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Traffic Data Input for Mechanistic Empirical Pavement Design Guide (MEPDG) for Tennessee

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DISCLAIMER

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16. Abstract

Traffic loading is one of the key inputs for the structural design and analysis of pavement structures using both the AASHTO Guide for Pavement Design (1993) and the Pavement Mechanistic-Empirical Design (PMED) Guide. Traffic data provides necessary information in terms of traffic load distributions, intensity and number of repetitions. PMED requires a large number of design inputs that characterizes traffic, pavement materials and climate. PMED traffic input parameters include base year truck-traffic volume; truck growth factors; vehicle (trucks) class distribution; hourly distribution factors (HDF); monthly distribution factors (MDF); design lane factors; axle and wheel base configurations; average number of axle groups per vehicles for FHWA vehicle class 4 – 13; and Normalized axle load spectra (NALS).

The development of these parameters require data from vehicle counts, automatic vehicle classification (AVC) and weigh in Motion (WIM). Currently, TDOT lacks AVC and WIM stations; therefore, this study utilized data from other sources to develop Level 2 (Statewide) traffic inputs. Long-Term Pavement Performance (LTPP) sites in Tennessee were used to develop monthly adjustment factors. AADT and 24-hr classification counts were used to develop vehicle class distribution (VCD) factors. LTPP - Pavement Loading User Guide (LTTP-PLUG) is recommended for Normalized Axle Load Spectra (NALS). Other factors will use TDOT project specifications and level 3 parameters. The developed parameters will be used until TDOT installs WIM and AVC stations, and collects data and updates the current Level 2 traffic input parameters. The study also found that the continuous count data could not be used for developing VCD for the state of Tennessee.

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Executive Summary

This study was conducted by the University of Tennessee at Chattanooga (UTC) in collaboration with Tennessee Department of Transportation (TDOT) to develop Mechanistic Empirical Pavement Design Guide (MEPDG) Level 2 traffic input parameters for the State of Tennessee.

Both the AASHTO Guide for Pavement Design (1993) and the MEPDG (2004) require traffic loading as one of the key inputs for structural design and analysis of pavement structures. Traffic data provides necessary information in terms of traffic load distributions, intensity and number of repetitions needed for pavement design. The AASHTO 1993 design method uses the number of axle load repetitions in the design/analysis period in terms of equivalent singe axle loads (ESALS), while the MEPDG requires proper traffic characterization to determine traffic inputs parameters required for the pavement design process. MEPDG was developed by the National Cooperative Highway Research Programs (NCHRP), Project 1-37A (2004), to provide pavement engineers with a more effective design guide that responds to changing design inputs, needs and the environment. The implementation of the MEPDG requires a large number of design inputs that characterizes traffic, pavement materials and climate. Traffic data elements for MEPDG design include: truck growth factors; vehicle (trucks) class distribution; base year truck-traffic volume; axle and wheel base configurations; hourly distribution factors; monthly distribution factors; average number of axle groups per vehicles for FHWA Vehicle Class 4 – 13; and axle load spectra. To facilitate the design process, MEPDG provides a hierarchical approach for traffic data input requirements, known as Level 1, 2 and 3 (ARA, 2001-1).

Level 1: Site-specific data with very good knowledge of past and future traffic characteristics
Level 2: Regional or statewide data, with modest knowledge of past and future traffic characteristics.
Level 3: Poor or limited knowledge of past and future traffic characteristics.

This project was aimed at determining MEPDG Level 2 traffic input parameters for the State of Tennessee.

SYNOPSIS OF THE PROBLEM BEING RESEARCHED

The implementation of MEPDG requires determination and local calibration of different input parameters, mainly materials, climate and traffic. This project was conducted to determine and recommend Level 2 (regional) traffic input parameters for the State of Tennessee. Currently, TDOT lacks actuated vehicle classification (AVC) and Weigh-in-Motion (WIM) stations, which are instrumental in the development of traffic input parameters. In the absence of these stations, the UTC research team and TDOT project sponsors determined alternative methods to develop the needed traffic inputs. Different data sources were obtained, processed and analyzed to determine their suitability for developing Level 2 traffic input parameters. These data sources include: Traffic data from TDOT continuous traffic count stations; TDOT 24-hour classification counts; LTPP sites in Tennessee and Long-Term Pavement Performance - Pavement Loading User Guide (LTPP-PLUG). The AASHTOWare PMED software was used for analysis and prediction of pavement performance. The research team utilized the local calibrated coefficients to model and predict distresses, namely, alligator cracking, longitudinal cracking, rutting, and international roughness index. The distresses were measured against TDOT thresholds at the respective reliability and design period.

From the analysis the following were observed:

- The base year traffic inputs, such as two way AADTT, number of lanes, percent trucks in the design lane, direction distribution, and operational speed will follow TDOT project specification.
- For traffic volume adjustment factors, the monthly adjustment factors were determined using the analysis of traffic data from the LTPP sites in Tennessee, where monthly adjustment factors for vehicle classes 4 to 13 for the months of January to December were determined. National default values are

recommended for hourly adjustment factors.

- TDOT traffic growth factors are recommended for all vehicle classes.
- The 24-hour classification counts were used to develop the vehicle class distributions for all road functional classes in Tennessee except for local roads both rural and urban.
- The LTPP-PLUG axle load distribution factors or axle load spectra are recommended for level 2 traffic inputs.
- Other general inputs, such as number of axles groups per truck for VC 4 to 13, axle configuration, wheel-base configuration and lateral wander will use national default values.

The final report is attached to this executive summary and provides information on available data, data analysis and tables of traffic input parameters developed from this research project. The input parameters were not verified because the research team was unable to gain access to pavement section(s) that have a long-term record of distress without having any surface treatments.

List of Acronyms

AADTT : Average Annual Daily Truck Traffic.
AASHTO : American Association of State Highway and Transportation Officials
AC : Asphalt Concrete.
ADOT : Arizona Department of Transportation.
ADTT : Average Daily Truck Traffic.
AGPV : Axle Group Per Vehicle.
ALD : Axial Load Distribution.
ALDF : Axial Load Distribution Factors.
ALDOT : Alabama Department of Transportation.
ALS : Axle Load Spectra.
APC : Axle per Truck.
ARA : Applied Research Associates.
ASTM : American Society of Testing and Materials.
ATRC : Arizona Transportation research center.
AVC : Automated Vehicle Classification.
DDF : Directional Distribution Factors.
ESAL : Equivalent Single Axle Loads.
FC : Functional Class.
FHWA : Federal Highway Administration.
GDOT : Georgia Department of Transportation.
HAF : Hourly Adjustment Factors.
HDF : Hourly Distribution Factors.
HMA : Hot Mix Asphalt.
IRI : International Roughness Index.
ITD : Idaho Department of Transportation.
JPCP : Jointed Plain Concrete Pavement.
LTPP : Long-Term Pavement Performance.
LTPP PLUG : Long-Term Pavement Performance Pavement Loading User Guide
MAF : Monthly Adjustment Factors.
MDF : Monthly Distribution Factors.
MDOT : Michigan Department of Transportation.
MEPDG : Mechanistic Empirical Pavement Design Guide.
MPD : Multimodal Planning Division.
MU : Multi-Unit Trucks.
MVD : Motor Vehicle Division.
NALS : Normalized Axle Load Spectra.
NCDOT : North Carolina Department of Transportation.
NCHRP : National Cooperative Highway Research Program.
NVCD : Normalized vehicle Class distribution.
NYSDOT : New York State Department of Transportation.
ODOT : Oregon Department of Transportation.
PCC : Portland Cement Concrete.
PMED : Pavement Mechanistic Empirical Design.
PTR : Permanent Traffic Recorders.
SPS : Specific Pavement Studies.
SU : Single-Unit Trucks.

TADT : Truck Average Daily Traffic.
TCC : Tennessee Continuous Count.
TDOT : Tennessee Department of Transportation.
TMAS : Travel Monitoring Analysis System.
TN : Tennessee.
TPF : Transportation Pooled-Fund.
TTC : Truck Traffic Classification.
UTC : University of Tennessee at Chattanooga.
UTK : University of Tennessee Knoxville.
VC : Vehicle Class.
VCD : Vehicle Class Distribution.
VCF : Vehicle Class Factors.
VDOT : Virginia Department of Transportation.
WIM : Weigh in Motion.
WSDOT : Washington State Department of Transportation.

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Chapter 1: Introduction

1.1 MEPDG Background

Since the development of the Mechanistic-Empirical Pavement Design Guide (MEPDG) by the National Cooperative Highway Research Programs (NCHRP), Project 1-37A (2004), significant efforts have been made by numerous State Highway Agencies and transportation organizations to evaluate the Mechanistic-Empirical (ME) pavement design procedure for implementation as a pavement design standard or adopt it as part of existing or new pavement design, evaluation and analysis procedures (Mallela, 2009). The guide is based on comprehensive pavement design procedures that use existing mechanistic methods to calculate pavement load response and empirical methods to predict the performance of the designed pavement (ARA, 2004-1). The MEPDG utilizes hierarchical design inputs in materials, traffic and environment (climate) to provide designers with flexibility based on available funds and criticality of the project. The guide provides three input levels (ARA, 2004-1), namely:

Level 1 inputs: Useful for heavily trafficked pavements because they provide the highest level of accuracy and hence the lowest level of uncertainty or error. Level 1 inputs requires more resources and time compared to other levels.

Level 2 inputs: Provide an intermediate level of accuracy and would be closest to the typical procedures used with earlier editions of the AASHTO Guide. Uses regional or statewide inputs.

Level 3 inputs: Provide the lowest level of accuracy, where minimal consequences from early failures are expected. These are AASHTOWare PMED default values.

For a given project, the design inputs may be used as mixed levels depending on the availability of the relevant input data. The implementation of the Pavement ME Design (PMED) as a design procedure requires developing a database of inputs for Level 1 or Level 2 that the State may adopt. Level 3 input parameters are available as the default values in the AASHTOWare PMED software. To adopt PMED as alternative design procedure for the State of Tennessee, the Tennessee Department of Transportation (TDOT) has invested resources and time to develop Level 2 inputs for the PMED guide. Material transfer functions are already developed, and currently, traffic input parameters are being developed.

Traffic loading is one of the key inputs for pavement structural design. The previous *Guide for Design of Pavement Structures* (1993), which was based on the AASHTO design method used Equivalent Single Axle Loads (ESAL) for traffic load input, while the current guide requires a large number of inputs to characterize traffic. As explained in details in Chapter 4 of the final report of NCHRP Project 1-37A (ARA 2004-2), traffic data elements for the design guide include the following: truck growth factors; vehicle (trucks) class distribution; base year truck-traffic volume; axle and wheel base configurations; hourly distribution factors; monthly distribution factors; average number of axle groups per vehicles for FHWA Vehicle Classes 4 – 13; and axle load spectra. To facilitate the design process, ARA (2004) explains the hierarchical traffic inputs as follows (ARA 2004-2):

Level 1: Site-specific data with very good knowledge of past and future traffic characteristics.

Level 2: Regional or statewide data, with modest knowledge of past and future traffic characteristics.

Level 3: Poor or limited knowledge of past and future traffic characteristics.

1.2 Requirements for Traffic Inputs

Traffic input data for Pavement ME Design requires traffic inputs from the Federal Highway Administration (FHWA) Vehicle Classes 4 to 13, as explained in Figure 1 below.

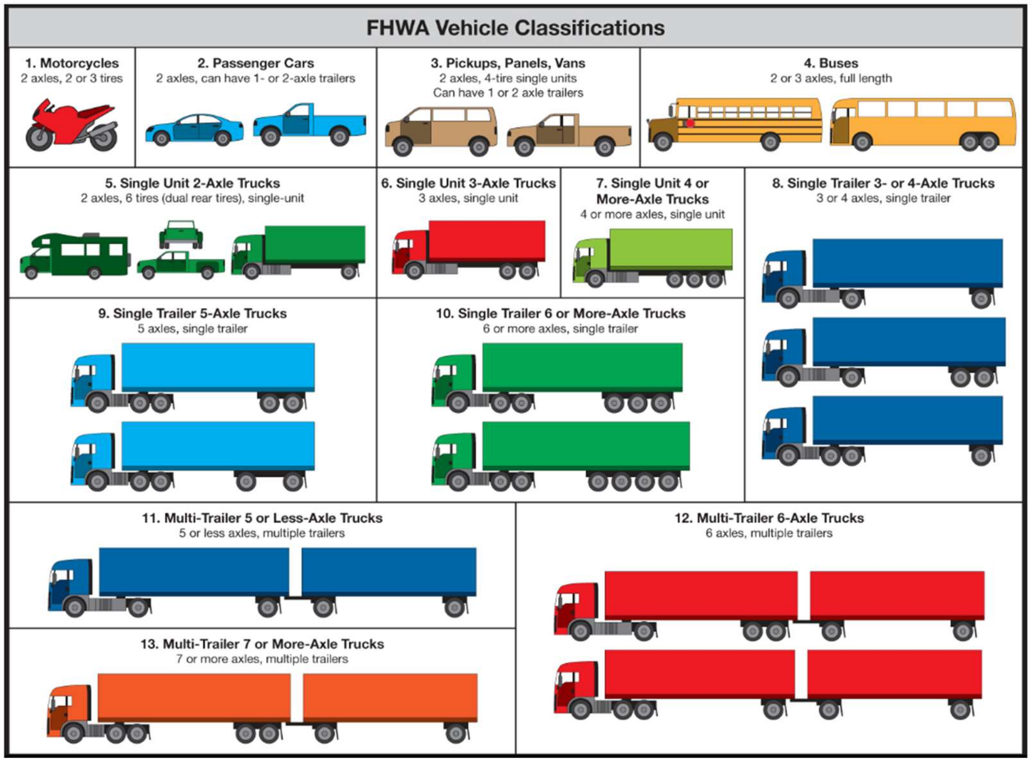

Figure 1: FHWA Vehicle Classification (James & Randall, 2012)

Automatic Vehicle Classification (AVC) data

AVC data are used to determine the normalized vehicle class for truck distribution over a specified period of time. Currently TDOT does not have AVC stations installed; instead, it collects continuous volume counts and 24 hour classified counts to obtain AADTT for the AASHTO 93 design guide.

Weigh-in-Motion (WIM) data

WIM data are used to determine the normalized axle load distribution, or axle load spectra, for each axle type within each vehicle class. These axle weight data are needed for Level 1, 2 and 3 inputs. Currently, TDOT does not own WIM stations, therefore TDOT and the research team agreed to use the available alternative data sources for traffic analysis for the State of Tennessee. The team also compared design outputs using LTPP PLUG and Level 3 (default) axle load spectra. The factors required for PMED traffic input include:

- i) Average Annual Daily Truck Traffic (AADTT)
- ii) Average Annual Daily Traffic (AADT) or Vehicle Counts
- iii) Percent Trucks
- iv) Truck Traffic Classification (TTC) for Pavement Structural Design
- v) Loading details of the axle loads and axle configuration
- vi) Traffic factors, such as:
  - a) Traffic hourly distribution factors

b) Weekday and weekend truck traffic factors
c) Directional distribution factor
d) Lane distribution factor
e) Lateral wander distribution factor
f) Traffic growth factor or function
g) Axle load spectra
h) Traffic growth factors.

The traffic input factors above are developed from AVC and WIM analysis. Since TDOT has neither WIM nor AVC stations, the following data was used for developing traffic input factors, (1) LTPP sites in Tennessee, (2) current TDOT design inputs (continuous count stations and short-term classification counts), and (3) Level 3 input as it is explained in the Methodology and data analysis chapter.

1.3 Problem Statement

Developing a database of traffic inputs for PMED requires rigorous statewide traffic data collection and analysis. This includes establishing statewide Weigh in Motion (WIM) and Automated Vehicle Classification (AVC) stations; collecting data; clustering and analyzing data to obtain all the traffic input parameters required; and running PMED analyses for the traffic clusters, keeping all other inputs constant, to evaluate the effect of variability of traffic inputs to pavement response. This analysis provides information on pavement response to the traffic cluster(s) and is used to determine the statewide (level 2) traffic inputs for the AASHTOWare PMED software. The main challenge is that some or most of the data needed for analysis is not available statewide. Therefore, alternative data sources were used to develop the needed traffic input parameters, as a provisional solution, until WIM and AVC data are collected and analyzed. When that occurs, the traffic inputs will be updated.

1.3.1 Objective

The main objective of this research project was to determine Level 2 traffic input parameters for pavement design in the State of Tennessee. The specific objectives included the following:

1) Obtain from TDOT and LTPP sites the available traffic and material data for the State of Tennessee.
2) Cluster the available traffic data based on the similarity of traffic patterns for a given parameter.
3) Perform AASHTOWare PMED analysis for each cluster to determine the variation of each traffic input parameter (sensitivity analysis) using Level 3 (nationwide) axle spectra.
4) Compare outputs (predicted distresses) obtained using site-specific, regional and national input parameters to measured values (as available).
5) Recommend Level 2 traffic data input parameters for the State of Tennessee.

1.3.2 Scope of the Project

The scope of the research work included the following:

- Extensive literature review of journals and reports from state DOTs that have already calibrated traffic input parameters.

- The NCHRP Project 1-37A final report and PMED software were used for the guidance and analysis respectively.
- Clustering and analysis to obtain traffic input parameters for the PMED using the available traffic data from continuous count stations, short-term classification counts and LTPP sites.
- Sensitivity analysis of traffic input parameters to assess pavement response to traffic inputs.
- Determination of traffic data input parameters for MEPDG implementation in the state of Tennessee.
- Submission of quarterly reports, recommended traffic input parameters and a detailed project final report.

1.3.3 Benefits to TDOT

The study benefits TDOT in the following aspects:

1) The proposed study provides TDOT with Level 2 PMED traffic data input parameters.
2) These parameters are part of the MEPDG implementation plan for design of pavements in the state of Tennessee.
3) MEPDG is an alternative design method that TDOT will use to design cost effective and long-lasting pavements.

1.3.4 Deliverables

The deliverables of this research project include the following:

1) Cluster and analyze the 24 hour classified count data.
2) Run the data on the AASHTOWare PMED for performance prediction.
3) Perform a sensitivity analysis to evaluate the effects of traffic input parameters on pavement response.
4) Evaluate LTPP PLUG axle load data in comparison to AASHTOWare Level 3 axle load data.
5) Recommend Level 2 traffic input parameters for Tennessee according to the available data.
6) Final Report documenting process analysis and recommended traffic inputs.

This report provides the traffic input parameters for the State of Tennessee. The report has five (5) chapters. Chapter 1: Introduction, Chapter 2: Literature Review, Chapter 3: Methodology/Data Analysis, Chapter 4: Findings and Deliverables and Chapter 5: Conclusion and Recommendations. Throughout this report MEPDG and PMED are sometimes used interchangeably to mean the Mechanistic Empirical Pavement Design Method (The Pavement Design Guide and the Pavement Design Software).

Chapter 2: Literature Review

Traffic loading is one of the key inputs for the structural design and analysis of pavement structures using both the AASHTO Guide for Pavement Design (1993) and the Mechanistic-Empirical Pavement Design Guide (MEPDG) (2004), or currently PMED. Traffic data provides necessary information in terms of traffic load distributions, intensity and number of repetitions. While the AASHTO design method uses the number of axle load repetitions in the design/analysis period in terms of equivalent singe axle loads (ESAL), the MEPDG/PMED requires proper traffic characterization to determine traffic parameters required as inputs for the pavement design process. MEPDG was developed by the National Cooperative Highway Research Programs (NCHRP), Project 1-37A (2004), to provide pavement engineers with a more effective design guide that responds to changing design inputs, needs and the environment. Implementation of the MEPDG requires a large number of design inputs that characterizes traffic, pavement materials and climate (Abdullah, Romanoschi, Bendana, & Nyamuhokya, 2014). As explained in detail in Chapter 4 of the final report of NCHRP Project 1-37A, traffic data elements for the design guide include: truck growth factors; vehicle (trucks) class distribution; base year truck-traffic volume; axle and wheel base configurations; hourly distribution factors; monthly distribution factors; average number of axle groups per vehicle for FHWA Vehicle Classes 4 – 13; and axle load spectra. To facilitate the design process, MEPDG provides a hierarchical approach for traffic data input requirements, known as Level 1, 2 and 3 (ARA 2004-2).

Level 1: Site-specific data with very good knowledge of past and future traffic characteristics
Level 2: Regional or statewide data, with modest knowledge of past and future traffic characteristics
Level 3: Poor or limited knowledge of past and future traffic characteristics.

Since MEPDG became the state of art in pavement design and rehabilitation, state DOTs started to calibrate their statewide traffic inputs to PMED software. Throughout this chapter, the efforts and accomplishments by several state DOTs are briefly described.

2.1 State of Georgia DOT (GDOT)

In 2014, Applied Research Associates Inc. (ARA) conducted a study for Georgia DOT (GDOT) to develop statewide traffic input for MEPDG and evaluate GDOT traffic data collection and pavement design practices (Selezneva & Von Quintus, 2014). The research obtained data from nine (9) permanent weigh-in-motion (WIM) stations located along interstate roads, as well as portable WIM sites. Due to the unreliability of portable WIM stations, most of the data acquired through this means was inadequate as direct Level 1 input. Hence, Level 1 traffic inputs were developed based on 2010 data from piloted permanent WIM stations, to include normalized axle load spectra (NALS), normalized Vehicle Class distribution (NVCD), axle per class coefficients, and hourly truck volume distributions.

To assess the potential of data collected from GDOT's portable WIM stations to serve as MEPDG input, GDOT's contractor collected 107 directional WIM data samples taken between 2002 and 2012 at 56 portable WIM stations along 31 roads, for a total of 107 directional WIM data samples. The study found Vehicle Class (VC) 9 to be the major heavy vehicle class in Georgia, accounting for approximately 70% of all trucks passing through these sites. It was also observed that VCs 7 and 11-13 were the least represented.

Based on these data and data collected from pilot permanent WIM stations, researchers grouped traffic loading on GDOT roads into three loading categories:

- **Moderate** - meaning 10-30% of VC9 trucks are heavily loaded. Moderate loading is typically observed on roads used for local distribution, or those that have an annual average daily truck traffic (AADTT) of fewer than 1,000 trucks in the design lane and for which VC9 represents less than 50% of the truck distribution.
- **Heavy 1** – meaning 30-40% of VC9 trucks are heavily loaded. Heavy 1 loading is found on roads used for both local and State-to-State distribution, or those that have an AADTT of 1,000-3,000 trucks in the design lane and for which VC9 represents between 50-80% of the truck distribution.
- **Heavy 2** – meaning 40-50% of VC9 trucks are heavily loaded. Heavy 2 loading is found primarily on interstates, or those that have an AADTT greater than 2,000 trucks in the design lane and for which VC9 represents more than 80% of the truck distribution.

Comparisons of the NALS from each category showed a statistical difference from the LTPP default; however, the validity of this finding is inconclusive as the GDOT data was collected from portable WIM stations, which provides less accurate data.

A sensitivity analysis compared the predicted distresses, design life and pavement thickness for both flexible and rigid pavements using NALS from Georgia NALS, MEPDG Default NALS, LTPP PLUG NALS, and Florida NALS. To develop traffic loading inputs, researchers focused on roads with at least: two lanes in the design direction, an initial two-way AADTT of 7,500, 50% trucks in the design direction, 95% trucks in the design lane, and a truck compound growth rate of 2.5%. The parameters for the design features analyzed included an IRI of 160 in/mile, AC bottom-up fatigue cracking at 10%, permanent deformation for the total pavement at 0.4 in., rigid pavement transverse slab cracking at 10%, and mean joint faulting at 0.15 in. The analysis found a greater than 50% difference in pavement design life when using Georgia observed NALS but a difference in pavement thickness of less than one inch. It was recommended that GDOT install permanent WIM stations in order to generate state-specific inputs, including Level 1 VCD data, to inform pavement design.

Additionally, researchers investigated software developed by FHWA, WIM vendors, NCHRP and state products, and recommended the following software selection guidelines:

- Use software from WIM vendors that include quality control.
- Use FHWA TMAS software for processing and summarizing WIM data and generating inputs that are compatible with the AASHTOWare Pavement ME Design software.
- Customize the LTPP PLUG database application for state use.

2.2 State of North Carolina DOT (NCDOT)

In 2011, North Carolina State University performed a study for NCDOT to develop traffic inputs for MEPDG (Stone et al., 2011). The research used sensitivity analysis to investigate factors that affect North Carolina pavement performance. North Carolina defined the following factors for flexible pavements: IRI, alligator cracking, longitudinal cracking and rutting. For Jointed Plain Concrete Pavement (JCRP), the only rigid pavement type used in North Carolina State, IRI, faulting and percentage of slabs cracks were used as performance measures.

The study used NCDOT data from 1997 to mid-2007, collected from 44 WIM sites, 19 of which were LTPP stations, at 12-month consecutive intervals. In addition, data was used from a statewide 48-hour truck traffic count survey conducted in 2006 and 2007, which collected vehicle classification counts at more than 1,000 locations across the state. To develop Axial Load Distribution Factor (ALDF) inputs, the researchers clustered data from WIM sites with similar attributes and estimated traffic data for road segments lacking available data using these clusters.

Researchers identified situations where national default or statewide values could be used as design inputs:

- **Axle load and axle configuration**. State-specific values should be used for the average number of axles by axle type per vehicle classification and axle spacing, while national default values can be used for lateral traffic wader; average axle width, tire pressure, dual tire spacing; wheelbase distribution; percent trucks in design direction; and operational speed.
- **Other traffic factors.** National default values can be used for the directional distribution factor, lane distribution factor, and operational speed.

With these inputs, researchers conducted a MEPDG damage-based sensitivity analysis to find the sensitivity of pavement performance to each traffic factor. Parameters for the analysis included a maximum IRI of 14 in/mile, 0.1 in. rutting, alligator cracking in 1% of the lane area, 264 feet/mi for longitudinal cracking, and 0.1 in for JPCP faulting. Results of the sensitivity analysis found the following:

- Hourly distribution factors have no significant impact on pavement performance for all types of pavements, and as such statewide averages may be used for Level 2 and Level 3 inputs for both flexible and rigid pavement designs.
- Monthly adjustment factors have no significant impact on rigid pavement performance or predicted fatigue cracking in flexible pavement; therefore, statewide averages may be used for Level 2 and Level 3 designs.
- ALDF and VCD inputs do have a significant impact on the performance of various pavement types and as such site-specific ALDF inputs should be developed using single and tandem axles as the primary dimensions of the clustering analysis.

2.3 State of Virginia DOT (VDOT)

In 2010, the Virginia Transportation Research Council analyzed Virginia-specific traffic data inputs for the MEPDG in Virginia (Smith & Diefenderfer, 2010). VDOT’s Traffic Engineering Division provided 1-week continuous data from 15 WIM sites on interstate and highway road segments between June 2007 and May 2008. The data included values for each of the following: site identification number, vehicle identification number, lane of travel, date and time, FHWA vehicle classification number, the vehicle speed, the gross vehicle weight, the number of axles, the weight of each axle, and the distance between the axles.

Researchers compared the predicted pavement conditions generated by site-specific data to that generated by default MEPDG values using trial pavement sections from a high-traffic interstate and a high-traffic highway (primary). The research team found statistically significant differences for both flexible and rigid pavements, as follows:

- **Flexible Pavement.** Significant differences in asphalt rutting, total rutting, and the predicted time to failure were found between site-specific and default MEPDG axle load site spectra, monthly adjustment factors, and vehicle class distribution factors. The different values for the number of axles per truck was not found to be statistically significant.
- **Rigid Pavement.** A significant difference in predicted load transfer efficiency was found between site-specific and default MEPDG axle load site spectra and vehicle class distribution factors. A difference was also found for monthly adjustment factors; however, it was noted that incomplete WIM data may have influenced the results. The different values for the number of axles per truck was not found to be statistically significant.

Given these findings, researchers recommended the following:

- For flexible pavements: site-specific axle-load spectra and default MEPDG values for monthly adjustment factors, vehicle class distribution factors, and number of axles per truck should be used for analysis.
- For rigid payments: site-specific vehicle class distribution factors should be used for analysis of interstate rigid pavements while default class distribution factors should be used for analysis of primary rigid pavements. Default axle-load spectra, monthly adjustment factors, and number of axles per truck may be used for analysis of both interstate and primary rigid pavements.

2.4 Arizona State DOT (ADOT)

In 2013, Applied Research Associates Inc. (ARA) conducted a study for ADOT to develop statewide traffic input for MEPDG (Darter, Titus-Glover, & Wolf, 2013). The main objectives of this study were to identify MEPDG traffic data input needs; evaluate ADOT's current practices for collecting, storing and analyzing traffic data; and perform a quality performance check of existing traffic data.

In order to develop the ADOT MEPDG traffic input data system for Arizona, the research team acquired inputs from various traffic data monitoring and collection equipment at 10 WIM sites and eight automatic vehicle classification (AVC) sites. In addition, data from Arizona Transportation Research Center, ADOT Multimodal Planning Division and ADOT Motor Vehicle Division were utilized.

As in North Carolina, the Arizona research team clustered the data into groups based on shared characteristics and distribution patterns relevant to monthly adjustment factors, hourly truck distribution, vehicle class distribution, axle load distribution, and number of axles per truck. It was determined that for the State of Arizona there were three optimal clusters, none of which aligned with MEPDG defaults:

- **Cluster 1 -** Class 9 vehicles dominate, ranging 60-80%. Class 5 vehicles range 5-20%. The primary Functional Class for this cluster is Rural Principal Arterial – Interstate (FC 1).
- **Cluster 2:** Class 5 vehicles dominate, ranging 20-70%. Class 9 vehicles range 20-40%. The primary Functional Class for this cluster is Urban Principal Arterial (FC 11).
- **Cluster 3:** Class 4 vehicles dominate, at approximately 90%, common to both Rural and Urban Principal Arterial Functional Classes (FC 1, 11).

A sensitivity analysis found that axle load distribution (Arizona clusters and MEPDG national default) and hourly truck distribution did not significantly impact overall HMA and JPCP design, but that VCD did impact both pavement designs, with a difference of 4.3-28.6% for HMA thickness and 2.9-9.4% for PCC thickness.

The study called for ADOT to improve data collection efforts by establishing a homogenous traffic segment database inclusive of all Arizona highways and collect Level 1 inputs.

2.5 State of Alabama DOT (ALDOT)

Researchers from Auburn University investigated the differences among traffic inputs at the national, state, and site-specific levels in order to provide recommendations on MEPDG inputs (Turochy, Timm, & Mai, 2015). The project used data from 12 WIM stations, 11 of which were quality-checked, across Alabama during 2006-2008. Level 1 and 2 traffic inputs were developed using TrafLoad. To characterize low, medium and high truck traffic volumes, the project analyzed AADT data from ALDOT's traffic data website and truck average daily traffic percentages from 120 continuous traffic count stations. This process established the low truck traffic volume at 110, medium at 530, and heavy at 2440 heavy trucks per day. Researchers applied a quality control procedure that includes both threshold-value and rational checks to the raw WIM data prior to inclusion in the study, which eliminated approximately 24% of the data.

A sensitivity analysis was conducted, using statewide averages (Level 2 inputs) as the baseline value for comparison against site-specific (Level 1) inputs and nationwide values (Level 3). The analysis found that, for rigid pavement designs, differences between Level 3 and Level 2 inputs did not significantly impact pavement thickness, and differences between Level 2 and Level 1 inputs were only statistically significant for tandem axle load spectra (ALS) on medium and high volume roadways. For flexible pavement designs, differences between Level 3 and Level 2 inputs significantly impacted pavement thickness on high volume roadways to the extent that using Level 3 data would result in an under-design for all traffic input groups except VCD. Between Level 2 and Level 1 inputs, significant differences in pavement thickness were found for tandem ALS, monthly distribution factor (MDF) for tractor trailers and VCD on roadways of all volumes. For high-volume roadways, significant differences in pavement thickness were also found for single ALS, tridem ALS and tridem axle group per vehicle (AGPV).

The report recommends ALDOT implement a quality control procedure at WIM stations monthly and utilize the statewide inputs developed in the study, rather than national inputs for both flexible and rigid pavement design. Statewide inputs were also recommended over regional inputs for quad ALS; single, tandem, and tridem AGPV; MDF tractor-trailer Classes 8-10; and VCD. Regional inputs can be used for single ALS on high-volume roadways and VCD on low to medium volume roadways; however, site-specific (Level 1) inputs are recommended. The report recommends ALDOT install more WIM sites across Alabama to improve the quality of inputs for MEPDG design.

2.6 Other State DOT's

Several other states have undertaken studies to facilitate the development of traffic inputs for the MEPDG guide. They used cluster analysis to predict Level 2 traffic input parameters from the results of the processed data. A summary of these studies is provided below:

2.6.1 New York State

Several studies have been conducted on the traffic volume and corresponding performance of the pavements of the State of New York. Development of traffic inputs by the MEPDG software is one of the tasks for the FHWA pooled fund project TPF-5(079). The Traffic Monitoring Unit of the New York State Department of Transportation developed ALS inputs using 2004-2009 WIM data and collected vehicle count and data from vehicle classification stations (Romanoschi, Momin, Bethu, & Bendana, 2011). The report recommends that site-specific Hourly Adjustment Factors (HAF) and Vehicle Class Distribution Factors be used for MEPDG design as the values varied significantly from site to site; however, state averages may be used for Monthly Adjustment Factors.

In 2014, researchers developed new Level 1 and Level 2 design tables for MEPDG traffic inputs for the State of New York (Abdullah et al., 2014). Data was collected from 52 vehicle classification sites and 19 WIM sites across New York and then clustered. The analysis revealed that the WIM sites could not provide enough data to analyze the traffic load spectra. The report recommended cluster specific values for VCD and statewide averages for ALS, MDF, hourly distribution factors (HDF) and average number for axle group per vehicle (AGPV).

2.6.2 Michigan State

In 2011, researchers at Michigan State University carried out a study in order to characterize the traffic of the State of Michigan. The researchers considered monthly distribution factors, hourly distribution factors, truck traffic classifications, axle groups per vehicle and axle load distributions for various axle configurations (Haider, Buch, Chatti, & Brown, 2011). The team developed Level 1 traffic inputs based on the data collected from 44 WIM and 51 classification stations from November 2005 to October 2007. Level 2 inputs were developed based on Ward's method of cluster analysis, and Level 3 inputs were generated from the average of data for all sites. Analyses were conducted to predict rigid pavement performance using these inputs in MEPDG models.

An analysis of the monthly distribution factor (MDF) was conducted for three vehicle class (VC) clusters: single-unit trailers (VCs 4-7), tractor-trailer combinations (VCs 8-10) and multi-trailer combinations (VCs 11-VC 13). The analysis found no significant differences among single AGPV and in tandem AGPV only VC 4 had a significant difference. Significant differences were found for VCs 7, 10 and 13 (tridem AGPV) as well as quad AGPV clusters.

Among single axle clusters, trucks 4-7 kips and 9-14 kips were dominant with a similar distribution pattern among all sites, and as such statewide ALS can be used for MEPDG inputs. Among tridem-axle clusters, 12 kip trucks were dominant, followed by 40-45 kips. Among quad ALS clusters, three values were dominant: 15-20, 50-60, and 104 kips.

After extensive research and evaluation, in 2017, Michigan DOT published an interim user guide for MEPDG to help pavement designers use the software to design the pavement cross-sections in MDOT projects (Division, November 2017). The guide details software operation, design types to be used with MEPDG, the inputs to be used, and how to assess the design results. The guide recommends using cluster values for traffic inputs in which Level 1 and Level 2 result in a significant difference in time to failure. Statewide values may be used for traffic inputs in which there is no significant difference in time to failure.

2.6.3 Idaho State

In 2012, the National Institute for Advanced Transportation Technology at the University of Idaho conducted a study for the Idaho Department of Transportation (ITD) on the implementation of MEPDG for flexible pavements (El-Badawy, Bayomy, & Santi). The main objective of the study was to establish a database for the required inputs (i.e., materials, traffic and climatic data) for MEPDG for Idaho conditions. Researchers analyzed classification and weight data from 25 WIM sites across Idaho to establish site-specific (Level 1) axle load spectra (ALS), traffic adjustment factors, and number of axles per truck class. Statewide and regional ALS inputs were developed based on the analysis of the weight data from the 14 WIM sites that had data in compliance with FHWA recommended quality checks. The statewide inputs for longitudinal and alligator cracking were significantly higher than MEPDG defaults; however, there was no significant difference in predicted asphalt concrete (AC) layer rutting, total pavement rutting, and IRI. A sensitivity analysis of predicted pavement performance related to cracking, rutting and IRI found that the average annual daily truck traffic (AADTT) most impacted these factors. As such, Level 1 inputs should be used (El-Badawy et al.).

Inputs for the materials database included hot mix asphalt (HMA) layers, unbound layers and subgrade soils. To calculate HMA inputs, dynamic modulus (E*) tests were conducted on 27 plant-produced mixes. The report recommends that MEPDG Level 3 should not be used to characterize Idaho HMA mixtures in absence of Level 1 due to highly biased predictions at the high-test temperature values.

2.6.4 Oregon State

Researchers from Oregon State University calculated axle load characteristics using WIM sites located on state highways with different truck volume levels for the Oregon DOT (Pelphrey & Higgins, 2006). Average Daily Truck Traffic (ADTT) were used to describe traffic load factors that vary depending on truck volume levels. WIM sites distributed across Oregon were chosen to represent three different ADTT volume levels: high (5,000), moderate (1,500) and low (500). Because low volume conditions may produce a greater variation in data, two sites were used (Pelphrey & Higgins, 2006).

Representative data for one month of each season between September 2005 and August 2006 wer used in the analyses. A 24-hour period was randomly selected to represent typical daily truck traffic volume characteristics, with a limit of one weekend day per site to minimize the influence of weekend traffic on the results. For each WIM site, the team evaluated group and individual axle weights, axle spacing, average number of axles per truck and hourly truck volumes. A "virtual" truck classification was created in the MEPDG program to run the WIM data, which bypasses the MEPDG's truck classification and resulted in more accurate pavement designs. These data are available for online download.

2.6.5 Washington State

Researchers from the University of Washington in collaboration with the State of Washington DOT conducted a study to update the WSDOT Pavement Design Catalog using 1993 AASHTO

Guide, MEPDG and historical performance data (Li, Uhlmeyer, Mahoney, & Muench, 2011). Historical performance data was obtained from prior WSDOT studies of WIM stations. These data were used to recalibrate the MEPDG. The recalibration, however, does not accurately model several distress types common to WSDOT pavements, including bottom-up fatigue cracking, flexible pavement roughness, studded tire wear, and longitudinal cracking for rigid pavements. As such, the report does not recommend WSDOT rely on MEPDG alone for pavement design.

Chapter 3: Methodology/Data Analysis

3.1 Methodology

The AASHTOWare Pavement ME Design procedure requires traffic input data obtained from the following:

1) Automated Vehicle Classification (AVC) stations, availing vehicle classification for FHWA Vehicle Classes (VC) 4 to 13 collected from different count stations. The data is stored in C-files and may be processed using FHWA - TrafLoad software to obtain traffic data outputs, which will serve as AASHTOWare PMED traffic input parameters.
2) Weigh in Motion (WIM) data from different count stations, preferably the same stations/locations as AVC. The WIM data provides the axle load distribution of VCs 4 to 13 from each station. From the WIM and AVC data the following traffic input parameters are developed:
    i) Average Annual Daily Traffic (AADT) and Average Annual Daily Truck Traffic (AADTT)
    ii) Truck Traffic Classification (TTC) for Pavement Structural Design
    iii) Loading details of the axle load and axle configuration
    iv) Traffic factors, such as:
        a) Traffic hourly distribution factors
        b) Weekday and weekend truck traffic factors
        c) Monthly distribution factors
        d) Directional distribution factor
        e) Lane distribution factor
        f) Lateral distribution factor (lateral wander)
        g) Traffic growth factor or function
        h) Axle load spectra

Currently, TDOT uses the AASHTO 1993 pavement design guide, which requires AADTT and Equivalent Single Axle Loads (ESAL) obtained from continuous count stations and 24-hour classification counts. The collection of this data does not require WIM or AVC stations. Consequently, this data is not adequate for the PMED guide. Therefore, the research team tried different data sources; (1) Continuous Counts, (2) 24-hour classified counts and (3) Long Term Pavement Performance (LTPP) database and (4) LTPP PLUG to develop Level 2 traffic inputs as explained on the data analysis.

3.1.1 Automated Vehicle Classifier (AVC) Data

AVC stations are used to determine the normalized vehicle class or truck distribution data over a specified period of time. For this research, TDOT made available traffic volume data from 25 continuous count stations (not AVC stations) collected in 2010-2015. This data was provided as an .ext file in Type 3 records formatted as defined by FHWA, but it is required to be introduced as Type 4 records (C-files) (classified counts) on PMED software.

The research team converted the files from volume counts to class counts using classification distributions obtained from 24-hour classification counts data provided by TDOT. This conversion method worked, and the data was used as Level 2 traffic inputs for the analysis. The challenge is that this method reduced the accuracy of the results. Furthermore, this data is insufficient for Level 1 inputs, because of its limitations. The Level 1 data requirement is extensive: at least one week per month for twelve months of classified traffic counts is required. Another evaluated traffic data source was from Long Term Pavement Performance (LTPP) data, this had most of the required data but from few sites that does not represent all Tennessee roads.

3.1.2 Weigh-in-Motion (WIM) Data

WIM data are used to determine the normalized axle load distribution or load spectra for each axle type within each vehicle class (VC 4 - 13). These axle weight data are needed for Levels 1, 2 and 3 inputs. Since TDOT lacks permanent WIM stations, the discussions involved using: (1) WIM data from nearby states that have similar traffic characteristics to Tennessee as Level 2 inputs. (2) WIM data from LTPP sites in Tennessee as support data or for comparison. (3) Nationwide axle load spectra (Level 3) data available on AASHTOWare PMED software. The research team evaluated LTPP database to find existing AVC and WIM data for the State of Tennessee and neighboring states that could be considered for the development of traffic data input parameters. Level 3 input, or Long-Term Pavement Performance - Pavement Loading User Guide (LTPP PLUG) data, was selected to be used as traffic load inputs due to its convenience until state WIM data is available.

3.2.3 Tasks

The tasks involved for the success of this project include:

1. **Data acquisition and processing.** Acquiring relevant traffic data needed for PMED analysis was a challenge since most of the traffic data was not readily available. Development of alternative data was necessary to get the required traffic input data for the implementation of PMED for the State of Tennessee. The available data was processed to assess its suitability for the Pavement ME Design.
2. **Evaluation of LTPP sites in the State of Tennessee.** LTPP sites located in the State of Tennessee were evaluated for the availability and suitability of the data for traffic analysis. LTPP data was obtained from the Infopave website, with assistance from LTPP personnel when detailed data was needed. The sites were evaluated, and suitable data formed part of this analysis.
3. **Pavement performance analysis using LTPP data and level 3 data.** The data obtained from Tennessee LTPP sites was compared to Level 3 (nationwide) data to evaluate the predicted pavement performance.
4. **Sensitivity analysis.** Using available LTPP data, performance analysis and sensitivity analysis were performed to evaluate the sensitivity of the design when different parameters are changed.
5. **Pavement analysis using short-term classification data.** Available short-term classification counts were used for analysis and to establish some of the traffic input parameters. Short-term classification data from 2155 data points were clustered and analyzed to establish traffic input data.
6. **Evaluation of WIM data using LTPP-PLUG and level 3 inputs.** A comparison of pavement performance using WIM data from LTPP PLUG and PMED Level 3 was conducted to determine suitable WIM data for Tennessee.
7. **Recommendation of traffic input parameters.** Traffic input parameters for the State of Tennessee were recommended based on the analysis performed on the available data.
8. **Quarterly and final reports.** Quarterly reports were submitted to TDOT documenting

project progress. This report represents the final report document findings and recommendations.

3.2 Data Analysis

Traffic data from WIM and ACV stations are required to generate statewide average traffic parameters for FHWA VC 4 - 13, including: vehicle class distribution (VCD); axle load spectra; monthly, weekday, weekend, and hourly distribution factors; average number for axle group per vehicle; directional distribution factors; lane distribution factors and traffic growth factors or function. Currently, TDOT does not have WIM or AVC stations installed; therefore, the research team established these parameters based on available traffic data, which include:

- AADT and Truck Traffic Classification (TTC) for pavement structural design
- Vehicle Counts from 25 count stations for the period 2010-2015
- Vehicle Classification: 24-hour classified counts for the period 2011-2015
- Traffic data from LTPP sites in Tennessee
- Long-Term Pavement Performance Pavement Loading User Guide (LTPP PLUG).

The UTC research team did not perform any data collection. Initially, the research team planned to use portable WIMs to collect axle loads and develop axle load spectra, but since there is no permanent WIM station in Tennessee, it was a challenge to calibrate data from portable WIM stations. Therefore, available data from continuous count stations, 24-hour classified counts, LTPP sites, and nationwide inputs were used for analysis. Recommendations are given based on the analysis of the available data.

3.2.1 Long-Term Pavement Performance (LTPP) Sites

The research team and TDOT agreed to explore the available WIM and AVC data in Tennessee through LTPP sites with the expectation that it will provide better results than using the available total volume counts or Level 3 default inputs. A preliminary analysis of LTPP data was conducted to investigate the suitability of available data for the purpose of this research. LTPP personnel made the raw data available to the research team to supplement the information that could not be obtained through the InfoPave website. This data was used for analysis. Figure 3.1 shows sixteen (16) LTPP sites in Tennessee, downloaded from the InfoPave website. Data from these sites were evaluated for their suitability to be used for the development of level 2 traffic input parameters.

Figure 3. 1: LTPP Site Locations

3.2.1.1 AVC Data Analysis

Based on the available truck traffic distribution data, only twelve (12) sites were retained for analysis and four (4) sites were eliminated due to the lack of suitable data. The normalized class distribution was then developed for each site and assigned a truck traffic class (TTC) as shown in Table 3.1. TTC provides default values for the normalized axle-load spectra and normalized truck classification volume distributions.

Table 3. 1: Normalized Vehicle Classification for Tennessee Sites

Site	**FC**	**FHWA Vehicle Class (VC)**										**TTC**
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
600	1	0.85	7.07	1.27	1.00	2.58	78.69	0.83	5.39	2.25	0.06	**1**
1023	1	0.85	8.79	2.37	0.15	7.09	74.66	0.44	4.71	0.78	0.18	**1**
1028	2	0.63	17.38	7.41	2.36	8.24	61.63	0.63	0.61	0.65	0.45	**2**
1029	2	0.61	30.26	9.55	0.92	9.55	47.10	0.67	0.53	0.36	0.44	**6**
2001	2	0.70	9.41	4.00	0.76	7.51	74.97	0.75	1.31	0.26	0.33	**1**
2008	2	0.96	16.23	5.90	5.32	13.83	55.21	0.80	1.18	0.29	0.27	**4**
3075	2	0.84	39.34	5.99	2.84	23.32	24.94	0.84	0.90	0.39	0.63	**13**
3108	1	0.87	10.69	2.29	0.13	5.32	74.57	0.43	4.71	0.78	0.24	**1**
3109	2	0.56	43.28	6.98	1.11	16.48	29.45	0.47	0.98	0.29	0.41	**12**
3110	2	1.57	25.83	11.25	1.05	15.51	42.22	0.97	0.56	0.36	0.69	**6**
6015	1	0.73	8.27	1.92	0.09	8.15	74.93	0.42	4.58	0.79	0.13	**1**
9024	2	2.89	31.86	13.31	2.50	21.68	25.20	0.99	0.70	0.01	0.85	**12**
9025	2	2.54	32.99	12.00	1.60	23.80	25.07	1.03	0.34	0.03	0.64	**12**

NOTE: FC = Functional Class; TTC = Truck Traffic Class

From Table 3.1, it is evident that based on the percentage distribution, VC 5 and 9 are predominant truck classes in Tennessee. Therefore, more focus will be placed on these two classes. It can also be observed that all sites with FC 1 have only one classification, namely TTC 1, but sites with FC 2 have different TTC classifications because they have different class distributions.

3.2.1.2 WIM Data Analysis

WIM data was available from nine (9) LTPP sites in Tennessee and were used for the analysis of VCs 5 and 9, which are prevalent on Tennessee highways. This analysis involved developing the single axle load spectra for VC 5, single axle load spectra and tandem axle load spectra for VC 9 for each site, and the normalized axle load for Tennessee for VCs 5 and 9. The axle load spectra were compared to PMED default values. As detailed below, a brief literature review on WIM data clustering was conducted to evaluate other clustering techniques.

WIM data clustering techniques of other DOTs

Oregon State

Oregon State clustered their sites based on ADTT, defining three clusters - high, medium and low - with ADTT limits of over 5000, 1500 and 500 for these clusters, respectively (Elkins & Higgins, 2008).

Arizona State

Arizona State clustered their sites based on VC 5 and VC 9 axle load distribution. They developed three main clusters, as follows (Darter et al., 2013):

- **Cluster 1:** In this cluster, VC 5 has one peak for single axles at approximately 25%, corresponding with a load of 6,000 lbs. The VC 9 single axle vehicles have one peak at approximately 20 %, with a corresponding load of approximately 11,000 lbs. VC 9 tandem axle vehicles have two peaks with a small difference in axle percentages.
- **Cluster 2:** In this cluster, VC 5 single axle peaks are similar to Cluster 1. VC 9 single axles peak at approximately 16%, with a corresponding load of approximately 11,000 lbs. VC 9 tandem axles have two peaks with a small difference in axle percentages.
- **Cluster 3:** In this cluster, VC 5 peaks at 32.5%, with a corresponding load of 6,000 lbs. VC 9 single axle peak at 25%, with a corresponding load of approximately 11,000 lbs. VC 9 tandem axles have two peaks with a 10% difference in axle percentages.

North Carolina

North Carolina DOT clustered their sites into four (4) factor groups based on Single-Unit Trucks (SU) and Multi-Unit Trucks (MU) percentages. SU includes Vehicle Classes 4-7 and MU includes Vehicle Classes 8-13, as follows (Stone et al., 2011):

- **Factor Group 1:** WIM sites with 8% ≤ SU% ≤ 33% and 66% ≤ MU% ≤ 92%
- **Factor Group 2:** WIM sites with 31% ≤ SU% ≤ 50% and 50% ≤ MU% ≤ 68%
- **Factor Group 3:** WIM sites with 47% ≤ SU% ≤ 70% and 30% ≤ MU% ≤ 52%
- **Factor Group 4:** WIM sites with 10% ≤ SU% ≤ 22% and 77% ≤ MU% ≤ 90%

In order to develop the normalized axle load spectra for the State of Tennessee, the research team evaluated different clustering techniques and proposed to use the existing clustering methods used by other state DOTs, as explained in the literature review above. The research team clustered the WIM data using AADTT clusters high, medium and low.

Data Clustering using AADTT

The data was clustered into three bins: high, for AADTT above 4500; medium, for AADTT between 1500 and 4500; and low, for AADTT below 1500. Using this criteria, only one (1) site was clustered as high, two (2) sites were clustered as medium and six (6) sites were clustered as low. This method was applied by Oregon State to develop a state Normalized Axle Load Spectra (NALS) using data from their four WIM sites. Figures 3.2 through 3.10 show the axle load spectra for Tennessee sites clustered in high, medium and low AADTT.

Initial findings show that TN average axle load spectra for VC 5 and VC 9 have a similar trend and distribution to PMED national default values at different peaks. These findings suggest that the differences are significant enough to warrant developing axle load spectra for the State of Tennessee. When other clustering techniques are implemented, a comparative analysis will provide a clear picture as to the most ideal clustering technique.

High AADTT Cluster Axle Load Spectra

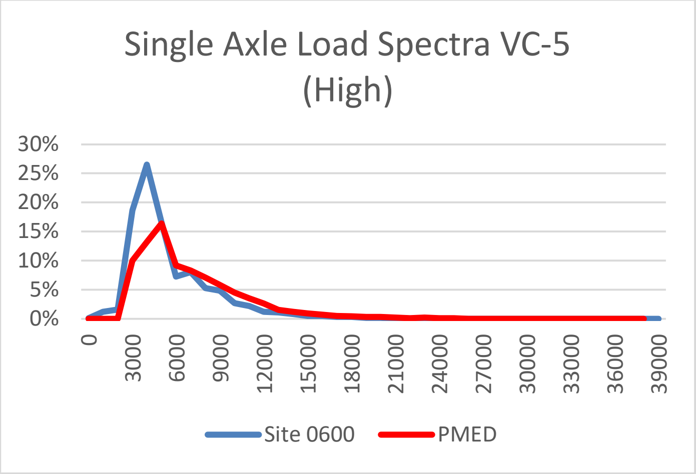

Figure 3. 2: Single Axle Load Spectra for VC 5 (High)

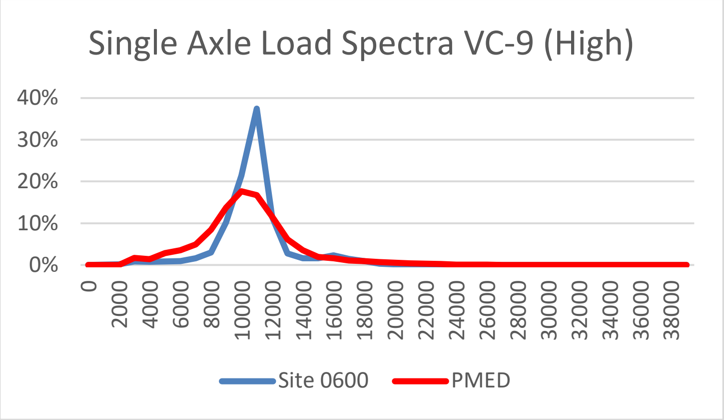

Figure 3. 3: Single Axle Load Spectra for VC 9 (High)

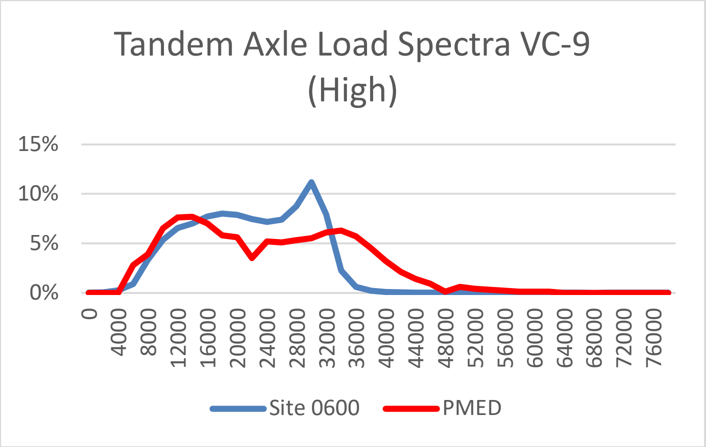

Figure 3. 4: Tandem Axle Load Spectra for VC 9 (High)

Medimum AADTT Cluster Axle Load Spectra Figures 3.5 – 3.7

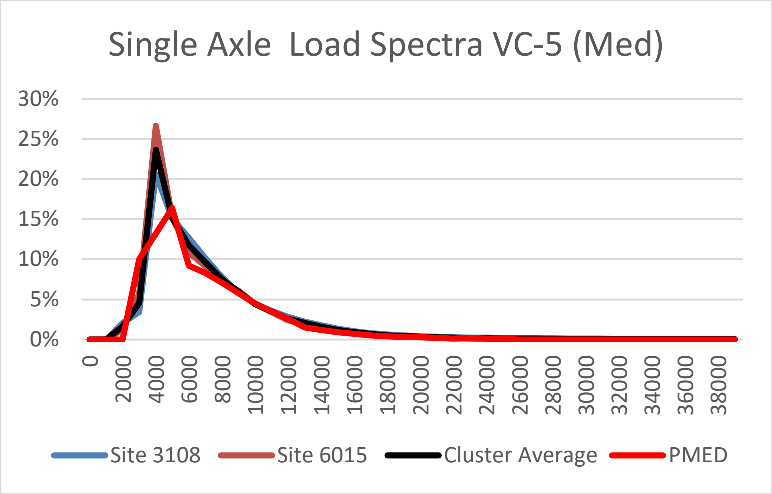

Figure 3. 5: Single Axle Load Spectra for VC 5 (Med)

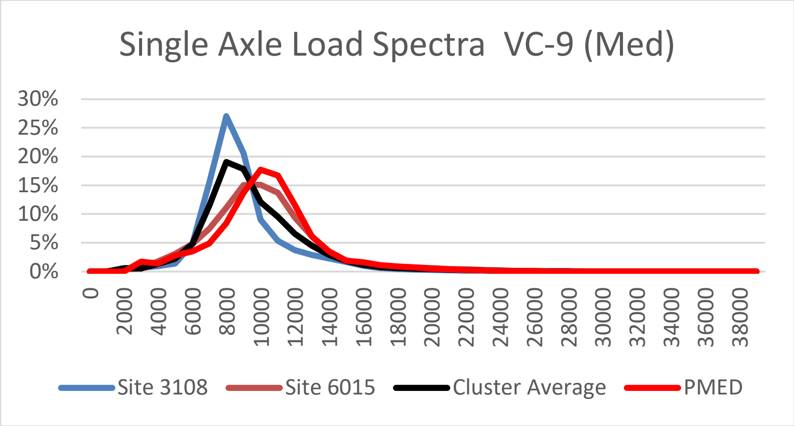

Figure 3. 6: Single Axle Load Spectra for VC 9 (Med)

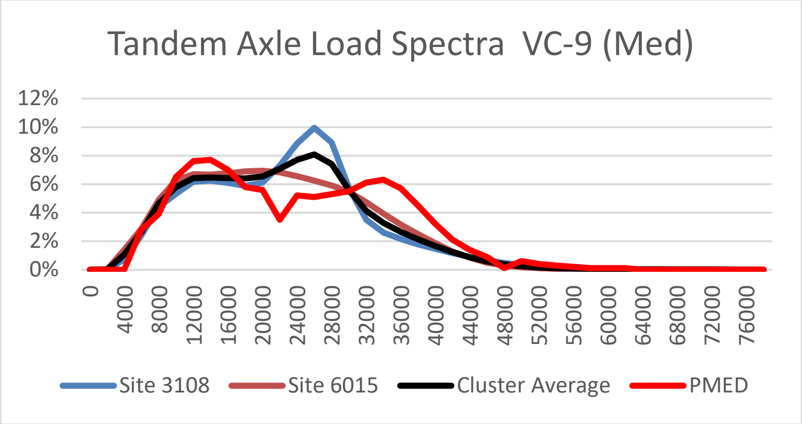

Figure 3. 7: Tandem Axle Load Spectra for VC 9 (Med)

Low AADTT Cluster Axle Load Spectra

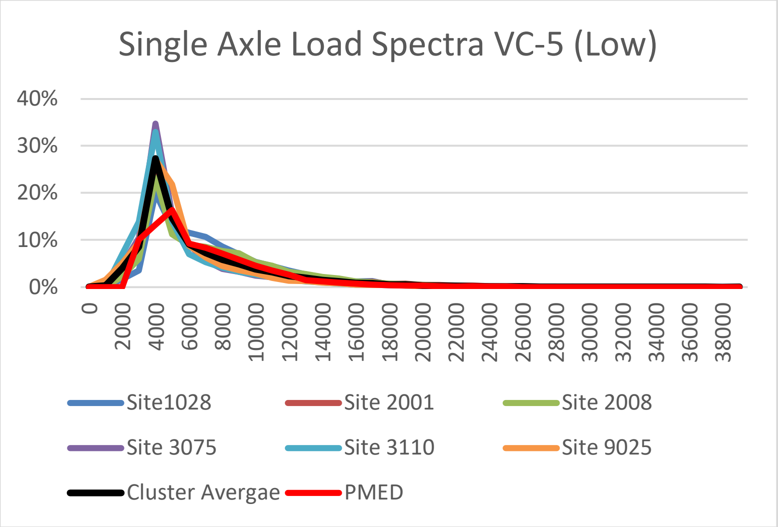

Figure 3. 8: Single Axle Load Spectra for VC 5 (Low)

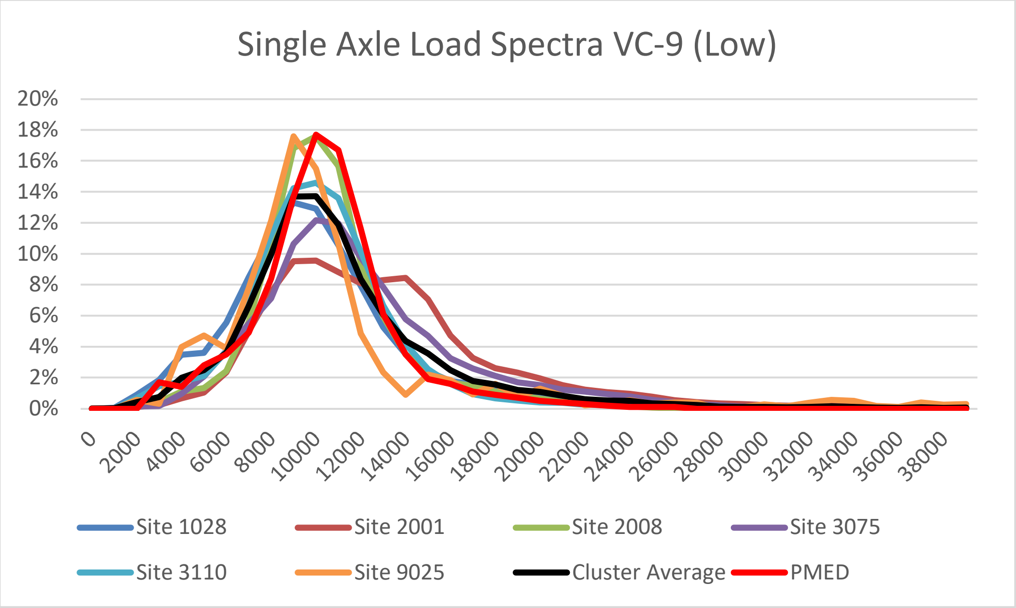

Figure 3. 9: Single Axle Load Spectra for VC 9 (Low)

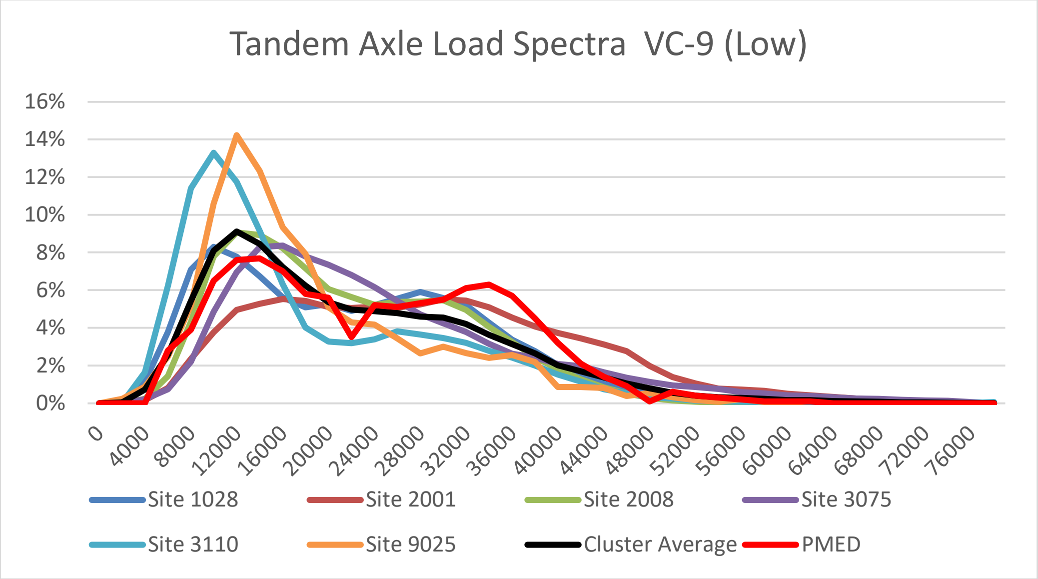

Figure 3. 10: Tandem Axle Load Spectra for VC 9 (Low)

3.2.1.3 Analysis of Flexible pavement sites

Eight (8) LTPP sites had complete data for Level 1 PMED analysis. A comparison analysis between Level 1 (Site specific) and Level 3 (National wide) inputs was performed for these sites for 20 years design period, with traffic data and other input parameters obtained from the LTPP site versus default values on PMED AASHTOWare. For analysis, both scenarios used same information for base year, pavement structure, AADTT, traffic growth rate, number of lanes, directional distribution, lane distribution, percent trucks in the design lane, reliability and climate station. The difference between Level 1 and Level 3 was the result of Vehicle Class Distribution (VCD), monthly adjustment factors and Axle load spectra. The distresses predicted were compared to the target distresses to determine if the pavement will fail within the 20 years and what will be the prevailing distresses. Table 3.2 show the target values used in the analysis. The data were not validated due to a lack of measured distress data on the LTPP sites.

Table 3. 2: Target/Maximum Allowable Distresses for Good Performance

Distress Type	**Target Distress**
Terminal IRI (in/mile)	160
Permanent deformation - total pavement (in)	0.4
AC bottom-up fatigue cracking (% lane area)	25
AC thermal cracking (ft/mile)	500
AC top-down fatigue cracking (ft/mile)	2000
Permanent deformation - AC only (in)	0.25

Table 3.3 shows a summary of the analysis and sites that predicted failure during the design period (20 years).

Table 3. 3: Summary of Flexible Pavement Analysis

Site #	AADTT	Layer Thickness		Predicted Distress at Failure	
		AC	Base	Level 1	Level 3
1028	720	15.6	3.8	None	None
1029	736	13	10	Fatigue cracking	Fatigue cracking
2008	1058	6.5	9.3	None	None
3075	660	5	9.2	Permanent deformation	Fatigue cracking
3101	146	8.1	3.3	None	None
3108	7918	8.2	8.0	None	None
6015	6720	14.3	7.5	Permanent deformation	Permanent deformation
9025	136	5.9	3	None	None

The optimized AC layer thickness was calculated for eight (8) Long Term Pavement Performance (LTPP) flexible pavements sites using the AASHTOWare PMED optimization tool. Level 1 used LTPP site-specific traffic inputs while Level 3 used national wide traffic inputs. It was noticed that the optimized AC layer thickness for LTPP was slightly higher for most sites and significantly higher for two (2) sites, both of which are Functional Class 1 and had heavier traffic loads than PMED default values (Table 3.4). These results indicate that it is important to have site-specific traffic information for interstates since they are expected to have heavier traffic loads than the default values. This data was not considered for further analysis for Level 2 traffic inputs for Tennessee due to the limited number of data points.

Table 3. 4: Optimized AC Layer Thickness for LTPP Sites

Site #	**Level 1**	**Level 3**	**Comments**
1028	7.5	7.5	Same thickness
1029	8	7	Difference in thickness due to issues with fatigue cracking
2008	7.5	7	Difference in thickness due to issues with fatigue cracking
3075	8	7.5	Difference in thickness due to issues with fatigue cracking
3101	6.5	6.5	Same Thickness
3108	13.5	11	Site specific data has heavier loads (IRI)
6015	10.5	10	Site specific data has heavier loads (IRI)
9025	7.5	8	Difference in thickness due to issues with fatigue cracking

3.2.2 Vehicle Classification Data from Tennessee Continuous Count Stations

The UTC research team received, from TDOT, traffic data from 25 continuous count stations across Tennessee for the years 2012 to 2017, as shown in Table 3.5. This was another attempt to obtain traffic data that could be used to define Level 2 vehicle class distribution (VCD) for the State of Tennessee. A preliminary evaluation of the data was performed to establish criteria that will be used to cluster the available data and develop statewide (Level 2) VCD for PMED analysis. From this evaluation, monthly and annual VCD charts were developed for the 25 continuous count stations. A comparative analysis using VCD and equivalent TCC on PMED was performed. The findings are detailed in Quarterly Reports 9 and 10. One station is reported here to illustrate the analysis performed. A summary of the findings is also reported. This data was found to be not suitable for PMED analysis.

Table 3. 5: TDOT Continuous Count Stations

ATR Station #	ADAM # (on maps as this #)	County	Route	Functional Class
5	990	Putnam	SR-111	12
6	990	Rutherford	SR-2	16
7	991	Maury	SR-6	12
8	990	Roane	SR-58	6
10	990	Grundy	SR-108	6
14	990	Madison	873	8
16	990	Monroe	SR-33	2
17	990	Bradley	SR-40	2
19	990	Lincoln	SR-15	2
21	990	Humphreys	SR-1	6
24	992	Rutherford	SR-96	6
26	991	Grainger	SR-1	6
27	990	Benton	SR-1	6
28	990	Decatur	SR-20	2
33	991	Davidson	I-24	11
39	991	Humphreys	I-40	1
40	991	Rutherford	SR-10	2
42	992	Sevier	I-40	11
45	990	Dyer	I-155	11
46	990	Clay	SR-53	6
62	991	Robertson	SR-52	7
65	991	Coffee	SR-127	7
512	994	Shelby	SR-388	16
540	992	Hamilton	SR-2	14
553	992	Knox	SR-33	14

Station 39

Continuous count Station 39 is located on I-40 in Humphreys County. Because it is an interstate, PMED findings predict that VC 9 would be the predominant vehicle class; however, after analyzing data from continuous count stations, it was determined that VC 10 is dominant on this station (Figure 3.11 and 3.12), which is contrary to national data on interstates. Moreover, Station 39's normalized VCD does not meet requirements of any of the TTC classes. It is close to TTC 15 but does not meet all the requirements. This data was not considered for the development of Level 2 traffic input parameters.

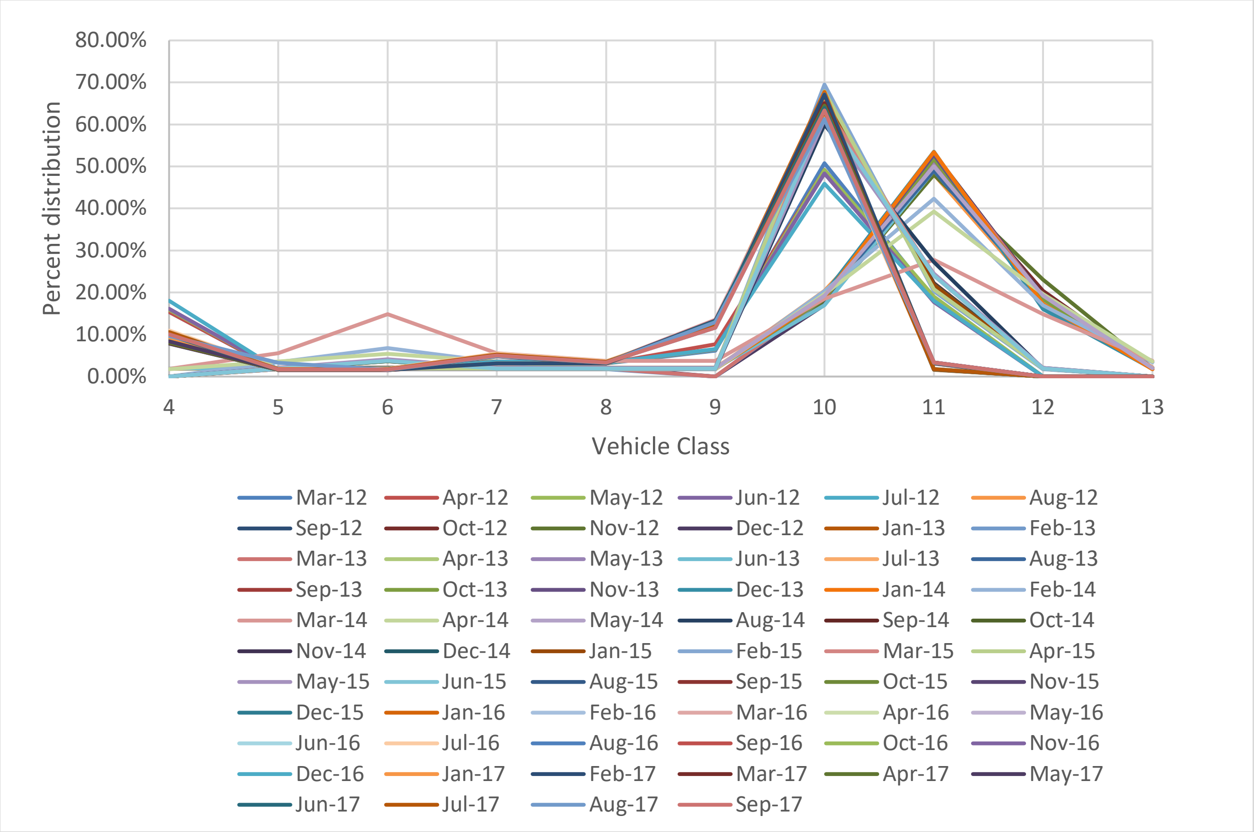

Figure 3. 11: Station 39 VCD

Comparing Station 39's normalized VCD to TTC 15 truck class distribution indicates that these two distributions vary from each other, as shown in Figure-3.12. TCC 5 and TCC 6 were also used to evaluate the data fit. Of the three truck class distributions, TCC 6 best represents the traffic distribution at this station. The traffic analysis was performed for all three TCC.

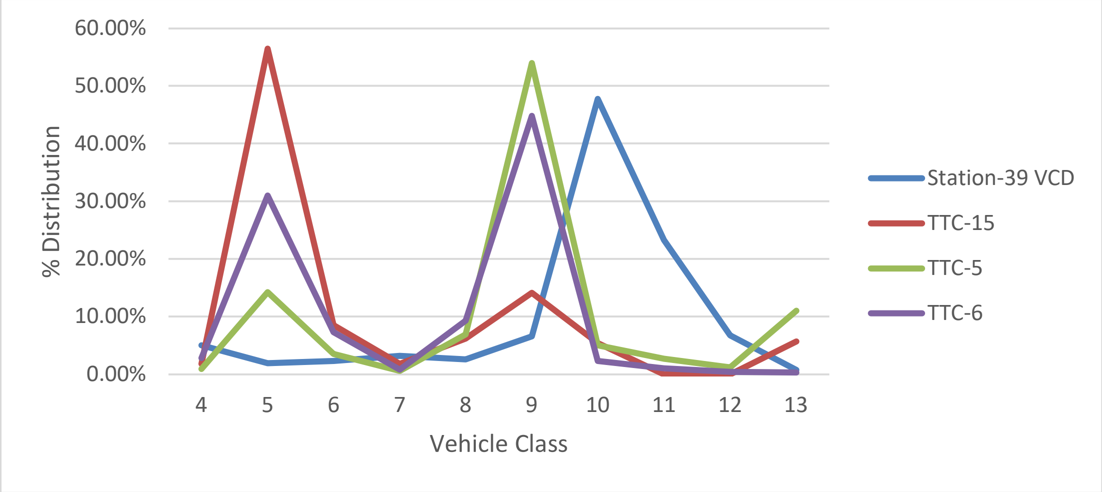

Figure 3. 12: Station 39 VCD vs. TTC 15, TCC 5 and TCC 6

A further analysis was performed on Station 39 using TTC 5 and TTC 6, which are predominantly VC 9. The distresses predicted using TTC 5 and TTC 6 were higher than the site-specific values, although still below the thresholds (Table 3.6).

Table 3. 6: Station 39 Predicted Pavement Performance using TTC 5 and TTC 6

		Site specific	**TTC 6**			**TTC 5**		
Distress Type	**Distress Limit**	**Predicted Distress**	**Predicted Distress**	**Predicted Reliability**		**Predicted Distress**	**Predicted Reliability**	
Terminal IRI (in/mile)	160	105.28	138.12	97.96	Pass	139.33	97.72	Pass
Permanent deformation - total pavement (in)	0.4	0.16	0.26	100	Pass	0.28	99.97	Pass
AC bottom-up fatigue cracking (% lane area)	25	2.00	2.08	100	Pass	2.07	100	Pass
AC thermal cracking (ft./mile)	500	26.31	26.31	100	Pass	27.17	100	Pass
AC top-down fatigue cracking (ft./mile)	2000	281.99	286.4	100	Pass	286.4	100	Pass
Permanent deformation - AC only (in)	0.25	0.01	0.02	100	Pass	0.03	100	Pass

The analysis of the 25 continuous count stations showed that changing the vehicle class distribution alone did not significantly change the results. It was also noticed that Stations 5, 6, 7 and 8 located on different routes with the functional classifications 12, 16, 12 and 6, respectively, had VC 4 as a predominate vehicle class and were classified as TTC 17.

Using the normalized VCD values detailed above, the predicted pavement performance was estimated for the 25 stations and compared to the predicted pavement performance using default TTC vehicle class distributions. For comparison purposes, only VCD values were changed while all other traffic, material, and climate inputs remained the same, as TDOT is currently preparing the material inputs for these continuous count stations and will provide it to UTC when it is ready. Because material inputs were not readily available, two pavement sections from the LTPP database were used for the comparative analysis. The UTC research team plan to perform another comparative analysis when the material inputs for these stations are available; however, the results of the comparative analysis are expected to be similar to these results since the material will be changed for both scenarios.

From the analysis, it can be concluded that:

- The VCD from continuous count classification data was significantly different from the default VCD values (TTC). However, the predicted distresses are very similar because of similar NALS, MAF, axle per truck and material inputs.
- Changing only VCD is not expected to significantly change the results of the analysis, which will challenge the proposed idea of using default NALS, MAF, axle per truck and regional VCD values for PMED in the State of Tennessee.
- Vehicle Class 4 is the dominant truck class for most of these count stations, although they are located on routes with different functional classes.

- The VCD for stations located on interstates showed that VC 10 is the dominant vehicle class. These results were unexpected since nationwide the major truck class is VC 9, which questions the accuracy of the classification data. It is reported that the vehicle lengths used in continuous counts in Tennessee are different from those used for vehicle classification.
- The UTC team further evaluated the use of short-term classification count data, comparing them to the permanent count stations and using LTPP PLUG for NALS and number of axles per truck in Tennessee.

3.2.3 Evaluation of TDOT Short-Term Classification Data to Develop Level 2 Vehicle Class Distribution (VCD) Inputs

From the evaluation of continuous count stations in Tennessee it was found that VCD developed using continuous count data are significantly different from the default VCD values and the national trend. Therefore, UTC research team evaluated data from TDOT's short-term classification count stations. TDOT has about 2155 data points at the 24-hour classification counts, collected between 2011 and 2016. The 24-hour classification data has enough data points to represent the different road functional classes (FC) in Tennessee, except FC 9 and FC 19, which are the rural local and urban local systems, respectively, and are not under TDOT jurisdiction.

The UTC research team performed quality control checks on this data to remove any data outliers. The quality-controlled samples were used to develop Level 2 VCD values by clustering the roads using the road functional classifications shown in Table 3.7. As previously mentioned, there were no data for FC 9 and FC 19 (local roads); therefore, these functional classes were not included in the analysis. Level 3 inputs may be used for analysis of local roads.

Table 3. 7: Tennessee Functional Class Description

Code	Functional Class Description
1	Rural Principal Arterial - Interstates
2	Rural Principal Arterial - Other
6	Rural Minor Arterial
7	Rural Major Collector
8	Rural Minor Collector
9	Rural Local System
11	Urban Principal Arterial - Interstates
12	Urban Principal Arterial – Other Freeways and Expressways
14	Urban Principal Arterial - Other
16	Urban Minor Arterial
17	Urban Collector
19	Urban Local System

The 24-hour count data was clustered according to Road Functional Class per TDOT Region, excluding local roads. The data points are summarized in Table 3.8 on page 32.

Functional Class 1: Rural Principal Arterial – Rural Interstate

For FC 1, it can be noted that VCD has high presence of VC 9, which agrees with the national trend. A similar VCD is recorded across all four (4) years, as shown in Figure 3.13.

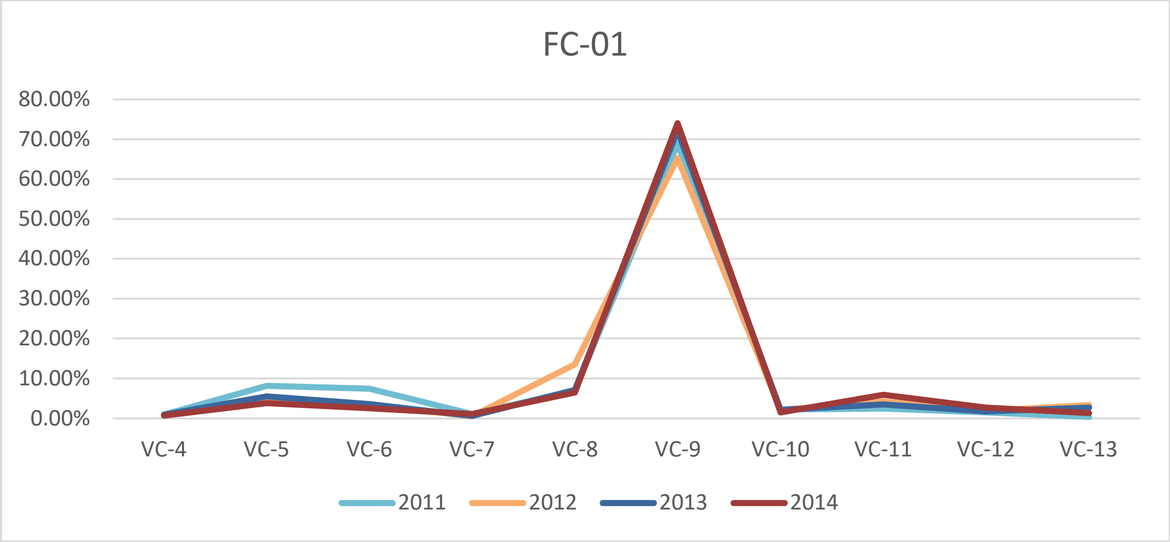

Figure 3. 13: FC 1 VCD

Functional Class 2: Rural Principal Arterial-Other

Similarly, FC 2 VCD indicate VC 9 is the dominant vehicle class. However, FC 2 has lower percentages of VC 9 and higher percentages VC 5 and VC 6 compared to FC 1, as shown in Figure 3.14. It can be noted that there is good agreement among each of the five (5) years for which data is available.

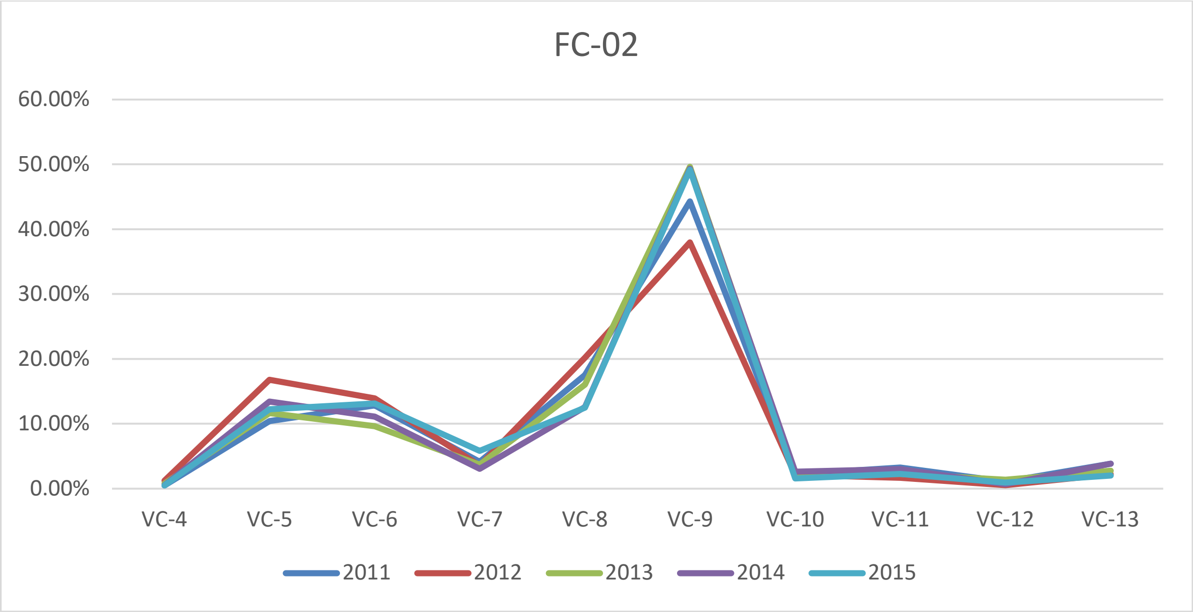

Figure 3. 14: FC 2 VCD

Functional Class 6: Rural Minor Arterial

For FC 6, VC 9 is dominant across all six years of available data, followed by VC 5, which agree with national trends (Figure 3.15).

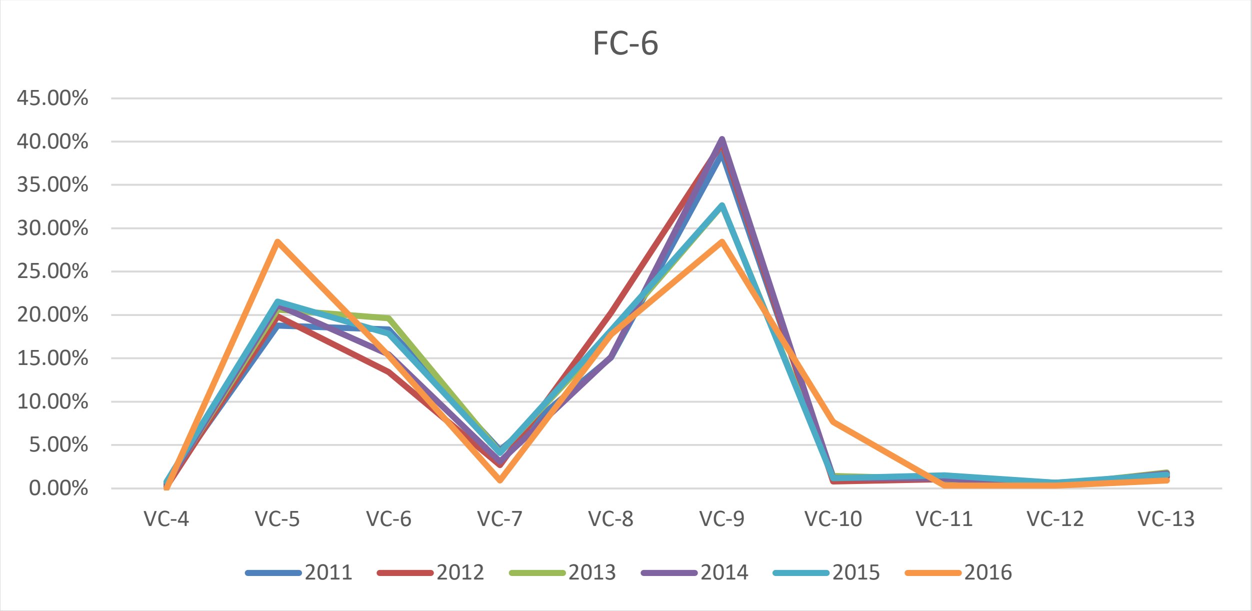

Figure 3. 15: FC 6 VCD

Functional Class 7: Rural Major Collector

For FC 7, VC 5 is the leading vehicle class, at about 30%, for all five years of data, followed closely by VC 9, at 24% (Figure 3.16). The VCD also agrees with national trends.

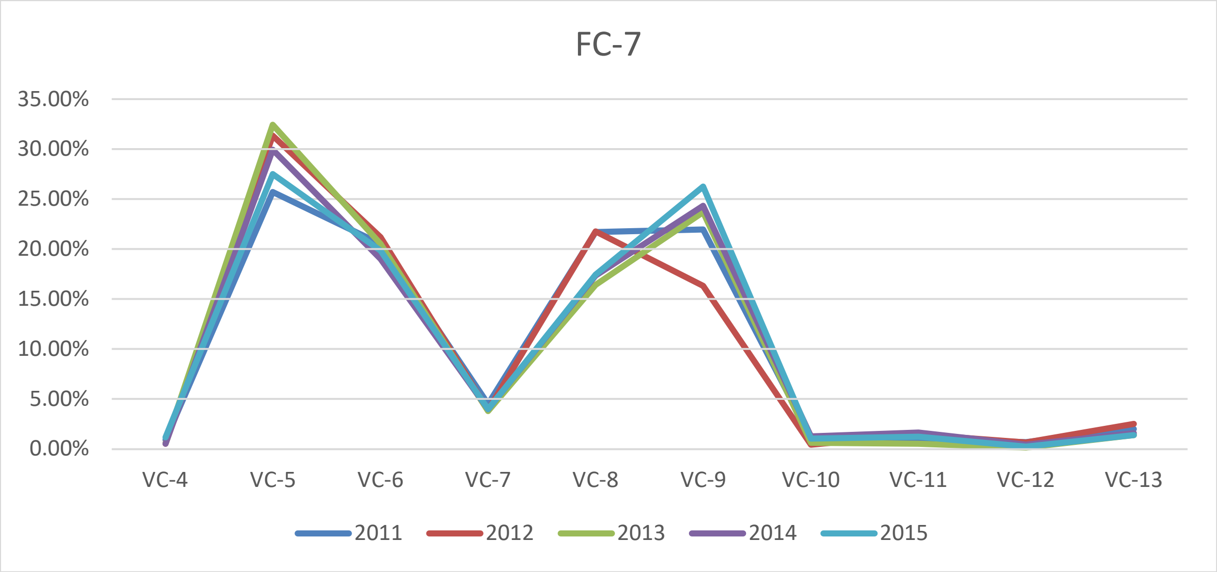

Figure 3. 16: FC 7 VCD

Functional Class 8: Rural Minor Collector

The VCD for FC8 shows notably higher percentages of VC 5, at approximately 40% (Figure 3.17) for all five years of available data.

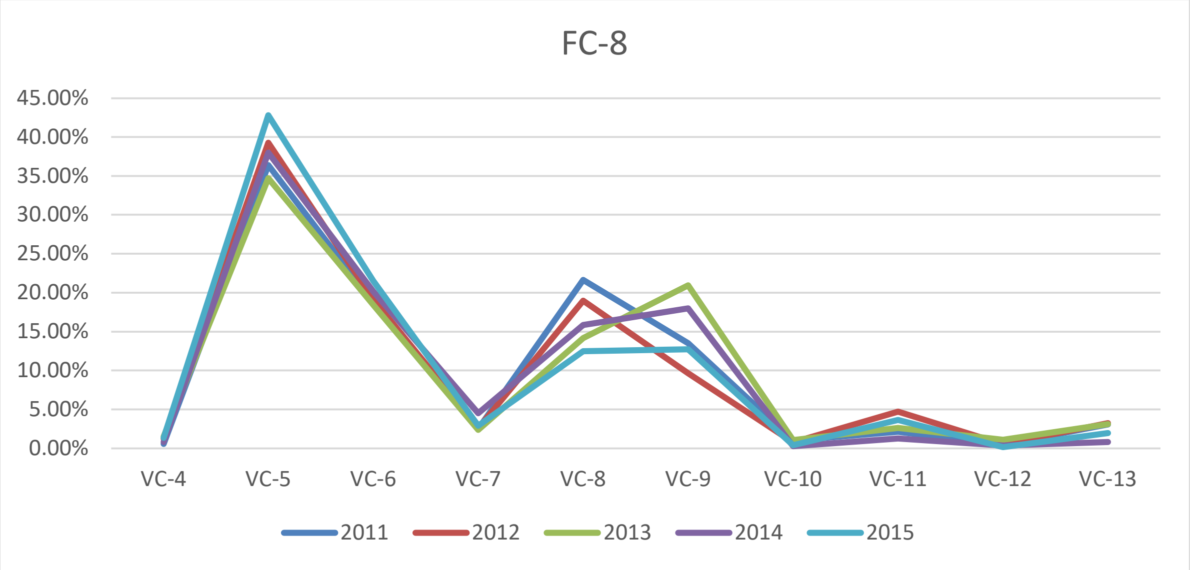

Figure 3. 17: FC 8 VCD

Functional Class 11: Urban Principal Arterial - Urban Interstate

For FC 11, VC 9 is the leading class for all four years of available data, with an average of 60% of total trucks (Figure 3.18). This agrees with national trend for urban intestates.

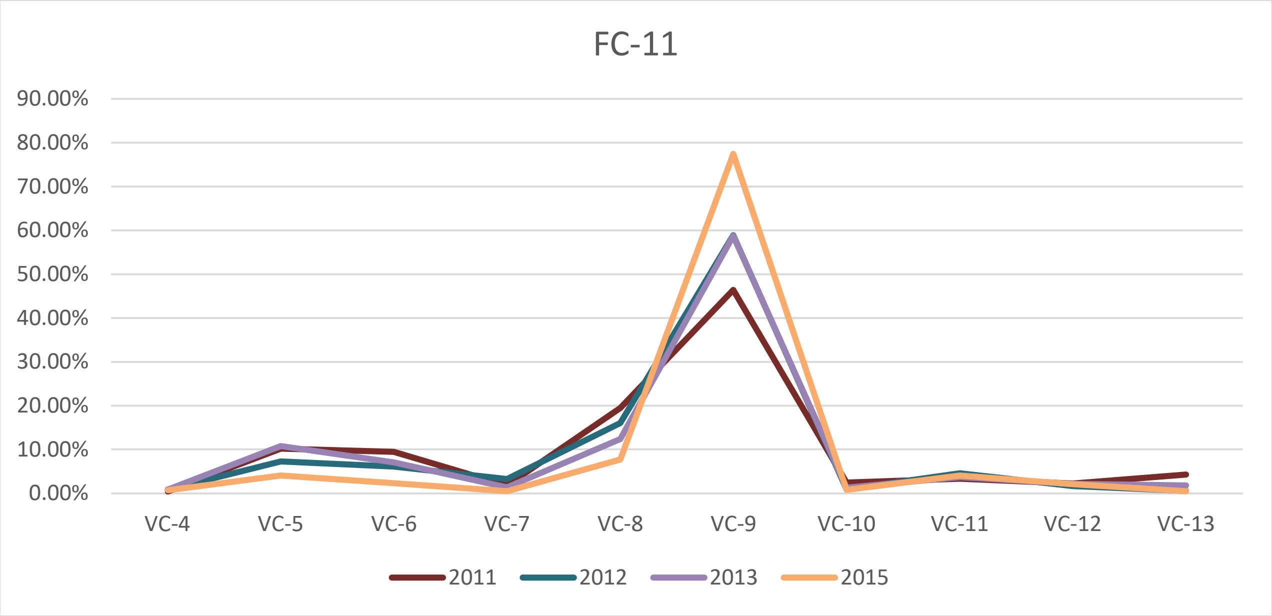

Figure 3. 18: FC-11 VCD

Functional Class 12: Urban Principal Arterial-Other Freeways and Expressways

For FC 12, VC 9 and VC 5 are dominant, with about 30% and 15% of the total trucks, respectively (Figure 3.19). Data was available for four (4) years, 2011 to 2014. From the data, there was an increase of VC 5 in year 2014, since 2015 data was not available, it is hard to say whether it was just one year increase or a change in trend. More data is required for years 2015 to 2018 to have a more conclusive statement.

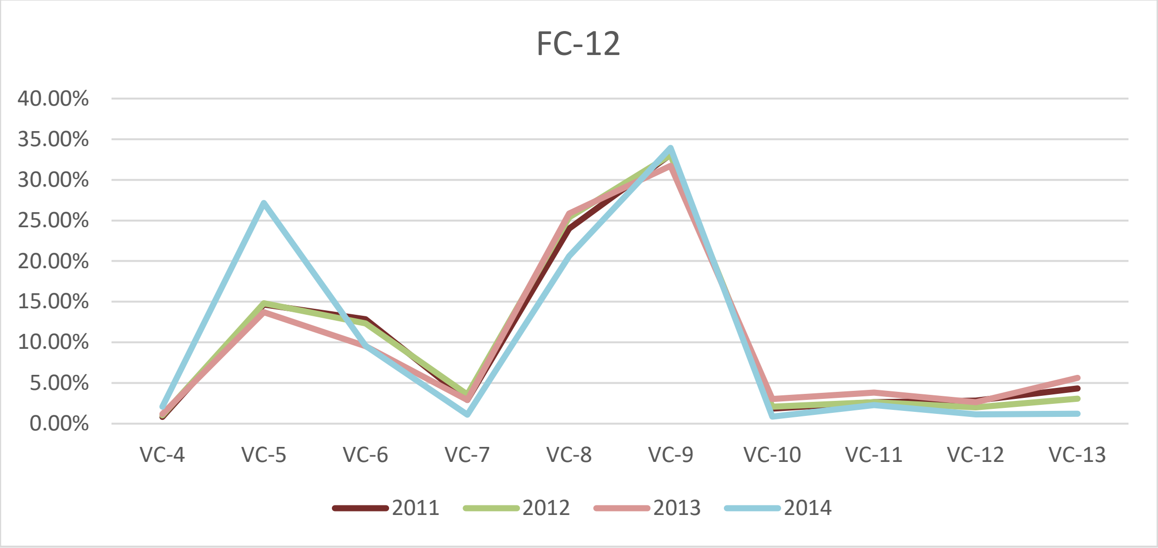

Figure 3. 19: FC 12 VCD

Functional Class 14: Urban Principal Arterial-Other

For FC 14, VC 8 was the dominant class in years 2011-2013, with about 30% of the total trucks, and VC 9 was the dominant class in years 2014-2015. With only 5 years data the trend could not be clearly explained, availability of more data could establish whether it was a change in trend or due to different 24-hour count stations considered on those years.

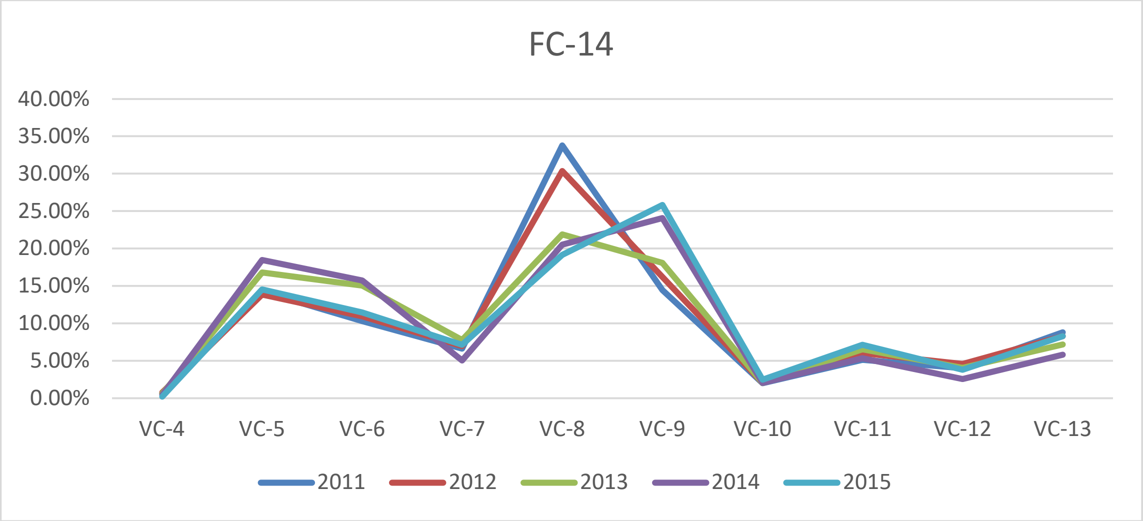

Figure 3. 20: FC 14 VCD

Functional Class 16: Urban Minor Arterial

FC 16 VCD indicate that most of the trucks across four years of data are VC 8 and VC 5, with about 28% of the total trucks each (Figure 3.21).

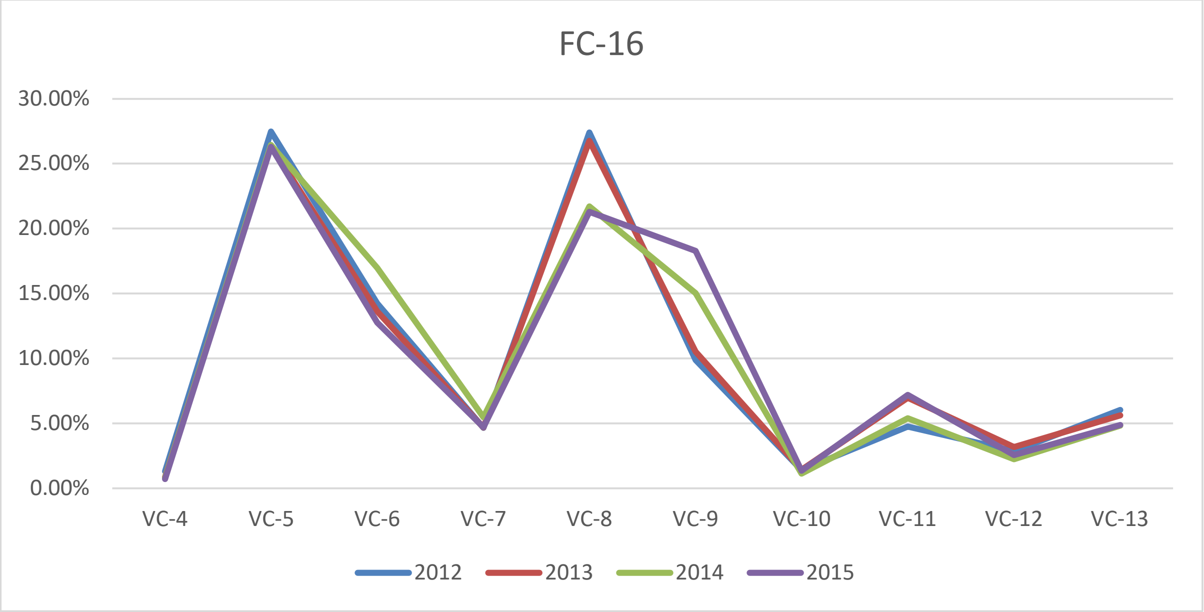

Figure 3. 21: FC 16 VCD

Functional Class 17: Urban Collector

FC-17 VCD indicate that VC 5 is the dominant vehicle class across all five years of available data, representing approximately 45% of total trucks (Figure 3.22).

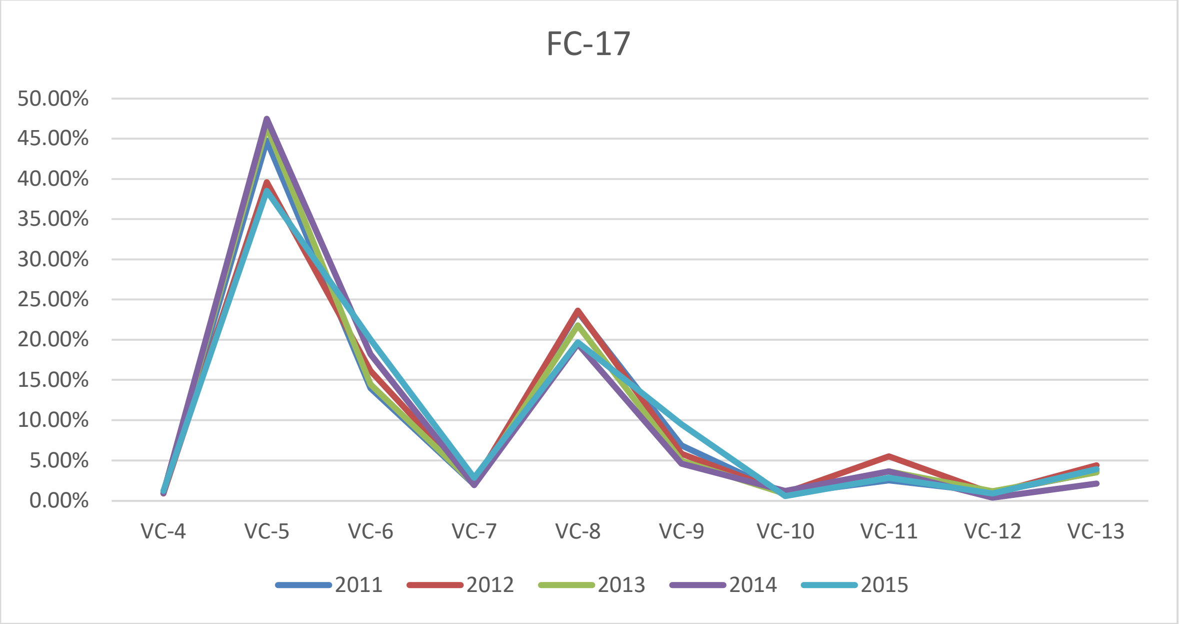

Figure 3. 22: FC 17 VCD

From the analysis, the VCD developed short-term classification data for most of the functional classes show similar VCD for the different years of data collection (2011 to 2015) as shown in Figures 3.13 to 3.22. These VCD values also follow the nation trend for the different road functional classes. Using the short-term classification data, the UTC research team developed Level 2 VCD for the State of Tennessee, as shown in Table 3.8.

Table 3. 8: Level 2 Vehicle Class Distribution (VCD) Values

	VC 4	VC 5	VC 6	VC 7	VC 8	VC 9	VC 10	VC 11	VC 12	VC 13
FC 1	0.90%	5.57%	4.10%	0.73%	10.25%	68.22%	2.09%	3.82%	1.83%	2.49%
FC 2	10.21%	0.68%	12.93%	11.56%	3.48%	15.39%	47.73%	1.99%	2.37%	0.84%
FC 6	0.51%	20.29%	16.95%	3.60%	16.09%	38.63%	1.15%	1.03%	0.38%	1.37%
FC 7	0.61%	30.15%	19.22%	3.51%	17.93%	24.61%	0.90%	1.09%	0.36%	1.62%
FC 8	0.75%	40.81%	19.56%	2.50%	18.11%	13.19%	0.52%	1.90%	0.26%	2.40%
FC 11	0.73%	8.15%	5.96%	1.33%	11.84%	62.40%	1.83%	3.80%	1.99%	1.98%
FC 12	1.18%	15.88%	11.26%	2.55%	24.84%	33.54%	2.07%	2.90%	1.99%	3.79%
FC 14	0.50%	15.29%	12.50%	6.68%	26.20%	19.67%	2.09%	6.05%	3.78%	7.22%
FC 16	0.80%	27.24%	13.92%	4.55%	27.68%	11.34%	1.23%	5.19%	2.63%	5.41%
FC 17	0.79%	45.57%	15.28%	1.72%	22.23%	5.82%	0.61%	3.59%	0.83%	3.57%

3.2.4 Evaluation of using LTPP Pavement Loading User Guide (LTPP PLUG) as a source for axle load spectra for the State of Tennessee

The PMED-default National Axle Load Spectra (NALS) was developed during the National Cooperative Highway Research Program (NCHRP) Project 1-37A using LTPP traffic data available in 1998, but there are some concerns about the lack of documented quality controls for the available data. Therefore, LTPP conducted Specific Pavement Studies (SPS) Transportation Pooled-Fund (TPF) study that focused on the installation of highly reliable and well calibrated, permanent WIM systems on 26 sites nationwide to provide better default NALS values. This study produced two Tiers of NALS defaults as follows:

- **Tier 1** - global defaults based on all applicable SPS TPF data
- **Tier 2** - supplemental defaults that represent different loading conditions (e.g., conditions heavier or lighter than the global default) observed in the SPS TPF.

This study also provided Axle per Truck (APC) values that can be used for Mechanistic Empirical Pavement Design Guide implementation.

The UTC research team conducted a comparative analysis between PMED-original NALS and Long-Term Pavement Performance Pavement Loading User Guide (LTPP PLUG) typical NALS using 26 sites across Tennessee to investigate the possibility of using LTPP PLUG as a source of WIM data for the State of Tennessee. This comparative analysis considered total rutting, AC bottom-up cracking, AC thermal cracking, IRI, and AC top-down fatigue cracking.

Total Rutting

The predicted total rutting distresses using PMED-default NALS and LTPP PLUG-typical NALS were very similar. However, PMED-default NALS estimated higher distresses than LTPP PLUG NALS, as shown in Table 3.9.

Table 3. 9: Total Rutting Distresses

#	Target	Default NALS Prediction	PLUG NALS Prediction	Difference
ATR-26	0.75	0.18	0.17	0.01
ATR-27	0.75	0.18	0.17	0.01
ATR-28	0.75	0.2	0.19	0.01
ATR-33	0.75	0.2	0.17	0.03
ATR-40	0.4	0.33	0.31	0.02
ATR-42	0.75	0.21	0.19	0.02
ATR-45	0.4	0.27	0.25	0.02
ATR-46	0.4	0.2	0.19	0.01
ATR-62	0.75	0.19	0.18	0.01
ATR-65	0.75	0.18	0.17	0.01
ATR-512	0.75	0.18	0.17	0.01
ATR-516	0.75	0.21	0.2	0.01
ATR-540	0.75	0.21	0.19	0.02
ATR-553	0.75	0.21	0.2	0.01
ATR-21	0.75	0.23	0.21	0.02
ATR-5	0.4	0.19	0.18	0.01
ATR-6	0.75	0.23	0.22	0.01
ATR-7	0.75	0.22	0.2	0.02
ATR-8	0.75	0.23	0.21	0.02
ATR-39	0.75	0.18	0.17	0.01
ATR-10	0.4	0.23	0.22	0.01
ATR-14	0.75	0.19	0.17	0.02
ATR-16	0.75	0.25	0.24	0.01
ATR-17	0.75	0.16	0.15	0.01
ATR-19	0.75	0.21	0.19	0.02
ATR-24	0.75	0.18	0.17	0.01

AC Bottom-up Cracking

The predicted AC bottom-up cracking distresses on PMED-default NALS and LTPP PLUG NALS were also similar, with PMED default NALS slightly higher than LTPP PLUG NALS, as shown in Table 3.10.

Table 3. 10: AC Bottom-up Cracking Distresses

#	Target	Default NALS Prediction	PLUG NALS Prediction	Difference
ATR-26	25	1.99	1.99	0
ATR-27	25	2.01	2	0.01
ATR-28	25	2.01	1.99	0.02
ATR-33	25	2.17	2.13	0.04
ATR-40	25	2.01	2	0.01
ATR-42	25	2.07	2.07	0
ATR-45	25	2.03	2.03	0
ATR-46	25	1.99	1.99	0
ATR-62	25	1.99	1.99	0
ATR-65	25	1.99	1.99	0
ATR-512	25	2.01	2.01	0
ATR-516	25	2.01	2.01	0
ATR-540	25	2.01	2.01	0
ATR-553	25	2.02	2.02	0
ATR-21	25	1.99	1.98	0.01
ATR-5	25	2.02	2.01	0.01
ATR-6	25	2.03	2.03	0
ATR-7	25	2.02	2.02	0
ATR-8	25	1.99	1.99	0
ATR-39	25	2.04	2.04	0
ATR-10	25	1.99	1.99	0
ATR-14	25	1.99	1.98	0.01
ATR-16	25	2.04	2.04	0
ATR-17	25	1.97	1.97	0
ATR-19	25	2.01	2.01	0
ATR-24	25	1.99	1.99	0

AC Thermal Cracking

Similar to previous distresses, PMED-default NALS estimated higher AC thermal cracking distresses than LTPP PLUG NALS, with slightly higher differences (Table 3.11).

Table 3. 11: AC Thermal Cracking Distresses

#	Target	Default NALS Prediction	PLUG NALS Prediction	Difference
ATR-26	2000	367.06	355.59	11.47
ATR-27	2000	434.89	416.55	18.34
ATR-28	2000	434.89	348.79	86.1
ATR-33	2000	624.49	589.41	35.08
ATR-40	2000	450.09	429.21	20.88
ATR-42	2000	375.62	360.9	14.72
ATR-45	2000	295.07	291.82	3.25
ATR-46	2000	376.33	363.87	12.46
ATR-62	2000	365.42	354.13	11.29
ATR-65	2000	360.68	349.95	10.73
ATR-512	2000	463.1	441.58	21.52
ATR-516	2000	451.01	430.16	20.85
ATR-540	2000	459.43	437.82	21.61
ATR-553	2000	565.55	533.48	32.07
ATR-21	2000	400.78	369.41	31.37
ATR-5	2000	616.66	581.21	35.45
ATR-6	2000	929.55	868.32	61.23
ATR-7	2000	558.92	527.49	31.43
ATR-8	2000	363.77	352.67	11.1
ATR-39	2000	304.69	297.49	7.2
ATR-10	2000	363.98	352.88	11.1
ATR-14	2000	395.85	366.65	29.2
ATR-16	2000	777.87	727.39	50.48
ATR-17	2000	308.87	303.91	4.96
ATR-19	2000	456.67	435.84	20.83
ATR-24	2000	365.73	354.45	11.28

International Roughness Index (IRI)

The predicted IRI distresses followed a similar trend to the other distresses, with default PMED NALS indicating higher distresses than LTPP PLUG NALS with small differences (Table 3.12).

Table 3. 12: IRI Distresses

#	Target	Default NALS Prediction	PLUG NALS Prediction	Difference
ATR-26	200	110.77	110.32	0.45
ATR-27	200	111.85	111.3	0.55
ATR-28	200	111.85	110.64	1.21
ATR-33	160	118.44	117.32	1.12
ATR-40	200	112.68	112.13	0.55
ATR-42	160	114.63	113.5	1.13
ATR-45	160	112.55	111.99	0.56
ATR-46	200	111.82	111.36	0.46
ATR-62	200	112.15	111.71	0.44
ATR-65	200	111.09	110.64	0.45
ATR-512	200	112.55	111.99	0.56
ATR-516	200	112.73	112.18	0.55
ATR-540	200	112.25	111.66	0.59
ATR-553	200	112.87	112.22	0.65
ATR-21	160	111.15	110.46	0.69
ATR-5	200	113.61	113.06	0.55
ATR-6	200	104	103.43	0.57
ATR-7	200	113.64	113	0.64
ATR-8	200	111.05	110.61	0.44
ATR-39	160	140.44	139.9	0.54
ATR-10	200	111.09	110.64	0.45
ATR-14	200	111.88	111.23	0.65
ATR-16	200	114.29	113.5	0.79
ATR-17	200	109.76	109.42	0.34
ATR-19	200	112.15	111.59	0.56
ATR-24	200	111.64	111.2	0.44

AC Top-Down Fatigue Cracking

The predicted AC top-down fatigue cracking distresses using PMED default NALS were also higher than the predicted distresses using LTPP PLUG NALS, as shown in Table-3.13. However, the differences were slightly higher than the other distresses. These high differences are due some issues with PMED AASHTOWare Version 2.2 predictions of AC top down fatigue cracking.

Table 3. 13: AC Top-Down Fatigue Cracking

#	Target	Default NALS Prediction	PLUG NALS Prediction	Difference
ATR-26	2000	367.06	355.59	11.47
ATR-27	2000	434.89	416.55	18.34
ATR-28	2000	434.89	348.79	86.1
ATR-33	2000	624.49	589.41	35.08
ATR-40	2000	450.09	429.21	20.88
ATR-42	2000	375.62	360.9	14.72
ATR-45	2000	295.07	291.82	3.25
ATR-46	2000	376.33	363.87	12.46
ATR-62	2000	365.42	354.13	11.29
ATR-65	2000	360.68	349.95	10.73
ATR-512	2000	463.1	441.58	21.52
ATR-516	2000	451.01	430.16	20.85
ATR-540	2000	459.43	437.82	21.61
ATR-553	2000	565.55	533.48	32.07
ATR-21	2000	400.78	369.41	31.37
ATR-5	2000	616.66	581.21	35.45
ATR-6	2000	929.55	868.32	61.23
ATR-7	2000	558.92	527.49	31.43
ATR-8	2000	363.77	352.67	11.1
ATR-39	2000	304.69	297.49	7.2
ATR-10	2000	363.98	352.88	11.1
ATR-14	2000	395.85	366.65	29.2
ATR-16	2000	777.87	727.39	50.48
ATR-17	2000	308.87	303.91	4.96
ATR-19	2000	456.67	435.84	20.83
ATR-24	2000	365.73	354.45	11.28

Statistical Analysis

To evaluate the significance of the differences between the distress predictions of PMED-default NALS and LTPP PLUG NALS, a T-test was used with a hypothesis that there is no significant difference between these two NALS with a confidence level of 95%. The T-test results determined that there is no statistically significant difference on the AC thermal cracking predicted using PMED NALS and LTPP PLUG NALS; however, there is a significant difference between the predicated distresses using PMED default NALS prediction and LTPP-PLUG NALS for the other four distresses (Table 3.14).

Table 3. 14: T-test Results

Distress	**P-Value**	**Comments**
Total rutting	5.1 E-13(<0.05)	• Null hypothesis was rejected • The difference is statistically significant
AC bottom-up cracking	0.0077 (<0.05)	• Null hypothesis was rejected • The difference is statistically significant
AC thermal cracking	1.7 (>0.05)	• Failure to reject the null hypothesis • The difference is statistically insignificant
IRI	2.3 E-14(<0.05)	• Null hypothesis was rejected • The difference is statistically significant
AC top-down fatigue cracking	1.3E-07 (<0.05)	• Null hypothesis was rejected • The difference is statistically significant

To evaluate the significance of the differences between the distress predictions of PMED-default NALS and LTPP PLUG NALS, repeated T-test was used with the assumption that the distribution of the difference scores follows normal distribution. Otherwise, a nonparametric Wilcoxon signed-rank test is suggested. In this statistical analysis, we present results conducted using both methods (repeated t and Wilcoxon signed rank tests).

- The null hypothesis for the repeated t-test was there is no difference between the population mean difference of the distresses predicted by PMED-default NALS and LTPP PLUG NALS.
- The null hypothesis for the Wilcoxon signed rank test is there is no difference between the median difference of the distresses predicted by PMED-default NALS and LTPP PLUG NALS. A confidence level of 95% is adopted for all tests.

Reported in Table 3.14 is the outcome of the repeated t-test. On the contrary, the Wilcoxon signed rank tests yielded relatively large p-value (greater than 0.05), which means the difference between the median distresses by using LTPP PLUG NALS and PMED NALS is not statistically significant. The Wilcoxon singed rank test suggests that either NALS, (LTPP PLUG or PMED) could be used with similar results that are within the margin of error. Since there were no collected (actual) distresses from any of the LTPP sites to validate the predicted distresses, it is recommended to use LTPP PLUG NALS since they were developed from highly reliable and well calibrated permanent WIM stations, and it provides more economical design than PMED AASHTOWare default NALS. LRPP PLUG Tier 2 inputs, with heavier or lighter NALS can be used.

3.2.5 Analysis of Concrete Pavements – Site-Specific Pavement Analysis

The LTPP data in Tennessee is comprised of one concrete pavement that was analyzed as Level 1 input. This is Site 600 on I-40 in Madison, Tennessee. The analysis for Site 600 used data from the LTPP database and distress data provided by TDOT. This site has enough data collected between 2007 and 2014 that enables it to be designed as Level 1 in AASHTOWare PMED. Two scenarios were created for the analysis and comparison:

1. Using Level 1 LTPP traffic inputs.
2. Using Level 3 PMED default traffic inputs and changing the growth rate from 3% (the default value) to 1.34% per year (TN average).

Since the report on MEPDG local calibration of pavement materials for Tennessee did not provide calibrated material input parameters for rigid pavements in Tennessee and the climate data is not yet calibrated, the same PMED default values were used for both scenarios.

Design Inputs for Site 600

Using the parameters Two-way AADTT: 9620, Directional Distribution: 50:50, and Growth Rate: 1.34%/year linear growth, and a Design Life of 30 years, the vehicle class distribution (VCD) and hourly distribution factors (HDF) are shown in Figure 3.23 and Figure 3.24.

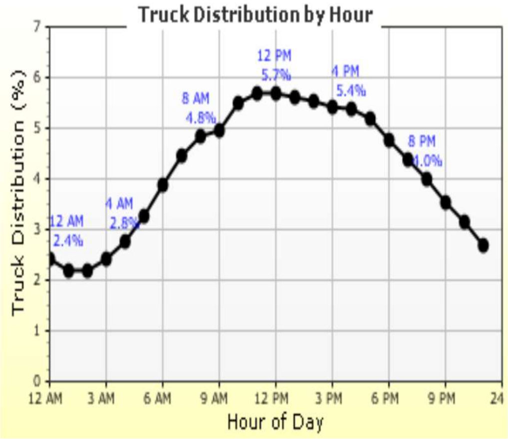

Figure 3. 24: Hourly Distribution Factors (HDF)

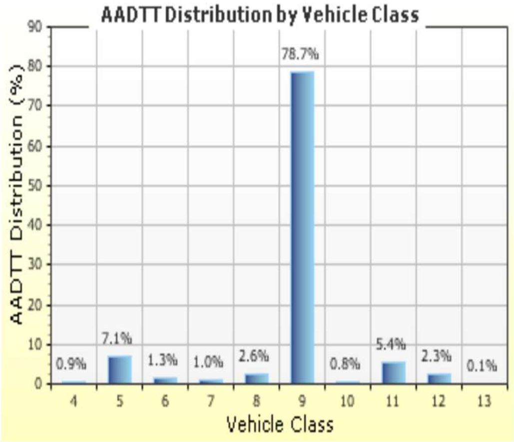

Figure 3. 23: Vehicle Class Distribution (VCD)

Design Structure for Site 600

The pavement structure at Site 600 is comprised of a Jointed Portland Cement Pavement (JPCP) slab with 10 in. thickness, 6 in. granular base course (AASHTO classification A-1-a) and subgrade material with classification of A-2-4. Table 3.15 shows the design structure for Site 600.

Table 3. 15: Design Structure for Site 600

Layer	Material Type	Thickness (in)
PCC	JPCP Default	10.0
Non-Stabilized	A-1-a	6.0
Subgrade	A-2-4	Semi-infinite

Performance Criteria for Site 600

The Performance Criteria for Site 600 used for this analysis is shown in Table 3.16. Three distresses; International Roughness Index (IRI), JPCP transverse cracking and mean joint faulting were evaluated. Figure 3.25 shows the pavement structure.

Table 3.16: Performance Criteria for Site 600

Criteria	Limit	Reliability
Terminal IRI	160	90%
JPCP transverse cracking (% slabs)	15	90%
Mean joint faulting (in)	0.12	90%

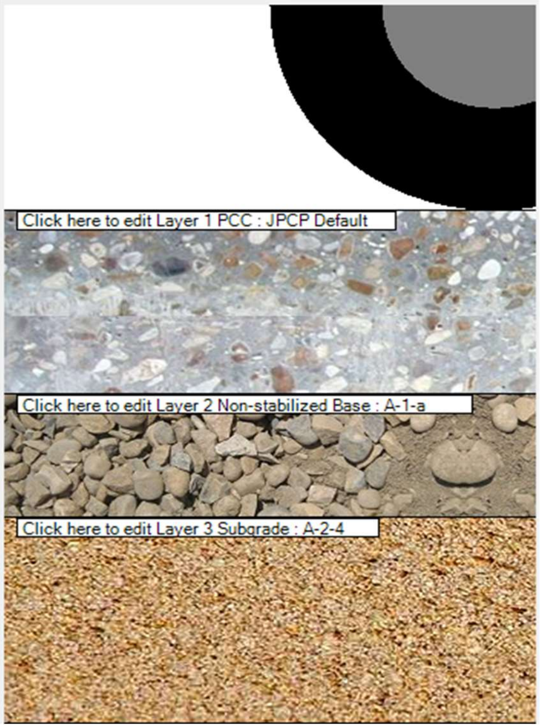

Figure 3. 25: Site 600 Design Section from AASHTOWare PMED

Design Outputs for Site 600

Input data was run on PMED AASHTOWare to predict the three distresses on the concrete pavement. Scenario 1 used LTPP site -specific input data (Level 1) and Scenario 2 used PMED default values (Level 3). The results from the analysis is presented below.

Scenario 1 (Level 1 data)

Table 3.17 presents Level 1 predicted distresses in comparison to desired (target) distresses at year 30. Figures 3.26 to 3.28 show the same distresses over 30 years for each distress type.

Table 3. 17: Distress Prediction Summary for Level 1

Distress Type	Distress at Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	160	182.12	90.00	77.81	Fail
Mean joint faulting (in)	0.12	0.17	90.00	49.22	Fail
JPCP transverse cracking (% slab)	15.00	3.21	90.00	100.00	Pass

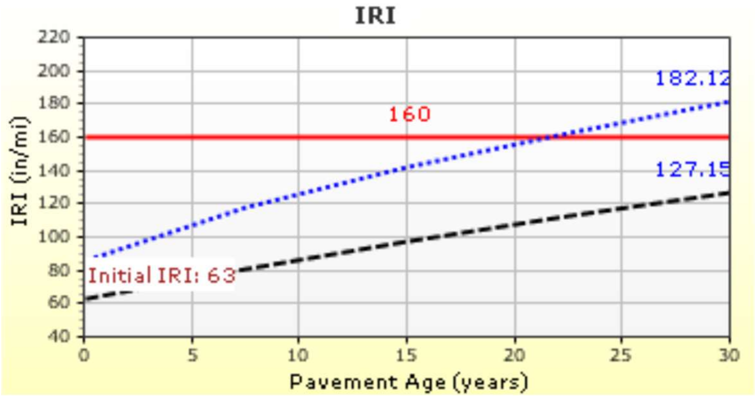

Figure 3. 26: Predicted IRI- Level 1

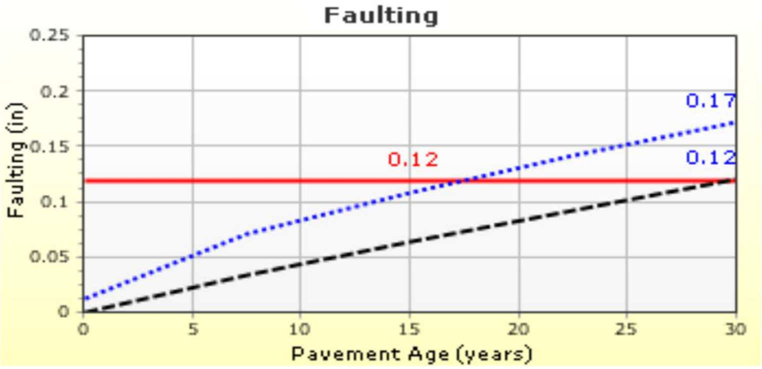

Figure 3. 27: Predicted Mean Joint Faulting- Level 1

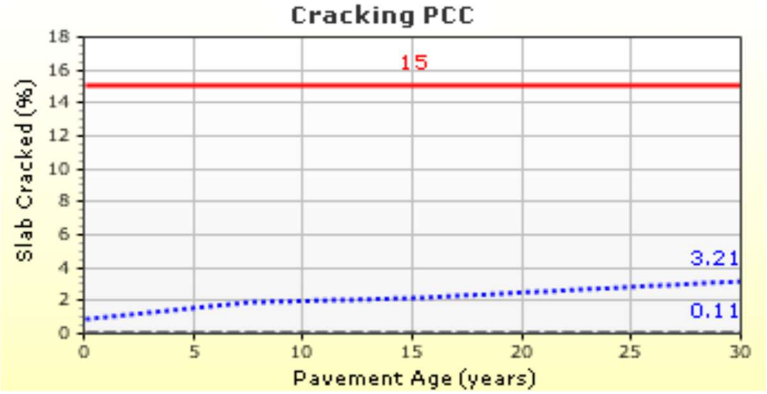

Figure 3. 28: Predicted Transverse Cracking- Level 1

Scenario 2 (Level 3 data)

Table 3.18 presents Level 3 predicted distresses in comparison to desired (target) distresses at year 30. Figures 3.29 to 3.31 shows the same distresses over 30 years for each distress type.

Table 3. 18: Distress Prediction Summary for Level 3

Distress Type	Distress at Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	160	183.92	90.00	76.71	Fail
Mean joint faulting (in)	0.12	0.12	90.00	52.35	Fail
JPCP transverse cracking (percent slab)	15.00	11.76	90.00	96.37	Pass

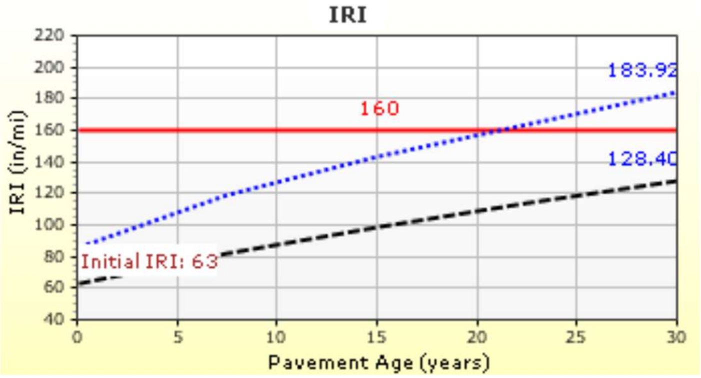

Figure 3. 29: Predicted IRI- Level 3

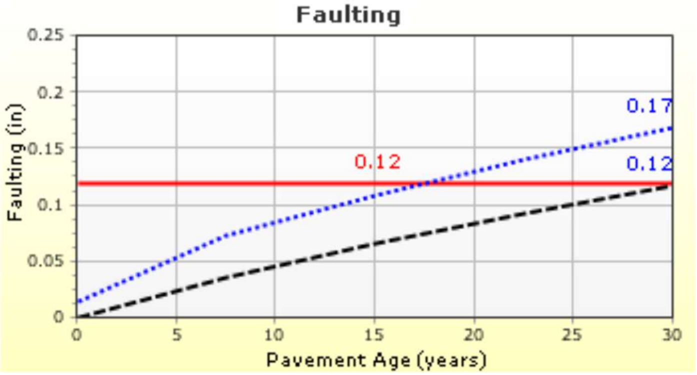

Figure 3. 30: Predicted Mean Joint Faulting- Level 3

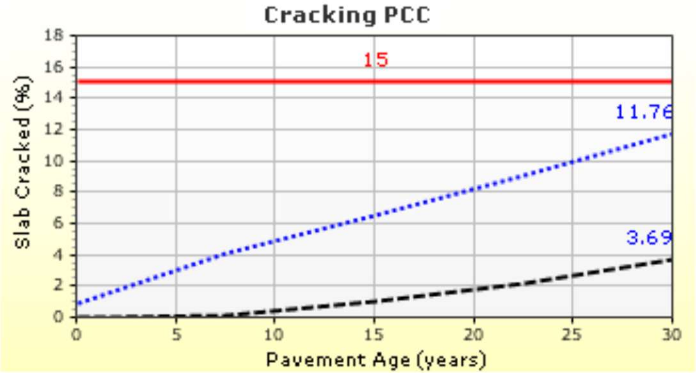

Figure 3. 31: Predicted Transverse Cracking- Level 3

The analysis indicates that both scenarios meet the cracking requirement, but they both fail on terminal IRI and joint faulting. For both scenarios, joint faulting is a big problem, giving a reliability level of 49% and 52% for Level 1 and Level 3, respectively, where the required design reliability is 90%. This calls for a major repair, such as dowel bar retrofits on year 15 or 16. The results of the two scenarios are within the margin of error of each other. The deviation of Level 1 output from Level 3 is 1%, 0% and 72% for Terminal IRI, mean joint faulting and transverse cracking, respectively. Transverse cracking for both scenarios is within the acceptable limits 30 years later, but Level 3 pavement will crack more than Level 1 pavement.

Further analysis performed on Site 600 used 2004 as base year and compared terminal values of International Roughness Index (IRI) predicated by Scenario 1 using site-specific inputs and Scenario 2 using default traffic inputs to the actual distresses. Additionally, using PMED AASHTOWare, a pavement optimization was performed. The Scenario 1 optimized pavement cross-section was compared to the Scenario 2 optimized section.

Values of terminal IRI, JPCP transverse cracking and mean joint faulting were calculated for both scenarios as shown in Table 3.19. The results indicate that both scenarios predict that pavement distress will be within the allowable limits after 30 years. However, distresses predicted from Scenario 2 using national values (Level 3) were higher than the distress predicted by site-specific data (Level 1) in Scenario 1: 17% higher for Terminal IRI, 33% higher for mean joint faulting and 53% higher for JPCP transverse cracking.

Table 3. 19: Distress Results

Scenario	**Terminal IRI (in/mile)**		**Mean joint faulting (in)**		**JPCP transverse cracking (percent slabs)**	
	Distress	**Reliability achieved (%)**	**Distress**	**Reliability achieved (%)**	**Distress**	**Reliability achieved (%)**
1	68.93	100	0.06	99.96	2.37	100
2	81.91	100	0.08	99.3	3.62	100
Limit	160	90	0.12	90	15	90

To validate these results, actual values for IRI measured in 2015 were compared to the predicated results. Measured IRI was 47.29 in/mile while predicated values from Scenario 1 were 50.91 in/mile and values from Scenario 2 were 55.98 in/mile. These values indicate that Scenario 1 overestimates the IRI by 7.65% while Scenario 2 overestimates IRI by 18.37%.

The optimized slab thickness resulted by the AASHTOWare optimization tool was 7.5 in. for Scenario 1, using site-specific inputs, while the optimized slab thickness for Scenario two was 8 in. This proves that using Level 1 traffic inputs will facilitate the use of thinner slabs, resulting in more economically viable sections.

Sensitivity Analysis

A sensitivity analysis for traffic inputs (AADTT), JPCP thickness, and base thickness was performed using the parameters shown in Table 3.20.

Table 3. 20: Sensitivity Analysis Parameters

Input parameter	Actual	Minimum	Maximum
AADTT	8420	200	26000
JPCP Slab Thickness (in)	9.0 in.	6	12
Base Thickness (in)	6.0 in.	3	9

Values ranging from 200 to 26000 were used to test JPCP sensitivity to AADTT using 9 in. slab thickness and 6 in. base thickness. When AADTT is less than 2000, the distresses predicted by the two scenarios are almost the same, with only a small deviation observed between Scenario 1 and Scenario 2. The reason for this is that the sections used were originally designed for high traffic volumes; therefore, no high distresses are expected from low traffic. However, the deviation becomes significant as AADTT increases, peaking at 26.1%, which is very high. Scenario 2 predicted the pavement will fail due mean joint faulting at 16000 AADTT while Scenario 1 estimated all distresses will be within the allowable limit until 25000 AADTT (Figure 3.32).

To perform the sensitivity analysis of the JPCP thickness, the slab thickness was increased from 6 to 12 inches using actual AADTT and base thickness. Using 6-inch slab, both scenarios predicted the pavement will fail due to cracking; however, Scenario 2 estimated that IRI will not meet the design criteria while Scenario 1 estimated it will meet the design criteria. The same distress trend was predicted by both scenarios for thicknesses from 7 to 12 in., but Scenario 2 overestimated all distresses, as shown in Figure 3.33.

The sensitivity analysis for base thickness ranged from 3 to 9 inches, keeping actual values for AADTT and slab thickness. This sensitivity analysis indicated the same deviation between distresses predicated from the two scenarios, but the deviation decreases as base thickness increase (Figure 3.34). An interesting finding was that all pavement distresses are within the allowable limit for all base thicknesses tested, which indicate that MEPDG can perform more economical designs than AASHTO-1993, which is currently used by Tennessee Department of Transportation.

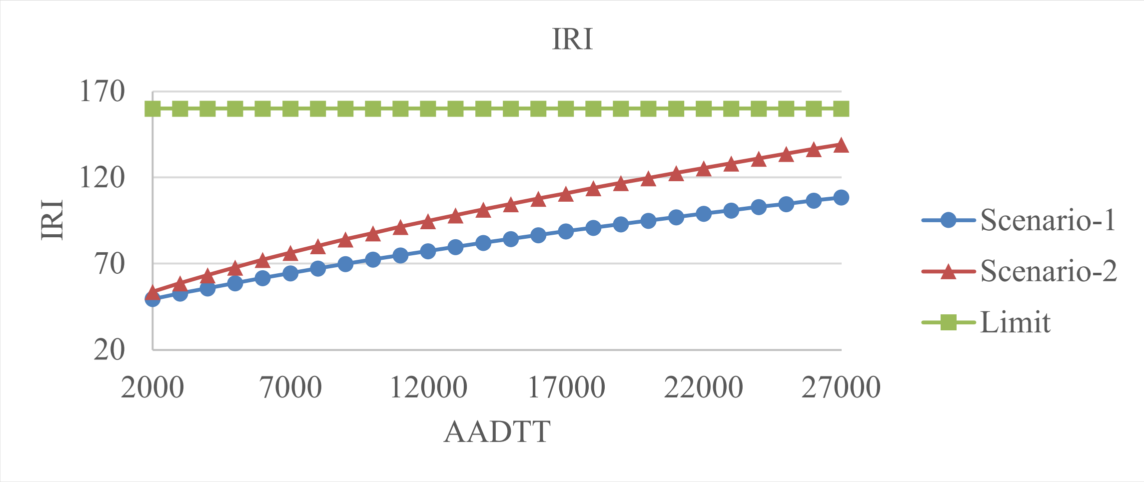

Figure 3.32-a: IRI

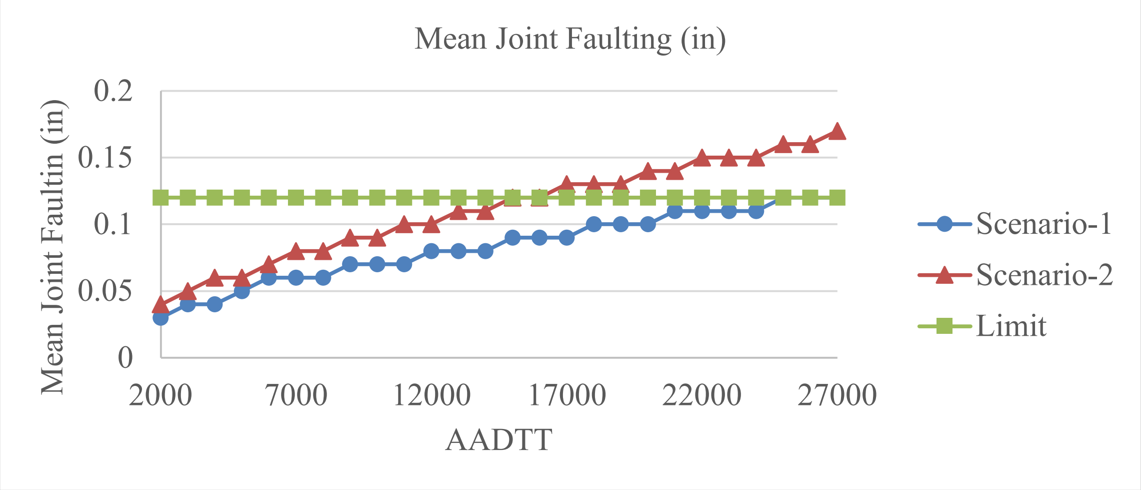

Figure 3.32-b: Mean Joint Faulting

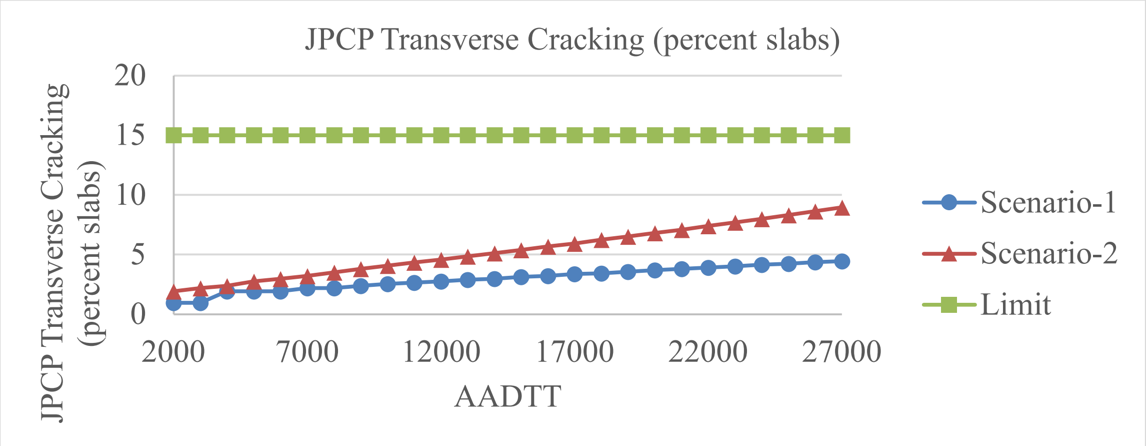

Figure 3.32-c: JPCP Transverse Cracking

Figure 3. 32: JPCP Sensitivity to AADTT

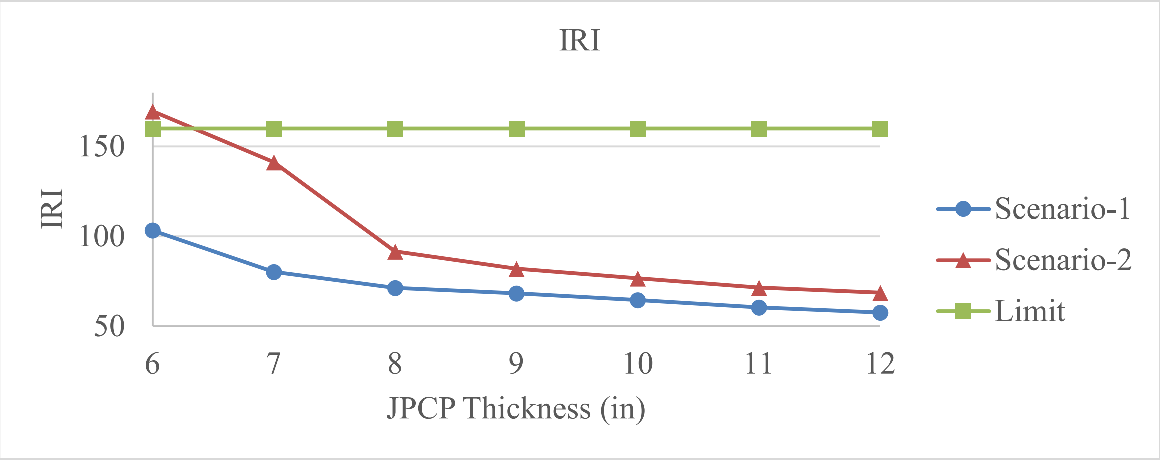

Figure 3.33-a: IRI

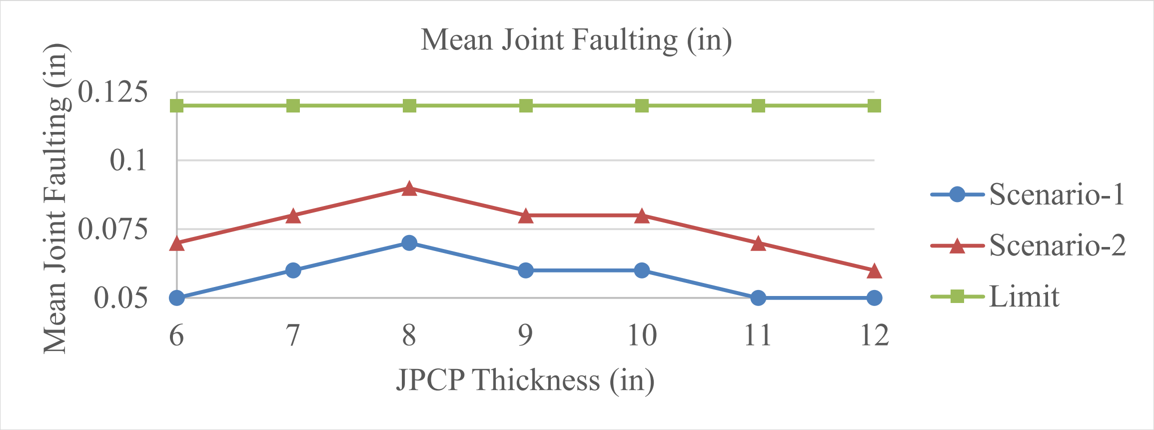

Figure 3.33-b: Mean Joint Faulting

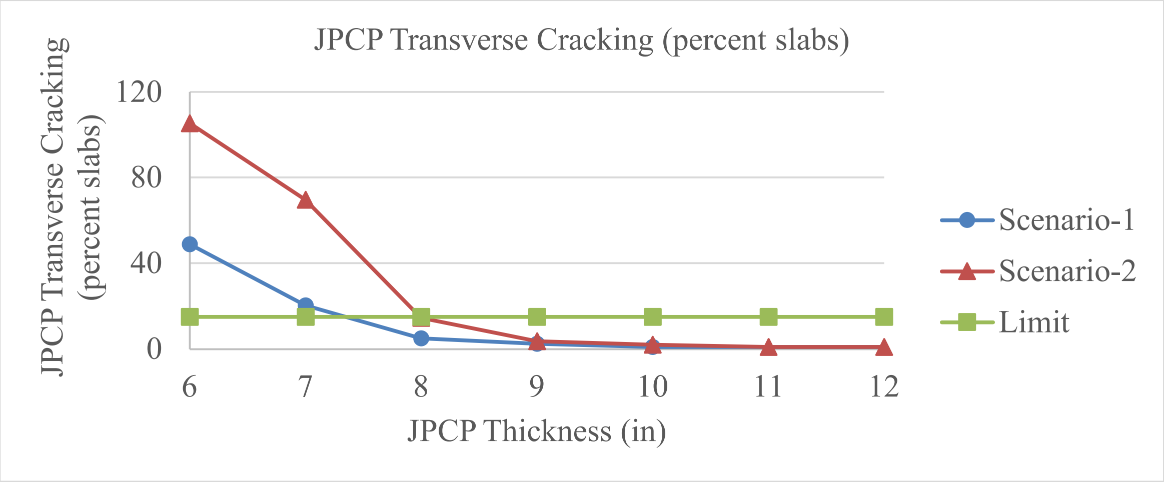

Figure 3.33- c: JPCP Transverse Cracking

Figure 3. 33: JPCP Sensitivity to Slab Thickness

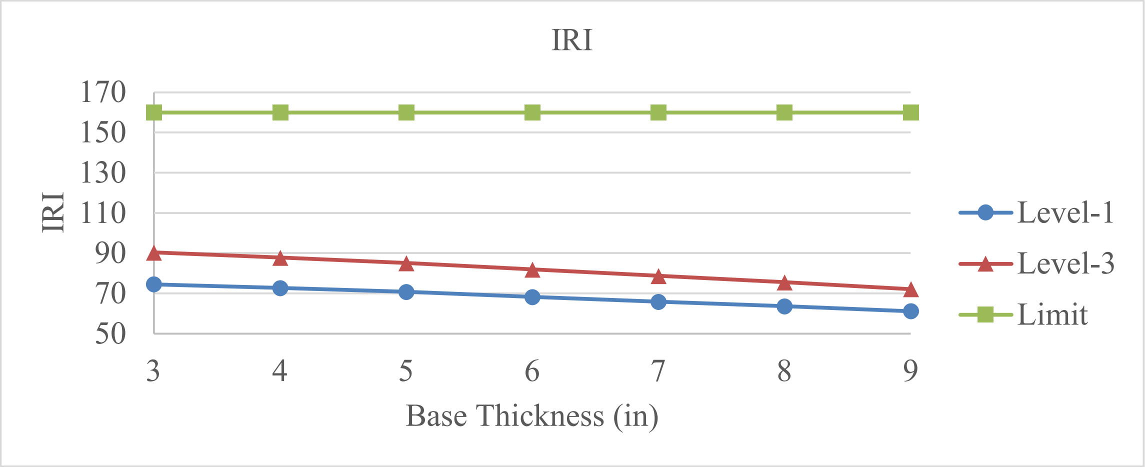

Figure 3.34- a: IRI

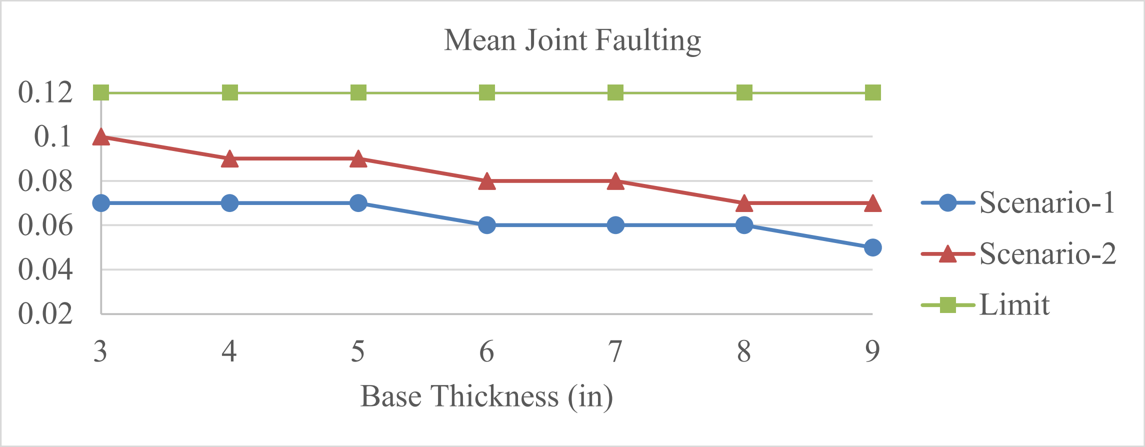

Figure 3.34-b: Mean Joint Faulting

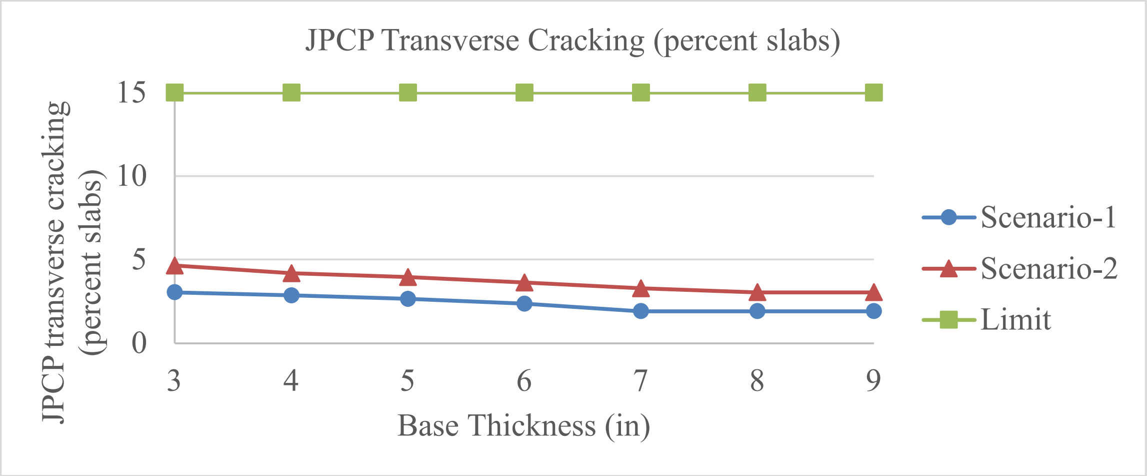

Figure 3.34-c: JPCP Transverse Cracking

Figure 3. 34: JPCP Sensitivity to Base Thickness

Chapter 4: Findings/Deliverables

The objective of this research project was to determine MEPDG Level 2 traffic input parameters for the State of Tennessee. The Pavement Mechanistic Empirical Design (PMED) Guide requires WIM and AVC data in order to develop the traffic inputs. In Tennessee, neither WIM nor AVC stations are currently in place. The research team looked at four different data sources in order to determine data that could be used until WIM and AVC stations are established and enough data is collected to update the current parameters. The data sources studied included:

1. Long Term Pavement Performance (LTPP) sites in Tennessee from 1992 to 2014.
2. Vehicle counts from 25 continuous count stations in Tennessee from 2010 to 2015.
3. AADT and Short-Term classification data from 2011 to 2016.
4. Long Term Pavement Performance Pavement Loading User Guide (LRPP-PLUG)

The team evaluated each of the data sources to determine its suitability for use on PMED analysis, as explained in Chapter 3. This chapter reports the findings and provides inputs that could be used as Level 2 traffic input parameters for PMED. It should be noted that the team could not perform any data verification due to the lack of measured pavement performance data on the selected sites.

PMED utilizes the hierarchical approach in traffic characterization, including:

Level 1: Site-specific data with very good knowledge of past and future traffic characteristics.
Level 2: Regional or statewide data with modest knowledge of past and future traffic characteristics.
Level 3: Poor or limited knowledge of past and future traffic characteristics.

This report provides Level 2, or regional wide traffic inputs.

The research team used material model parameters developed from the previous research (RES2013-33) for the analysis in this project (Table 4.1). On some sites where pavement structure and material properties were not readily available from TDOT, default material inputs were used.

Table 4. 1: Summarization of the Local Calibration of Coefficients

Model	C_1	C_2	C_3
Alligator cracking	1.023	0.045	6000
Longitudinal cracking	6.44	0.27	204.54
Rutting (plain area)	$\beta_{rI} = 0.111$	$\beta_{BS} = 0.196$	$\beta_{SG} = 0.722$
Rutting (Mountain area)	$\beta_{rI} = 0.177$	$\beta_{BS} = 1.034$	$\beta_{SG} = 0.159$
IRI (National defaults)	SF = 0.015; Total Cracking = 0.400; TC = 0.0080; RD = 40.0		

4.1 Developed Level 2 Input Parameters for Tennessee

Information required for traffic characterization includes:

1. Traffic Volume – Base year
    - Number of lanes
    - Design lane factor
    - Directional distribution factors
    - Operational speed
2. Traffic volume adjustment factors
    - Monthly adjustment factors
    - Hourly traffic distribution factors

  - Vehicle (trucks) class distribution
  - Traffic growth factors per vehicle class
3. Axle load distribution factors - Axle Load Spectra (ALS)
4. General Traffic input
  - Number of axle groups per truck for VCs 4 - 13
  - Axle configuration
  - Wheel base configuration
  - Lateral wander

Challenges

The base year truck traffic and traffic volume adjustment factors are obtained from WIM, AVC and vehicle counts, and ALS are determined from WIM data. However, WIM stations that were installed for the LTPP sites in the State of Tennessee are out of service, so there is currently no WIM data available. Alternative methods to determine Level 2 traffic inputs for PMED were used as reported in Chapter 3. The recommended data to be used for each category is provided below.

A. Traffic Volume – Base year. This depends on the base year considered for design. Due to lack of data, no base year was assumed for this case. The base year should align with the year WIM data starts to be collected. Other factors are as shown in Table 4.2.

Table 4. 2: Base Year AADTT and Related Traffic Input Parameters – Project Level

Base year two-way AADTT	TDOT Project Specification
Number of lanes	TDOT Project Specification
Percent trucks in design lane (Design lane factor)	TDOT Project Specification
Percent trucks in the design direction (Directional distribution factor)	TDOT Project Specification
Operational speed	TDOT Project Specification

B. Traffic Volume Adjustment Factors. Four (4) volume adjustment factors are presented:

B.1 Monthly Adjustment Factors

Five-year average monthly variation factors by day are available from TDOT, but the data do not contain monthly adjustment factors for each FHWA VC 4 – 13. This is due to the lack of traffic data from WIM and AVC stations. Therefore, the average monthly adjustment factors from the 14 LTPP sites in Tennessee were used to develop Level 2 monthly adjustments factors (Table 4.3). TDOT may use these factors or default (nationwide – Level 3) factors.

Table 4. 3: Level 2 Monthly Adjustment Factors Obtained from 14 LTPP Sites in Tennessee

	VC 4	VC 5	VC 6	VC 7	VC 8	VC 9	VC 10	VC 11	VC 12	VC 13
Jan	0.93	1.00	0.77	0.61	0.79	0.93	0.78	0.73	0.78	0.58
Feb	0.96	1.05	0.84	0.65	0.87	1.03	0.87	0.82	0.88	0.74
Mar	1.08	1.04	0.95	0.83	1.03	1.07	1.12	0.86	0.94	1.08
Apr	1.04	1.02	1.01	0.98	1.10	1.04	0.94	0.85	0.96	1.06
May	0.93	0.96	1.02	1.12	1.05	0.99	0.98	0.85	1.00	1.02
Jun	0.93	0.96	1.11	1.11	1.05	1.01	1.01	0.98	1.00	1.08
Jul	0.94	0.88	1.01	1.19	1.02	0.92	1.13	1.04	0.92	0.97
Aug	0.91	0.92	1.10	1.27	1.09	1.00	1.06	1.09	0.99	1.19
Sep	0.99	0.96	1.19	1.02	1.02	1.05	1.25	1.27	1.12	1.13
Oct	1.11	1.06	1.17	1.24	1.10	1.06	0.99	1.22	1.19	1.17
Nov	1.07	1.07	0.99	1.19	1.00	0.98	0.94	1.20	1.18	1.04
Dec	1.08	1.09	0.86	0.98	0.88	0.93	0.90	1.22	1.20	1.03

B.2 Vehicle (trucks) Class Distribution (VCD)

To determine vehicle class distribution (VCD), the research team used AADT and 24-hour classification data from approximately 2000 data collection stations collected between 2011 and 2015. This classification data represents all road functional classes except FC 9 and FC 19, which are rural and urban local roads, respectively. The classification data was clustered by the road functional classes in TDOT jurisdiction. It was noticed that VCD developed from short-term classification data for most of the road functional classes showed similar VCD for all years of data collection (2011 to 2015). It was also noticed that these VCD values follow the national trend for the different road functional classes. Table 4.4 presents the recommended Level 2 vehicle class distribution (VCD) that was developed using the 24-hour classification data for each Tennessee functional class (FC). Table 4.5 shows the description of the functional classification used for VCD.

Table 4. 4: Level 2 Vehicle Class Distribution (VCD) Using Short-term Classification Data

	VC 4	VC 5	VC 6	VC 7	VC 8	VC 9	VC 10	VC 11	VC 12	VC 13
FC 1	0.90	5.57	4.10	0.73	10.25	68.22	2.09	3.82	1.83	2.49
FC 2	10.21	0.68	12.93	11.56	3.48	15.39	47.73	1.99	2.37	0.84
FC 6	0.51	20.29	16.95	3.60	16.09	38.63	1.15	1.03	0.38	1.37
FC 7	0.61	30.15	19.22	3.51	17.93	24.61	0.90	1.09	0.36	1.62
FC 8	0.75	40.81	19.56	2.50	18.11	13.19	0.52	1.90	0.26	2.40
FC 11	0.73	8.15	5.96	1.33	11.84	62.40	1.83	3.80	1.99	1.98
FC 12	1.18	15.88	11.26	2.55	24.84	33.54	2.07	2.90	1.99	3.79
FC 14	0.50	15.29	12.50	6.68	26.20	19.67	2.09	6.05	3.78	7.22
FC 16	0.80	27.24	13.92	4.55	27.68	11.34	1.23	5.19	2.63	5.41
FC 17	0.79	45.57	15.28	1.72	22.23	5.82	0.61	3.59	0.83	3.57

NOTE: Numbers in the table are percentages.

Table 4. 5: Functional Class Description

Code	Functional Class Description
1	Rural Principal Arterial - Interstates
2	Rural Principal Arterial - Other
6	Rural Minor Arterial
7	Rural Major Collector
8	Rural Minor Collector
9	Rural Local System
11	Urban Principal Arterial - Interstates
12	Urban Principal Arterial – Other Freeways and Expressways
14	Urban Principal Arterial - Other
16	Urban Minor Arterial
17	Urban Collector
19	Urban Local System

B.3 Hourly Traffic Distribution Factors

There was not enough data to develop Level 2 Hourly Distribution Factors (HDF); therefore, it is recommended to use default values (Level 3) as Level 2 inputs temporarily until more data is gathered. Table 4.6 shows national default hourly distribution factors (Level 3) in percentages, the total percentage is 100.

Table 4. 6: Hourly Adjustment Factors – National Default Values

	AM											
Time of Day	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Percentage	2.3	2.3	2.3	2.3	2.3	2.3	5	5	5	5	5.9	5.9
	PM											
Time of Day	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Percentage	5.9	5.9	5.9	5.9	4.6	4.6	4.6	4.6	3.1	3.1	3.1	3.1

B.4 Traffic Growth Factors Per Vehicle Class

The statewide average linear growth factor of 1.34% per year is recommended as the Level 2 truck growth factor for the State of Tennessee. This is what Tennessee currently uses. The traffic growth factors per vehicle class will be developed after the installation of and implementation of WIM and AVC stations.

C. Axle Load Distribution Factors - Axle Load Spectra

The axle distribution factors include load per axle type (single, tandem, tridem and quad) for VCs 4 – 13. The load intervals are defined as:

1. **Single axle:** 3,000 lb. to 40,000 lb. at ,1000 lb. intervals
2. **Tandem axle:** 6,000 lb. to 80,000 lb. at 2,000 lb. intervals
3. **Tridem and quad axles:** 12,000 lb. to 120,000 lb. at 3,000 lb. intervals

Due to the lack of WIM data in Tennessee, UTC proposes using LTPP Pavement Loading User Guide (LTPP PLUG) WIM data. The PMED default for Normalized Axle Load Spectra (NALS) was developed during the National Cooperative Highway Research Program (NCHRP) Project 1-37A using LTPP traffic data available in 1998. There are some concerns about the lack of documented quality controls for the available data. LTPP-PLUG research team compared LTPP default NALS to the original MEPDG NALS defaults, and it was reported that original MEPDG NALS defaults are more conservative.

UTC studied the possibility of using LTPP PLUG as a source of WIM data for the State of Tennessee. To investigate the significance of the differences between MEPDG original NALS and LTPP PLUG NALS distress prediction, two tests, (1) T-test and (2) Wilcoxon signed rank tests were used with hypothesis that there is no significant difference between the population mean of the distresses predicted by the two NALS for t-test and there is no difference between the median difference of the distresses predicted by PMED-default NALS and LTPP PLUG NALS. Results of t-test indicated that there is a statistically significant difference on four out of five distresses predicted using NALS and LTPP PLUG NALS (Table 4.7). PMED NALS are more conservative. The FWHA website explains how to develop additional axle load default tables from LTPP PLUG data. The Wilcoxon signed rank test indicated that there is no significant difference between the two data sources, hence either one could be used for pavement design.

Table 4. 7: Statistical Analysis of NALS and LTPP-PLUG

Distress	**P-Value**	**Comments**
Total rutting	5.1 E -13 (<0.05)	Null hypothesis was rejected The difference is statistically significant.
AC Bottom-up cracking	0.0077 (<0.05)	Null hypothesis was rejected The difference is statistically significant.
AC Thermal cracking	1.7 (>0.0)	Failure to reject the null hypothesis The difference is statistically significant
IRI	2.3 E -14 (<0.05)	Null hypothesis was rejected The difference is statistically significant.
AC top-down fatigue cracking	1.3 E -07 (<0.05)	Null hypothesis was rejected The difference is statistically significant.

D. General Traffic Input

Other general inputs needed for AASHTOWare PMED namely: wheel base, axle spacing, tire pressure dual tire spacing, and axle width could not be determined from this study. It is recommended to use national default values. Other factors are as explained below:

D.1 Axle Configuration

National default values are recommended for the axle configuration, as shown in Table 4.8.

Table 4.8: Axle Configuration – National Default Values

Average axle width (ft.)	8.5
Dual tire spacing (in.)	12
Tandem axle spacing (in.)	51.6
Tridem axle spacing (in.)	49.2
Quad axle spacing (in.)	49.2
Tire pressure (psi)	120

D.2 Number of Axles Groups per Truck for VCs 4 – 13

The axle per truck inputs developed by LTPP PLUG are recommended as Level 2 axle per truck inputs for the State of Tennessee for FHWA VCs 4 to 13 (Table 4.9).

Table 4. 9: Number of Axles per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
4	1.43	0.57	0	0
5	2.16	0.02	0	0
6	1.02	0.99	0	0
7	1.26	0.2	0.63	0.15
8	2.62	0.49	0	0
9	1.27	1.86	0	0
10	1.09	1.15	0.79	0.05
11	4.99	0	0	0
12	3.99	1	0	0
13	1.59	1.26	0.69	0.31

4.3 Wheelbase Configuration

National default values are recommended to be used for the wheelbase configuration, as seen in Table 4.10. This is applicable to Jointed Plain Concrete Pavements (JPCP) design.

Table 4. 10: Wheelbase Configuration – National Default Values

Average spacing of long axles (ft)	18
Average spacing of medium axles (ft)	15
Average spacing of short axles (ft)	12
Percent trucks with long axles	61
Percent trucks with medium axles	22
Percent trucks with short axles	17

4.4 Lateral Wander

Wheel wander, or lateral wander, is an account of the uncertainty of lateral position of wheel loads on a lane. This is the distance between the edge of the tire and the road. This value is not constant and varies with the passage of vehicles. National default values (Table 4:11) are adopted for these factors due to lack of Tennessee-specific data.

Table 4. 11: Lateral Wheel Wander – National Default Values

Design lane width (ft.)	12 – could be changed in some instances
Mean wheel location (in.)	18
Traffic wander standard deviation (in.)	10

Chapter 5: Conclusion/Recommendations

The objective of this project was to develop PMED Level 2 traffic input parameters for the State of Tennessee. These are the input parameter for the PMED procedure, and each state is required to establish their own design parameters. The input parameters require extensive data input collected from vehicle counts, WIM and AVC stations. Currently, TDOT lacks WIM and AVC stations, which are important in developing PMED traffic inputs. Therefore, the research team utilized alternative data sources to develop the traffic input parameters. The developed data were not verified due to the unavailability of measured distress data on the sections from which other data were drawn. The research team expects that as the PMED climate data is developed, the sections with available design and distress data will be used to verify the developed input parameters.

The benefits of this research to TDOT include:

- Availability of PMED Level 2 traffic inputs parameters for the State of Tennessee that can be used when needed, since AASHTO 1993 Pavement Design Guide will not be updated and all states are expected to move to PMED. This data will be used until TDOT has established WIM and AVC stations and develop updated traffic input parameters.
- These parameters will be part of the MEPDG implementation plan for the design of pavements in Tennessee. Parameters include material inputs, traffic inputs (reported in this report) and climate data inputs.
- MEPDG is an alternative design method that after full implementation TDOT will use to design cost effective and long-lasting pavements.

The analysis was performed on traffic data obtained from Tennessee highways. The available data was utilized to develop the PMED Level 2 input parameters as presented in Chapters 3 and 4. These parameters can be used for all road functional classes except local roads (FC 9 and FC 19) (refer to Table 4.2). The implementation of PMED can be applied anywhere in Tennessee as long as the AASHTOWare PMED (ME design software) is available. A brief training on the use of the software may be needed.

5.1 Conclusion

The lack of WIM and AVC stations in Tennessee led to the UTC team evaluating four different data sources to develop the PMED traffic input parameters. The data sources are:

1. Long-Term Pavement Performance (LTPP) sites in Tennessee from 1992 to 2014.
2. Vehicle counts from 25 continuous count stations in Tennessee from 2010 to 2015.
3. AADT and Short-Term classification data from 2011 to 2016.
4. Long-Term Pavement Performance Pavement Loading User Guide (LRPP-PLUG).

Data analysis was performed using each data source as reported in Chapters 3 and 4. From the analysis the following can be concluded.

- From the available LTPP data, it was determined that LTPP sites in Tennessee should be utilized to develop the monthly traffic adjustment factors used for PMED for the State to Tennessee. Monthly adjustment factors were developed for FHWA VC 4 - 13.
- The analysis revealed that the continuous count stations data source could not be used for developing vehicle class distribution (VDC) because the VCD from continuous count

stations was significantly different from the default (national wide) VCD values (TTC) from AASHTOWare PMED. However, the predicted distresses using the VCD from the continuous count stations and default VCD were very similar because the same NALS, MAF, axle per truck and material inputs for each case were used for analysis. This shows that VCD is not expected to significantly change the pavement performance prediction if similar NALS and other inputs are used for the analysis.

- When AADT and 24-hour classification data were used to develop VCD, it was noticed that the developed VCD values followed national trends for the different road functional classes. This led to the adoption of this data for developing VCD as Level 2 inputs for the State of Tennessee.
- Due to the lack of WIM stations in Tennessee, the research team recommends using the normalized axle load spectra (NALS) developed by LTPP PLUG since they were developed from highly reliable and well calibrated permanent WIM stations, and it facilitates a more economical design than PMED AASHTOWare default NALS. LTPP-PLUG also provides Tier 2 inputs, with heavier or lighter NALS.
- Only one section of concrete pavement was analyzed due to a lack of data. From this analysis, it is recommended that Level 1 inputs should be used for interstate roads with site-specific inputs. On other roads, Level 3 inputs may be used.
- A summary of developed traffic input parameters is given in Table 5.1 showing what data source was used to develop the inputs and where it can be found in this report. With this report, Level 2 traffic input parameters have been developed and submitted to TDOT.

Table 5. 1: Summary of Traffic Input Parameters and Respective Data Source

PMED Traffic input parameter	**Data source used**	**Table**
1. Traffic Volume – Base year	TDOT project specification	4.2
▪ Base year two-way AADTT	TDOT project specification	4.2
▪ Number of lanes	TDOT project specification	4.2
▪ Design lane factor	TDOT project specification	4.2
▪ Directional distribution factors	TDOT project specification	4.2
▪ Operational speed	TDOT project specification	4.2
2. Traffic volume adjustment factors		
▪ Monthly adjustment factors	LTPP sites in Tennessee	4.3
▪ Vehicle (trucks) class distribution	AADT + 24- hr. classification	4.4
▪ Hourly traffic distribution factors	National default values	4.6
▪ Traffic growth factors per vehicle class	TDOT traffic growth factors	-
3. Axle load distribution factors - Axle Load Spectra (ALS)	LTPP-PLUG	-
4. General Traffic input		
▪ Number of axle groups per truck for VC 4 - 13	LTPP-PLUG	4.8
▪ Axle configuration	National default values	4.9
▪ Wheelbase configuration	National default values	4.10
▪ Lateral wander	National default values	4.11

5.2 Recommendations

Two challenges were encountered during the development of the PMED traffic input parameters. (1) Lack of WIM and AVC stations and hence the lack of relevant data for the development of the parameters. (2) Lack of measured distress data on the tested sections, which made it hard to verify or validate the developed traffic input parameters. It is therefore recommended that:

- When measured distresses and pavement design data on different sections on Tennessee roads become available, verification of these parameters should be performed. The verification should include traffic input parameters for Level 2, Level 3 and Level 1 (site specific) to determine which parameters predict values closest to actual measured distress values.
- It is recommended for TDOT put into its plans the installation of WIM and AVC stations. When TDOT acquires WIM and AVC stations and collects enough data, the parameters developed through this research should be revised to provide more accurate Level 2 traffic inputs.

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Appendix

Table A1.1- a: LTPP Sites Main Information

#	Site	Road	Functional Class	Available WIM Data			AVC	AADTT LTPP lane
				Years	Months	Days		
1	600	I-40	1	2001	4		N. A	N. A
				2002	5		N. A	N. A
				2007	8		2007	2007
				2008	12	7	2008	2008
				2009	12	7	2009	2009
				2010	12	7	2010	2010
				2011	12	7	2011	2011
				2012	12	7	2012	2012
				2013	12	7	2013	2013
				2014	9		2014	2014
2	1023	I-75	1	1993	7		1993	1993
				1994	4		N. A	N. A
				1995	3		N. A	N. A
				1997	11		1997	1997
				2000	1		N. A	N. A
				2001	1		N. A	N. A
3	1028	1	2	1993	12	7	1993	1993
				1994	8		1994	1994
				1995	10		1995	1995
				1996	4		N. A	N. A
				1997	9		1997	1997
				1998	5		N. A	N. A
				2000	1		N. A	N. A
				2001	3		N. A	N. A
				2002	3		N. A	N. A
4	1029	28	2	1993	12	7	1993	1993
				1996	6		1994	1994
				1997	12	7	1997	1997
				2000	3		N. A	N. A
				2001	10		N. A	N. A
				2002	5		N. A	N. A
5	2001	3	2	1993	12	7	1993	1993
				1994	8		1994	1994
				1995	5		1995	1995
				1996	5		N. A	N. A
				1997	9		N. A	N. A
6	2008	43	2	1993	12	7	1993	1993
				1994	11		1994	1994
				1995	9		1995	1995
				1996	1		N. A	N. A
				1998	5		N. A	N. A
				2000	3		N. A	N. A
				2001	6		N. A	N. A
				2002	8		N. A	N. A

Table A1.1- b: LTPP Sites Main Information

#	Site	Road	Functional Class	Available WIM Data			AVC	AADTT LTPP lane
				Years	Months	Days		
7	3075	56	2	1992	2		N. A	N. A
				1993	9		1993	1993
				1994	12	7	1994	1994
				1995	5		1995	1995
				1996	3		N. A	N. A
				1997	11		1997	1997
				1998	5		N. A	N. A
				2001	4		N. A	N. A
				2002	5		N. A	N. A
8	3101	96	2	1994	12	7	1993	1993
				1995	6		N. A	N. A
				1996	5		N. A	N. A
				1997	12	7	1997	1997
				1998	3		N. A	N. A
9	3104	370	7	1992	1		N. A	N. A
				1993	4		N. A	N. A
				1994	7		N. A	N. A
				1995	7		N. A	N. A
				1996	3		N. A	N. A
				1997	1		N. A	N. A
10	3108	I-75	1	1992	2		N. A	N. A
				1993	8		1993	1993
				1994	4		N. A	N. A
				1995	3		N. A	N. A
				1997	10		1997	1997
13	6015	I-75	1	1992	2		N. A	N. A
				1993	6		1993	1993
				1994	8		1994	1994
				1995	9		1995	1995
				1996	5		1997	1997
				1997	8		N. A	N. A
				1998	5		N. A	N. A
				2000	2		N. A	N. A
				2002	8		N. A	N. A
14	6022	111	2	1992	2		N. A	N. A
				1993	2		N. A	N. A
				1996	2		N. A	N. A
				1997	5		N. A	N. A
				1998	1		N. A	N. A

Table A1.1- c: LTPP Sites Main Information

#	Site	Road	Functional Class	Available WIM Data			AVC	AADTT LTPP lane
				Years	Months	Days		
15	9024	96	2	1993	6		1993	1993
				1994	11		1994	1994
				1995	10		N. A	N. A
				1996	6		N. A	N. A
				1997	12	5	1997	1997
				1998	4		N. A	N. A
				2000	1		N. A	N. A
				2001	3		N. A	N. A
				2002	6		N. A	N. A
16	9025	96	2	1993	2		1993	1993
				1994	11		N. A	N. A
				1995	6		N. A	N. A
				1996	5		N. A	N. A
				1997	12	7	1997	1997
				1998	3		N. A	N. A
				2002	6		N. A	N. A