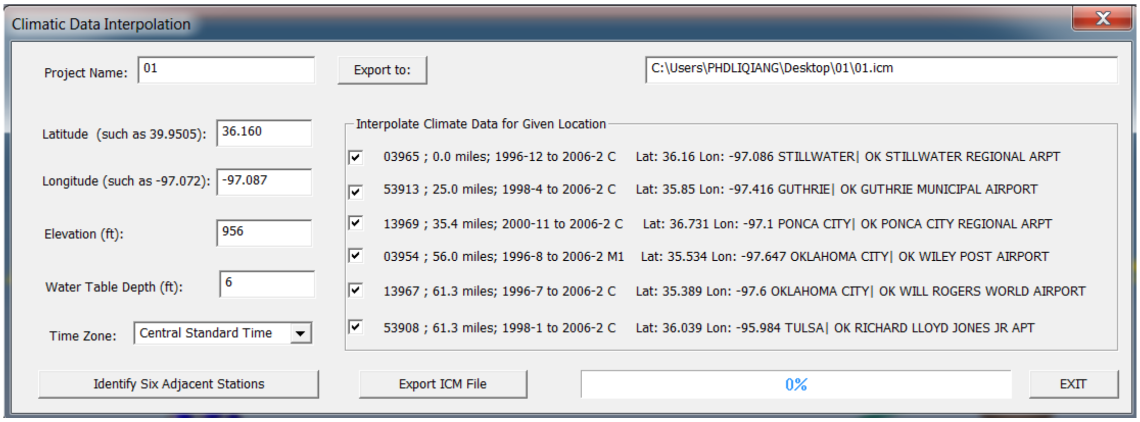



Figure 6.3 Interpolating Climate Files

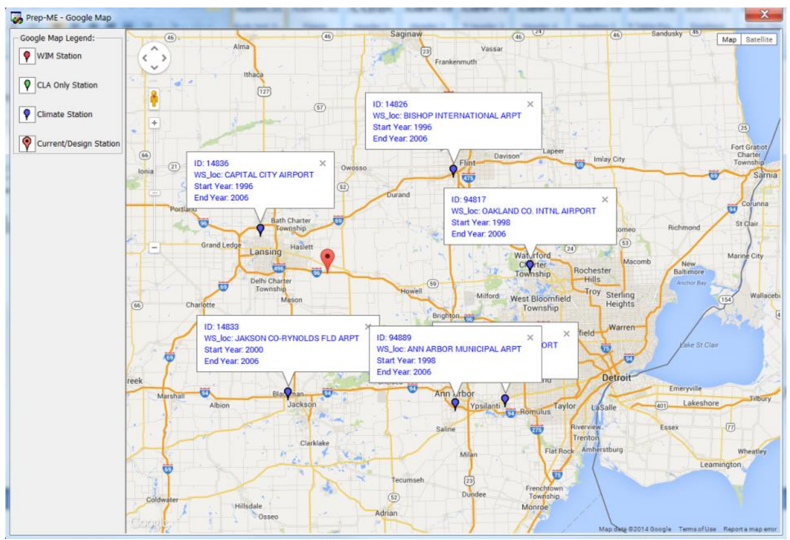



Figure 6.4 Selected Climate Stations on Google Map

# CHAPTER 7 MATERIAL MODULE

## 7.1 Introduction

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.

## 7.2 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. The E* test is generally conducted at five test temperatures and six loading frequencies.

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 7.1). 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.

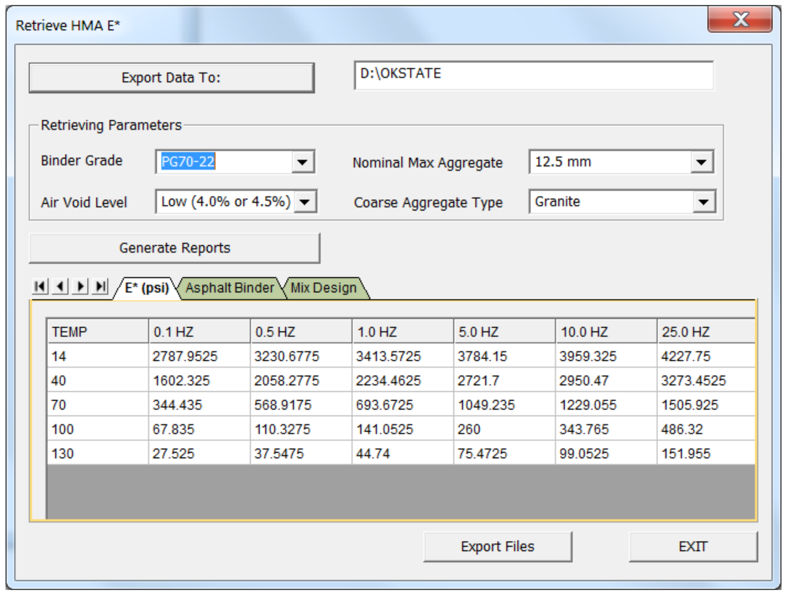


Figure 7.1 Retrieving Dynamic Modulus (E*) Data

## 7.3 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 mixture. 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, cementations paste, and mixture age (Figure 7.2). 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™.

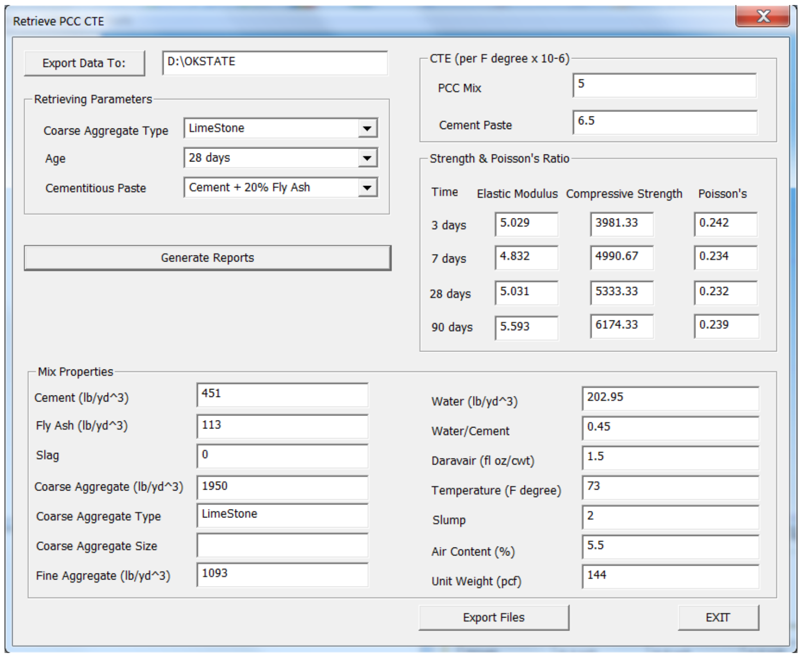


Figure 7.2 Retrieving CTE Data

## 7.4 Soil Map for Subgrade

The NCHRP 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 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 as below:

- By inputting the latitude and longitude of a design location, associated Soil Map image will be loaded into the software interface with an extinctive marking demonstrating the design location (Figure 7.3).
- Users can manually input the "Map Char" code on the soil map at the design location to the Prep-ME software interface (Figure 7.4).
- A soil report with all the required soil parameters in Pavement-ME Design™ will be generated for users to view (Figure 7.5). Users can also import the soil parameters in a txt file report (Figure 7.6).

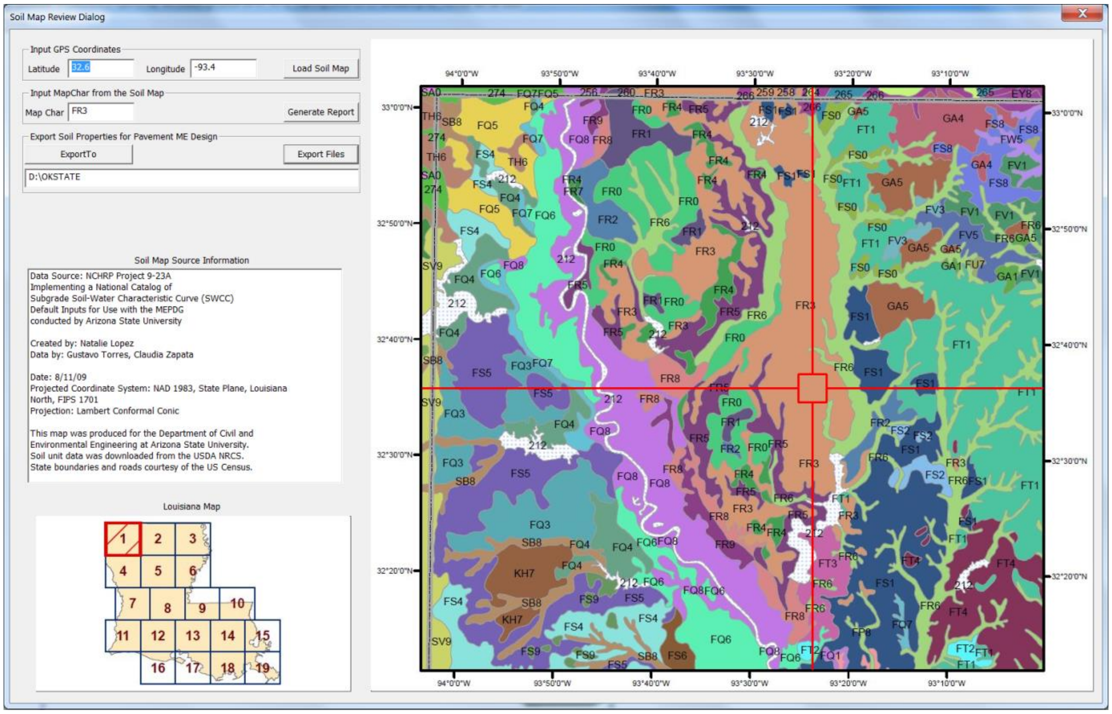



Figure 7.3 Soil Map Module in Prep-ME

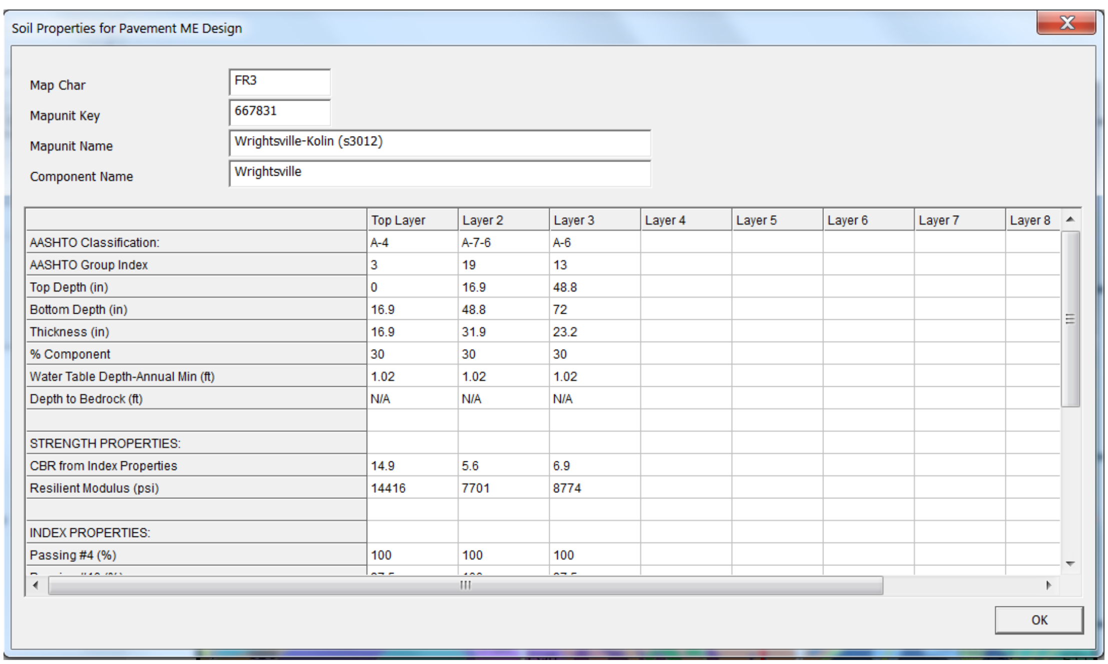



Figure 7.4 Retrieved Soil Properties

```
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 7.5 Generated Soil Property File for Pavement-ME Design™

# CHAPTER 8 Preliminary FWD Module

## 8.1 Introduction

Falling Weight Deflectometer (FWD) testing has grown in popularity to become one of the most effective tools in the evaluation and characterization of existing pavement structures for rehabilitation purposes and for construction of new pavements. In Pavement-ME Design™, it has been recommended that FWD data and subsequent data analysis results be used as input to determine rehabilitation strategies for exiting pavement structures.

## 8.2 FWD Capabilities

In Prep-ME, a preliminary FWD module has been developed, which can:

- Import raw FWD F25 data into Prep-ME database (Figure 8.1): currently only F25 FWD files can be imported into the Prep-ME database. Deflection data, temperature data, and general pavement information are saved;
- Input pavement structure data into Prep-ME database (Figure 8.1): 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 8.2);

- Generate FWD XML file for Pavement-ME Design™ (Figure 8.3): after the back-calculation analysis is completed using a third party software, user can manually input the back-calculated modulus for each pavement layer through Prep-ME. Prep-ME can output FWD XML file that can be read by Pavement-ME Design™.

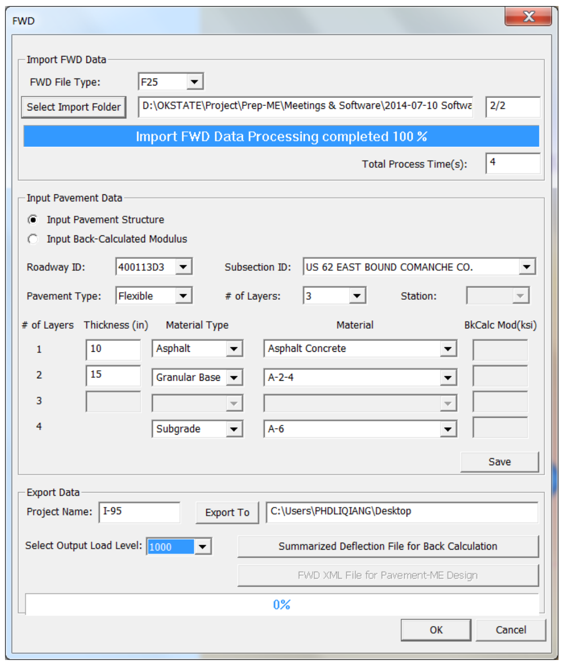
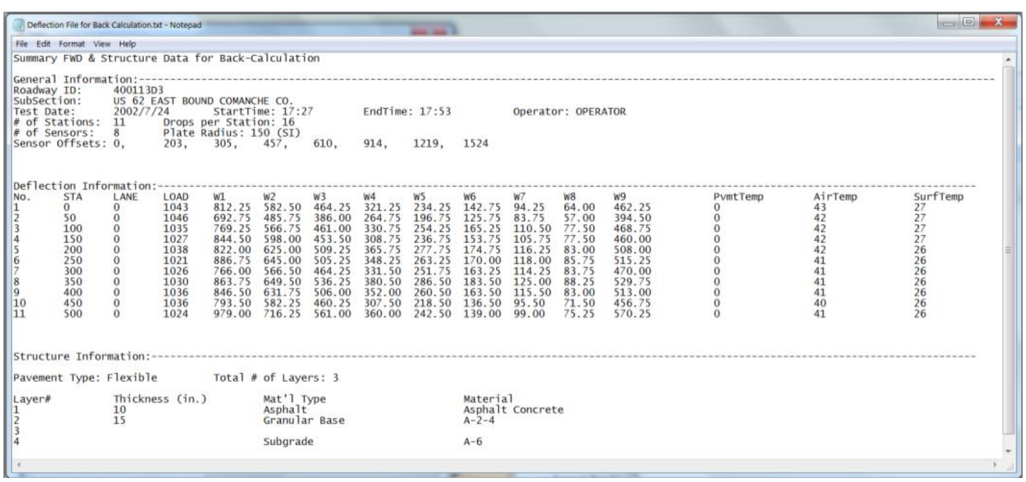



Figure 8.1 Import FWD Data



Deflection File for Back Calculation.txt - Notepad

```
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 8.2 Generate Report for FWD Back-Calculation

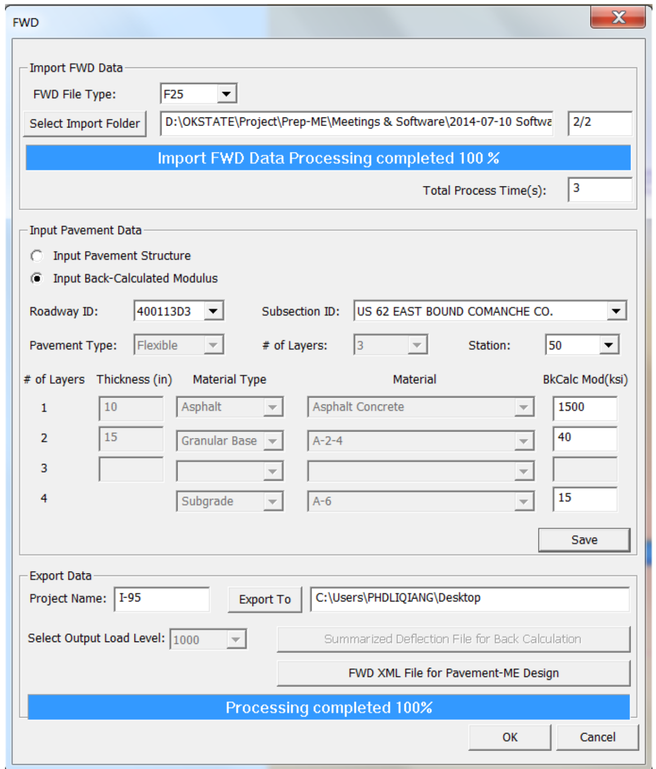


Figure 8.3 Output FWD XML File for Pavement-ME Design™

# CHAPTER 9 PREP-ME TOOLS

## 9.1 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.

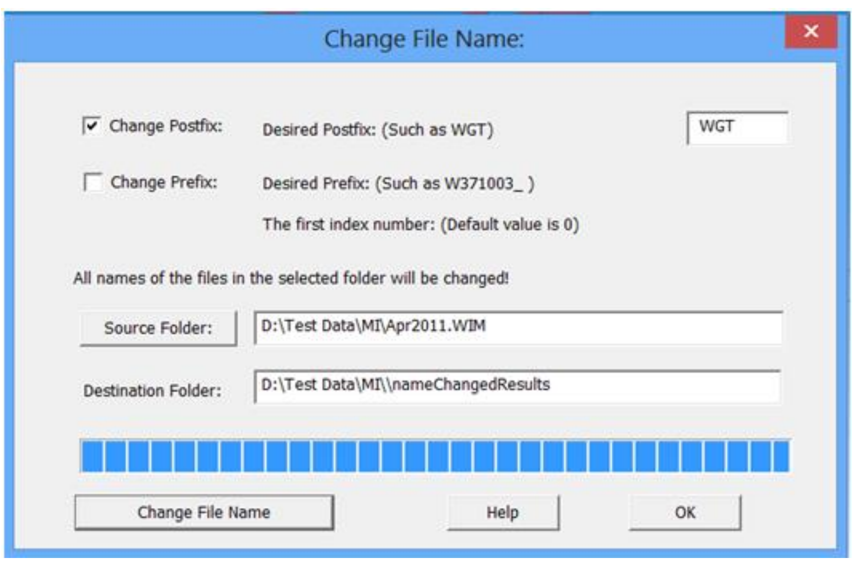



Figure 9.1 Change File Name Interface

## 9.2 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 9.2.

- Users have to input 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.

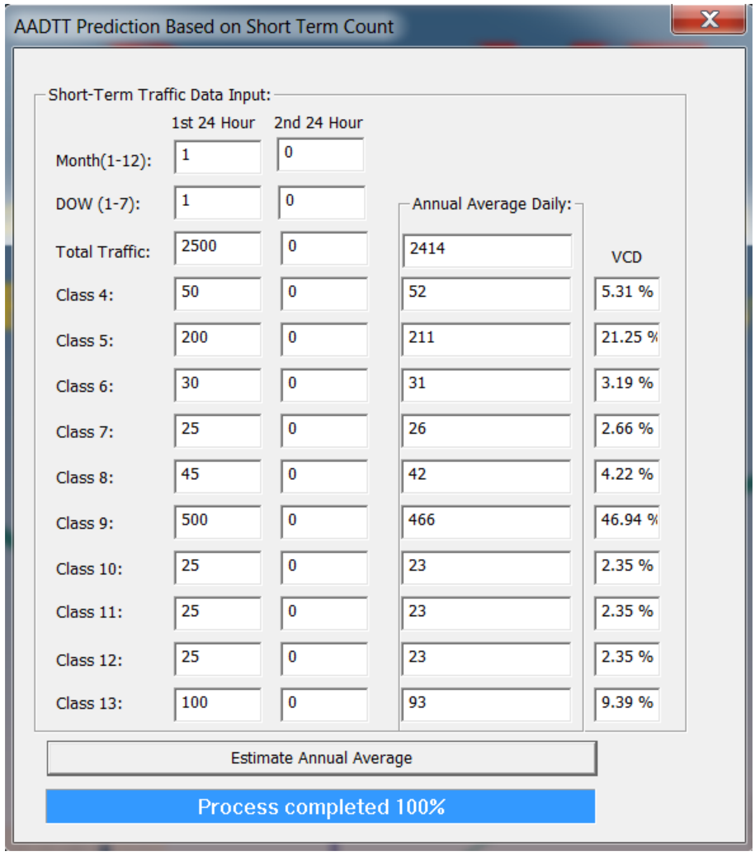



Figure 9.2 AADTT Prediction Based on Short Term Traffic Count

# CHAPTER 10 CONCLUSIONS

Pavement-ME Design™ (previously MEPDG/DARWin-ME) is a significant advancement in pavement design, but requires much more inputs from various data sources. In this project, a full-production Prep-ME 3.0 software with comprehensive database features is developed to assist AHTD 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 key functions:

1) Imports 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.
2) Conduct Travel Monitoring Analysis System (TMAS 2.0) data check and generate TMAS check error log for each imported raw file.
3) Perform automatic quality control checks by direction and lane of a WIM station for both classification and weight data following algorithms defined in TMG.
4) 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.

5) Generate three levels of traffic inputs: Level 1 site specific, Level 2 clustering average, Level 3 state average, and LTPP TPF-5(004) defaults.
6) Clustering methods developed by North Carolina and Michigan DOTs, the Truck Traffic Classification (TTC) method, and the simplified TTC approach are fully implemented, offering state agencies with the flexibility of generating Level 2 loading spectra inputs for Pavement-ME Design™ based on the availability of traffic data.
7) Generate input files in the file formats that can be directly imported into MEPDG and Pavement-ME Design™ software.

In addition, 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 DARWin-ME; and (3) importing FWD raw files and preparing FWD XML file for DARWin-ME 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.

# CHAPTER 11 REFERENCES

NCHRP 1-37A (2004). *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*. Applied Research Associates Inc. ERES Consultants Division, Urbana Champion, IL.

Haider Syed W., Neeraj Buch, Karim Chatti, and Joel Brown (2011). Development of Traffic Inputs for the Mechanistic-Empirical Pavement Design Guide in the state of Michigan. Journal of the Transportation Research Record, No. 2256, pp. 179-190.

Li Q., Kelvin C. P. Wang, Shi Qiu a, Zhongjie "Doc" Zhang, Mike Moravec (2013). Development of Simplified Traffic Loading for Secondary Road Pavement Design. Accepted for publication in the *International Journal of Pavement Engineering* (in press).

Lu, Q., and J. T. Harvey (2006). Characterization of Truck Traffic in California for Mechanistic-Empirical Design. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1945, Washington, D.C., pp. 61-72.

Lu Q., Y. Zhang, and J. T. Harvey (2008). Estimation of Truck Traffic Inputs for M-E Pavement Design In California. In CD-ROM, *84th TRB Annual Meeting*, Washington, D.C.

Papagiannakis A. T., Bracher M., and Jackson N. C. (2006). Utilizing Clustering Techniques in Estimating Traffic Data Input for Pavement Design. ASCE *Journal of Transportation Engineering*, Vol. 132, No. 11, pp: 872-879

Prozzi, J. A., and F. Hong (2005). Hierarchical Axle Load Data for Mechanistic-Empirical Design. In CD-ROM, *84th TRB Annual Meeting*, Washington, D.C.

Sayyady, F., J. R. Stone, K . L. Taylor, F. M. Jadoun, and Y. R. Kim (2010). Clustering Analysis to Characterize Mechanistic–Empirical Pavement Design Guide Traffic Data in North Carolina. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2160, Washington, D.C., pp. 118-127.

Wang, K., Li, Q., Hall, K., Nguyen, V., and Xiao, D. (2011). Development of Truck Loading Groups for the Mechanistic-Empirical Pavement Design Guide. *Journal of Transportation Engineering*, 137(12), 855–862.

Wang K., Joshua Q. Li, Vu Nguyen, Mike Moravec, Doc Zhang (2013). Prep-ME: An Multi-Agency Effort to Prepare Data for DARWin-ME. *2013 Airfield and Highway Pavements Conference*, Los Angeles, CA.

Wang Y., D. E. Hancher, and K. Mahboub (2007). Axle Load Distribution for Mechanistic-Empirical Pavement Design. *Journal of Transportation Engineering*, Vol. 133, No. 8, pp. 469-479.