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Evaluation of Pavement Performance Due to Overload Single Trip Permit Truck Traffic in Wisconsin

Valbon Latifi
University of Wisconsin-Milwaukee

EVALUATION OF PAVEMENT PERFORMANCE

DUE TO OVERLOAD SINGLE TRIP PERMIT

TRUCK TRAFFIC IN WISCONSIN

by

Valbon Latifi

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ABSTRACT

EVALUATION OF PAVEMENT PERFORMANCE DUE TO OVERLOAD SINGLE TRIP PERMIT TRUCK TRAFFIC IN WISCONSIN

by

Valbon Latifi

The University of Wisconsin – Milwaukee, 2014
Under the Supervision of Professor Hani Titi

This study researched the impacts of overweight permit vehicle traffic on flexible pavement performance in Wisconsin using field investigations and AASHTOWare MEPDG analyses. A database of Oversize/Overweight (OSOW) single trip permit truck records was analyzed and provided a network of Wisconsin corridors heavily trafficked by OSOW trucks. Four Wisconsin state trunk highways were selected for investigation due to a high level of OSOW truck traffic. The research included traffic counts to confirm the levels of truck traffic on these segments and to verify the high numbers of permits issued for OSOW trucks. Furthermore, the field work included the identification and quantification of pavement surface distresses by executing visual distress surveys allowing for the current pavement surface conditions to be rated using the pavement condition index.

Comprehensive analyses were conducted to evaluate pavement performance due to normal traffic loads as well as normal traffic loads plus the OSOW truck traffic loads. The use of AASHTOWare MEPDG analyses presented a potential methodology for determining the proportion of pavement deterioration attributable to OSOW truck traffic. OSOW axle load distributions were integrated with baseline truck traffic levels to develop axle load spectra and other traffic input parameters for the MEPDG analysis.

Visual distress surveys conducted at the selected segments of state trunk highways (STH) 140, 11, and 26 rated the pavement surface conditions as serious to poor, ranging from a PCI value of 13 on STH 140 to a PCI value of 52 on STH 11. Across these three segments, the maximum measured rutting depth along the outer wheel paths ranged from 0.82 in to 1.25 in, which exceeded WisDOT's threshold for acceptable rutting of 0.50 in. Only the segment of STH 23 exhibited a fair pavement surface condition due to PCI values of 63 and 66 in the two lanes, with a maximum rutting depth of 0.50 in. The generally poor pavement conditions across the sampled segments included significant pavement surface damage and distresses such as rutting, longitudinal and transverse cracking, significant fatigue cracking, and potholes.

The predicted total pavement deterioration levels from the AASHTOWare MEPDG software were generally consistent with the levels of deterioration observed during the site investigations. However, the proportion of pavement damage and deterioration attributable to OSOW truck traffic was predicted to be fairly insignificant, with most distress indices showing relative increases of approximately 0.5% to 4%, with a few outliers. The addition of OSOW truck traffic to the baseline truck traffic volumes resulted in a small increase in the amount of pavement damage, rutting depths, and loss of ride quality compared with the predicted deterioration levels due to only the baseline traffic.

To my family and friends,
Thank you for all your support and love.

To Xim,
The only brother I ever had and the only brother I will ever have.
I love you.
04/04/2013

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LIST OF ABBREVIATIONS

AASHTO: American Association of State and Highway Transportation Officials

ALS: Axle Load Spectra

FHWA: Federal Highway Administration

IH: Interstate Highway

GVW: Gross Vehicle Weight

MAP-21: Moving Ahead for Progress in the 21st Century

MEPDG: Mechanistic-Empirical Pavement Design Guide

NAPCOM: National Pavement Cost Model

NHS: National Highway System

OSOW: Oversize/Overweight

SHA: State Highway Agency

STH: State Trunk Highway

USDOT: United States Department of Transportation

USH: United States Highway

WisDOT: Wisconsin Department of Transportation

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CHAPTER 1

INTRODUCTION

1.1 Overview

States have the authority to issue permits to oversize overweight (OSOW) vehicles exceeding federal and state size and weight limits (FHWA 2003). Recent years have seen dramatic increases in the number of OSOW permits obtained in various states, especially in the number of superheavy vehicle permits, i.e. vehicles with GVW of at least 270 kips (Chen et al. 2009). Superheavy loads above 1,000 kips have been reported, including a 1,005 kip turbine skid in Ohio and a 1,978 kip hydroreactor in Louisiana. Although most overweight permit vehicles utilize rigs with 6+ axles or with 8 or more tires per axle in order to distribute the load more evenly, many permit vehicles also include axle loads above the federal standards of 20 kips for a single axle and 34 kips for a tandem axle. Premature fatigue cracking and rutting have been described on routes experiencing large numbers of overweight vehicles, for example in northern Wisconsin on federal highways with large numbers of overweight logging trucks (Owusu-Ababio and Schmitt 2005). Acute pavement damage from permit vehicle loads has also been reported, including seal coat stripping in Texas (Chen et al. 2009) and severe rutting and cracking in Louisiana (Oh et al. 2007). Research is also underway in Texas to evaluate the effects of heavy trucks on subgrade utility facilities (Kraus et al. 2014).

The Wisconsin Department of Transportation (WisDOT) issues both single-trip and multi-trip permits for OSOW vehicles (WisDOT 2013). Single trip permits are granted for a specific vehicle and a specific one-way or return route, and vehicle dimensions, axle weights, and the planned route are recorded. Permit routes for vehicles with GVWs < 270 kips are automatically analyzed by WisDOT's enterprise GIS system, which includes a database of segment restrictions such as bridge ratings, spring thaw limitations, and temporal restrictions due to traffic regulations or special events (Adams et al. 2002). Superheavy vehicle permits (≥ 270 kips) are analyzed manually by WisDOT's bridge and pavement engineering divisions before approval. Multi-trip permits allow the carrier to operate vehicles up to 170 kips GVW without restriction within the permit's timeframe (three to twelve months), but the vehicle weights, dimensions, and route information are not recorded by WisDOT.

1.2 Objectives

The objective of this research is to characterize pavement damage and deterioration induced by oversize overweight single permit truck traffic on selected hot mix asphalt pavements in Wisconsin.

1.3 Scope

This research investigated pavement damage through field studies of the selected highways and the corresponding pavement performance analysis using AASHTOWare MEPDG software.

1.4 Organization of Manuscript

This manuscript is organized in five chapters. Chapter One presents the problem statement and objectives and scope of the research. The background information on the impact of heavy loads on pavement damage and deterioration is discussed in Chapter Two. Chapter Three presents the research methodology and tools used to perform the research. The results of the research as well as critical analysis and evaluation of the results are presented in Chapter Four. The conclusions reached as a result of conducting this research are summarized in Chapter Five.

CHAPTER 2

BACKGROUND

This chapter presents the background information on the impact of heavy truck traffic loads on pavements in terms damage and deterioration. In addition, the history of pavement design methodologies and in particular the implementation of MEPDG methods via AASHTOWare MEPDG software is discussed.

2.1 Characterization of Oversize/Overweight Loads

The National Highway System (NHS) was created by the United States Congress in 1995, which included interstates, U.S. highways, state highways and county roads. Freight carried by truck travels mostly on these four arterial types crossing the country. The interstate system was created by the federal government, but the states in which they were built legally own the rights of way. State Highway Agencies (SHA) are responsible for all aspects of the highway infrastructure, including construction, maintenance, and rehabilitation.

Wisconsin's economy creates over $300 billion in goods annually, a figure which is growing rapidly and expected to rise an additional 70% by 2025 (Adams et al. 2009). Of the four main modes for transporting freight, trucks are growing at the highest rate in the nation and in Wisconsin. 74% of the total freight tonnage moved through the state is carried by truck with an average trip length of 183 miles (Adams et al. 2009). Over the last 25 years, loads transported on ships and trains have become heavier while trucks loads have stayed constant, largely due to size and weight limits.

The federal government and state governments have placed limits on truck weight and dimensions. Current federal highway regulations limit all vehicles' gross weight (GVW) to 80 kips, with single axle loads not to exceed 20 kips and tandem axle loads limited to 34 kips. Vehicle size limits are also in place, notably a maximum width of 8.5 feet; federal length limits vary depending on vehicle configuration and state, and no federal height limit is in place (although most states adopt 13.5-14 foot height limits). These limits apply on Interstate highways and National Network federal highways, but many state DOTs have adopted federal limits for state and local roads as well. Additionally, numerous exceptions to size and weight limits exist for grandfathered vehicles and grandfathered states such as Michigan, and a large amount of variability exists across different states' limits for state highways and for other vehicle parameters which are not federally regulated (FHWA 2013). Vehicles receiving permits to operate above applicable size and weight limits are classified as oversize or overweight (OSOW) vehicles.

Adams et al. (2009) conducted a comprehensive truck size and weight study in Wisconsin which assessed the potential economic, safety, and engineering impacts of changing state laws and policies to allow various heavy truck configurations with 6 to 8 axles and GVWs of 80 to 108 kips. The project's goals included the identification of configurations which could potentially benefit the state's economy while still protecting pavements and bridges, preserving roadway safety, and minimizing additional infrastructure costs. The research reviewed the maximum vehicle dimensions and weights in Wisconsin and in neighboring states (Table 2.1). Vehicles operating above any of these limits must have a valid OSOW permit. All four states have the same maximum height and width dimensions; however, single unit vehicle length varies from 40 to 45 feet. The permit application process for the states is similar, facilitating interstate travel without the need to reevaluate truck dimensions and weights from state to state.

Table 2.1: Single trip permit requirements for vehicle dimensions and weights (Adams et al. 2009)

Vehicle Characteristic		Wisconsin	Illinois	Iowa	Minnesota	Federal
Width		8'6"				
Height		13'6"				No Limit
Length	**Single Vehicle**	45'	42'	41'	40'	
	Semitrailer	53'				
	Twin Combo Trailers	28' 6"				
Axle Load	**Single (lbs)**	20,000				
	Tandem (lbs)	34,000				
	Tridem (lbs)	42,000				
Max GVW		80,000				

Chen et al. (2005) conducted research on superheavy load (SHL) moves in Texas. The objective of the research was to investigate and examine pavement damage and distress caused by SHLs. The study was conducted between November 2001 and November 2002 and included field monitoring of specific cases of SHL moves with GVWs over 500 kips. A high percentage of heavy truck freight movement takes place in Texas. The Texas Department of Transportation (TxDOT) requires a pavement analysis of heavy permitted non-divisible loads when the GVW exceeds 500 kips (Chen et al.

2005). In 2001, Texas issued 288 SHL permits, which increased to 364 the following year, a 26% increase (Chen et al. 2005). The major commodities moved during the monitoring period were transformers, generators, and combustion turbines. The typical GVW for SHL moves ranged from 600 to 700 kips. The distance the SHL traveled ranged from 1 mile to 710 miles, with an average of 30 miles. The history of the SHL permit records also determined that as the GVW increased, so did the tire load as shown in Figure 2.1.

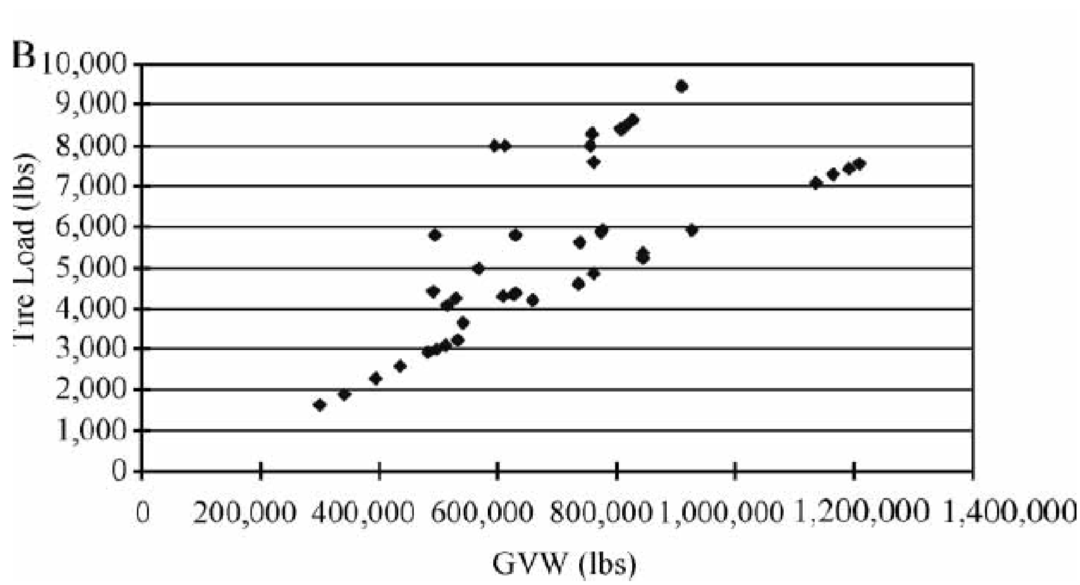


Figure 2.1: SHL permits comparing GVW vs tire load (Chen 2005)

Chen et al. (2009) continued the evaluation of SHLs from 2005 in Texas. In 2007, Texas issued 701 SHL permits, a drastic increase from the 364 reported in 2002. TxDOT holds the carriers liable for any damage cause to the pavement and are expected to pay for any damages.

Chen et al. (2013) conducted an evaluation of SHL movement on flexible pavements in Louisiana. The Louisiana Department of Transportation and Development (LADOTD) grants approximately 235,000 OSOW permits per fiscal year, averaging 900 per day. The state policy requires a SHL permit when the GVW exceeds 254 kips. If the GVW is 900 kips or greater, an independent engineering firm is consulted for additional analysis.

2.2 Impact of OSOW Loads on Pavement

Gillespie et al. (1992) conducted a comprehensive literature review and mechanistic analysis of truck loading characteristics and their effects on pavements, with specific emphasis on static and dynamic wheel and axle loading scenarios on both flexible and rigid pavements. The analysis included theoretical mechanistic calculations of pavement stress and strain for various tire and axle loading situations, finite element (FE) simulations, and a review of road test data. Although the research relied on the 4th-power ESAL methodology for some calculations of pavement wear, it also analyzed the significance of dynamic loading variations due to speed and driving behavior, and it demonstrated the significance of uneven axle loading within and between axle groupings. The two main pavement distresses in flexible pavements are fatigue cracking and rutting. Gillespie determined that the main attributable cause to fatigue cracking is heavy axle loads, which also leads to rutting.

Jooste and Fernando (1994) reported on a specific SHL move in Victoria, Texas in 1992. The route included local roads and a stretch of state highway, and pavement conditions along the route were recorded before and after the move. The load was divided into three 250 kip loads and one load of 534 kips. The weight per axle for the heaviest load was 29,700 lbs per axle, with a per-tire weight of 7,400 lbs per axle. Pre- and post-move field testing included thickness measurements, subgrade evaluation using dynamic cone penetrometers, structural testing with a Falling Weight Deflectometer

(FWD), and an Automated Road Analyzer (ARAN) pavement condition survey. Pavement typical sections included 2 in. hot-mix asphalt concrete (HMA) over 8 in. continuously reinforced concrete, 6 in. HMA over 8 in. river gravel, and 4 in. HMA over 6 to 13 in. stabilized shells. A multi-depth deflectometer (MDD) was embedded 3.7 in. into the pavement to measure deflection as the SHL passed. A comparison of predicted vs. measured pavement displacements showed that the load was not evenly distributed over the axles. In Figure 2.2 below, the calculated displacement had more uniform peaks throughout the time of the load passing (6 to 14 seconds). The MDD recoded lower amounts of deflection for the first 8 seconds compared to the calculated amount, then surpassed calculated amounts over the 6 seconds. Crucially, the results show that the assumption that SHL weights are evenly distributed over all trailer axles likely underestimates the maximum pavement stresses and strains experienced during the move.

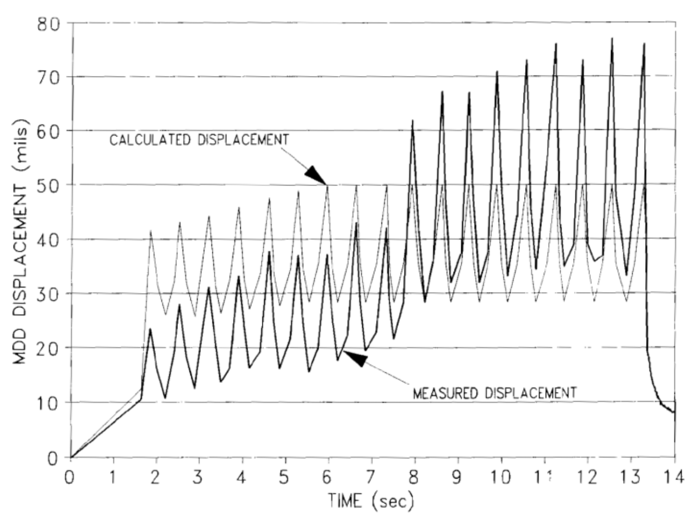


Figure 2.2: Measured vs calculated response for sensor depth at 3.7 in. below surface layer (Jooste and Fernando 1994)

Nonetheless, the field observations and mechanistic predictions both concluded that it was unlikely that the Victoria SHL move would cause subgrade shear failure or flexible pavement failure. The ARAN survey was done on the road before and after the move, showing low rutting (0.14 in). A follow-up visual survey confirmed the ARAN results.

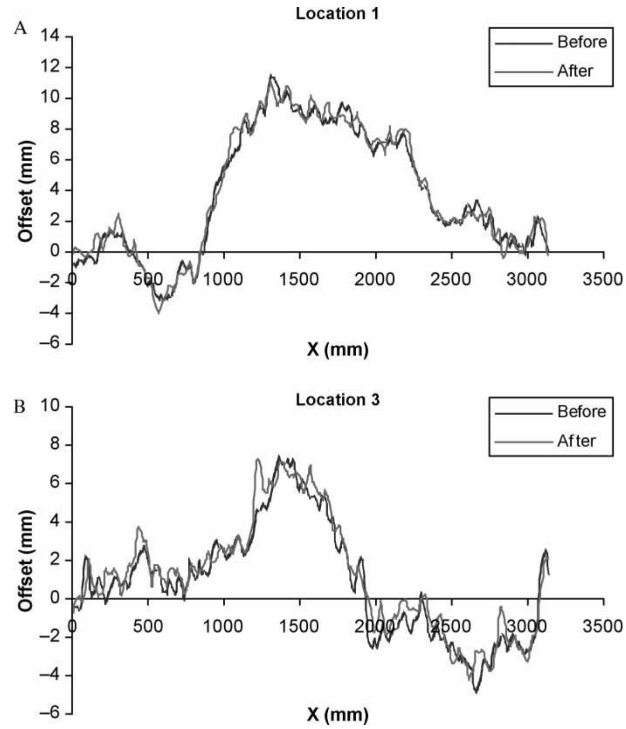
Oh and Wimsatt (2010) reviewed research and case studies regarding damage to seal coats from SHL's, developed a mechanistic model of seal coat stress and failure, and also conducted field testing of freshly load seal coats under multiple loading configurations. An example of damage from SHL's is the severe damage caused to a flexible pavement in Texas in 2004. A hydro reactor 21 ft wide and 117 ft long was moved 150 miles with a GVW of 1,978 kips, including a 7 mile section deemed inadequate by TxDOT to support the maximum tire load of 12,500 lbs due to the pavement structure of 2 in. HMA over 8 in. of flexible base (the carrier agreed to pay for any damages). Complete failure - severe rutting and fracturing - resulted. Figure 2.3 is an image of the severe pavement failure as a result of the load move. This incident highlights another important characteristic of many SHL: they often possess a wider-than-normal axle width, meaning that much of the load must be carried by pavement close to the road edge which might lack lateral support.

Figure 2.3: Pavement Damage to Farm to Market Road 796 in Texas (Oh and Wimsatt 2010)

Adams et al. (2009) used an equivalent single axle load (ESAL) approach to estimate the impacts of increasing truck weight limits in Wisconsin. A standard class 9 five axle truck with a GVW of 80,000 lbs would create 2.4 ESALs. If the GVW of the truck increased 10,000 lbs while still being transported on five axles, the ESALs would rise to 4.1, an increase of approximately 70%. If the previous GVW truck (90,000 lbs) were to be placed on six axles (class 10 configuration), the ESALs would drop to 2.0, even lower than the standard 2.4. The study concluded that a 90,000 lbs six axle truck would result in a 30% decrease of ESAL miles per payload ton-mile since fewer trips will need to be made. Since pavement damage occurs at a geometric rate, the more the load is distributed, the less damage the pavement will face. Wisconsin is a four season state, and during winter the pavement damage induced from trucks is not as significant as in the spring due to the frozen pavement structure. However, during the spring thaw the pavement is highly susceptible to distresses due to layers of the pavement structure and subgrade being moist.

Chen et al. (2005) included field monitoring for pavement failure during their study of four SHL moves in Texas. The first SHL move was Farm to Market (FM) 1644, which carried two identical SHLs slightly over 1,000,000 lbs each. Both of the loads were generators for a power plant with a route length of about 21 miles. Four sensor pads (10 ft x 12 ft) were laid out along the highway. After the load had passed, the pads were analyzed. Two of the pads showed deflection in the pavement at 0.01 in and the other two having a deflection of about 0.06 in. The typical deflection on a pavement from an FWD test for an interstate highway is 0.007 in. All four pads exceeded this expected deflection. The reason two of the pads had a much higher deflection was due to the subgrade being stronger in those areas. The pavement did not show any apparent damage after a thorough visual review. The conclusion was that there could be internal damage; however, this conclusion is uncertain without taking a core of the pavement. The second project was to monitor a SHL move on I-30. The GVW of the truck was 569,000 lbs, which was a shovel bucket only traveling 1.25 miles. When the SHL crossed a bridge segment in the route, extra axles were used to increase the load distribution. During the move the carrier provided a water truck, which sprayed water on the pavement surface during the SHL’s transport to reduce any shear forces between the surface and the tires. Once the truck ran out of water, minor scratches were observed on the pavement surface. The third project was monitoring the move of an autoclave with a GVW of 843,000 lbs traveling 710 miles on US285. The length of the trailer was 300 ft. Three sections along the route were selected to be analyzed with a mechanical profiler (Figure 2.4a) before and after the SHL move. The pavement was measured in the transverse direction. Pavement profiles collected before and after the SHL move are compared in Figure 2.4b, showing no major differences.

(a) Mechanical profiler at section of US285



(b) Displacement of pavement surface measured before and after SHL move

Figure 2.4: Field observations and measurements following SHL move in Texas (Chen et al. 2005)

The fourth field monitoring case was a turbine with a GVW of 628,400 lbs with a travel distance of 2 miles on FM688 (Chen et al. 2005). This final visual monitoring project turned out to be the most successful. Surface cracks were present in the pavement before the move, but no additional cracks were observed following the move. The pavement structure along this route included a concrete layer (8 in) under the asphalt surface (3.5

in), which likely provided a strong support structure. There were no structural failures reported in the few years after visual monitoring concluded, but three minor instances occurred:

1. Abrasion in the surface occurred when the carrier made a sharp turn in Houston.
2. A SHL move was done on a two week old freshly constructed pavement. As the load move, the seal coat was peeled off and the carrier was responsible for the repair charges ($7,174).
3. As in the previous pavement damage case, a SHL move caused the stripping of a two week old seal coat.

Field monitoring of the pavement by Chen et al. 2005 observed no structural failure but did have three minor instances of pavement damage reported.

Timm et al. (2008) utilized an AASHTO MEPDG model to estimate the impact of across-the-board axle load spectra shifts. The default MEPDG axle load spectra were shifted upwards by 3,000, 5,000, and 7,000 lbs per axle for single axles; 6,000, 10,000 and 14,000 lbs per axle for tandem axles, etc., for a total of four axle load situations (control plus three shift scenarios) as seen in Figure 2.5.

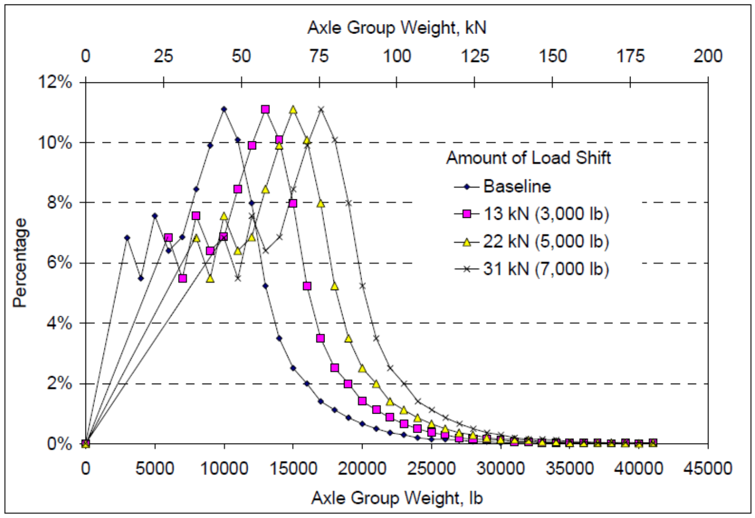


Figure 2.5: Single ALS shift (Timm et al. 2008)

Annual Average Daily Truck Traffic (AADTT) values of 250, 1,000, 4,500, and 8,000 were analyzed across each of the four axle load spectra (ALS) and two pavement models: flexible and rigid. The pavement thickness varied at each AADTT level to the minimum thickness necessary to prevent any failure criteria from occurring using default MEPDG failure threshold values.

The analysis showed that shifting the axle load spectra to increase average axle weights caused decreases in pavement performance for both rigid and flexible pavements across multiple AADTT levels according to the MEPDG models. They noted that "in all cases, pavement life tended to reduce exponentially with increases in load shift and significant reductions were evident even for moderate increases (e.g., 3,000 lbs)" (Timm et al. 2008). The analysis predicted that even a 3,000 lbs spectrum shift per individual axle - meaning 3,000 lb increases for single axles, 6,000 lbs for tandem axles, etc. - would lead to pavement life cycle costs at least 50% higher the current costs.

Owusu-Ababio and Schmitt (2005) examined the early concrete pavement failure in 2001 on USH 51 and USH 8 near Rhinelander, WI. The research also reviewed Wisconsin's rigid pavement design guidelines with reference to other DOTs and to the AASHTO 1993 and mechanistic-empirical (ME) pavement design guides. 14.5 miles of doweled jointed plain concrete pavement (JCPC) constructed in the early 1990s began to crack longitudinally only 2 to 4 years after construction. The early failure was attributed to an insufficient prediction of pavement damage from heavily-loaded logging industry trucks on those highways. In addition to noting a general lack of information regarding heavy loads in public DOTs' design manuals across the U.S. and Canada, the report concluded that the standard rigid ESAL tabulations used in 2005 (set by WisDOT in 1987) typically required modifications in order to account for OW vehicles in northern climates experiencing freeze/thaw cycles. The research also anticipated the upcoming change to an MEPDG-based design will be better-suited for addressing OW loads. The report did not however look at pavement performance from an MEPDG perspective, but rather advocated adopting higher ESALs (in line with other Midwest states) until a thorough truck weight and pavement study using MEPDG methods could be implemented in Wisconsin.

Chen (2009) identified roadways with steep slopes as a factor in pavement surface damage. Case studies throughout Texas were conducted to observe any damage done by SHLs to the pavement surface. One of the field visits took place on FM 109 in the Yokum District. The SHL had a GVW of 670,000 lbs. The truck moved on a hot day in August with a load per tire of about 8,000 lbs. Once the SHL started traveling up the slope (approximately 9% grade), the wheels on the drive axle began to spin on the 3 month old seal coat. Figure 2.6 depicts the stripping the seal cost with HMA clearly left on the tires. The belief is that the main cause of the damage was the load was only moved by a pull tractor and no push tractor. With such a steep slope, there needed to be push truck to help move the load. The high load per tire and high temperature during the move were also factors in the damage caused. The study concluded that the damage potential of seal coats increases drastically on hilly roads when there is not an additional push tractor. In addition, TxDOT prevents carriers from moving loads on pavements with a fresh seal coat (five weeks or less).

Figure 2.6: Pavement Damage on Farm to Market Road 109 in Texas (Chen et al. 2009)

Chen et al. (2013) conducted a study of a 4,000,000 lb load moved 1 mile on a flexible pavement in Louisiana. The load move was modeled with 3D FE software (BISAR) using the Mohr-Coulomb yield criterion on the existing pavement section. The model investigated whether any rapid shear forces would occur within the pavement layers. The modeled pavement section was rehabilitated in 2002, with a typical section of 13 in. HMA and a 6 in. base on the subgrade soil. The model had single, three, and five line loads to get a better range of how the load will act on the routed pavement section. The results of the SHL model found that instantaneous shear failure would not occur and the pavement was sufficient. The SHL would have been a contributing factor towards possible rutting and fatigue cracking in the pavement, which was determined with the single line load model. Distresses were highest near the bottom of the base layer indicating that the stress could reach fully through the pavement layer. The most conservative results were produced from the single line method with the BISAR program and would be the preferred method since it is much easier to use in practice.

Tirado et al. (2010) developed an FE model to estimate the permit costs for the actual cost of moving heavy trucks on the pavement. The representative flexible pavement designed for the model was from a state highway in Texas: 3 in. HMA and a 12 in. base on a subgrade with a modulus of elasticity of 10,000 psi. The FE software used for the analysis was IntPave, which uses an ME approach to predict pavement distresses. Two truck configurations were used to compare the damage done to the pavement by each. Both were class 9 vehicles, but one had a GVW of 80,000 lbs and the other had a GVW of 160,000 lbs. Figure 2.7 shows the rutting depth predicted by the model for the first 120 passes on the pavement by each truck. After 100 passes by the standard truck, the rutting depth is approximately 0.13 inches. The same rutting depth can be achieved by the second truck (GVW of 160,000 lbs) in only five passes.

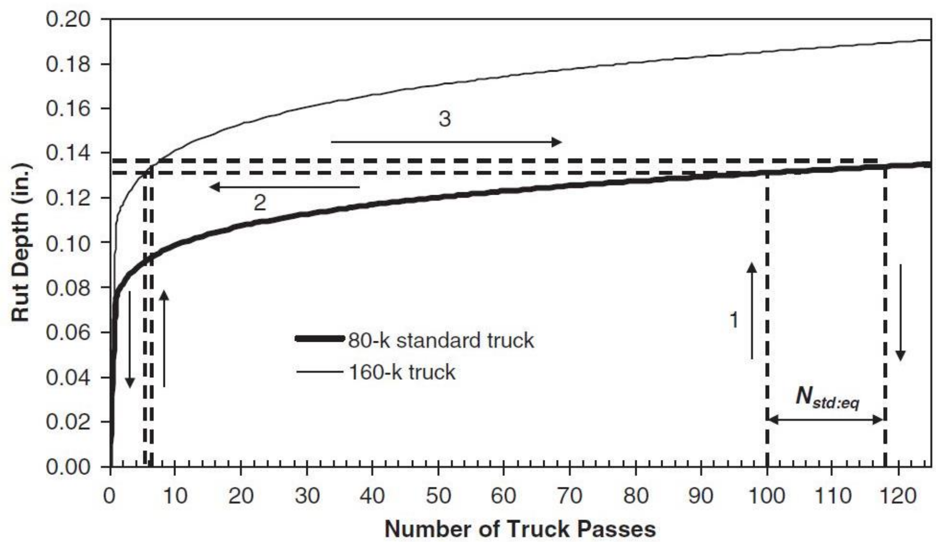


Figure 2.7: Rutting for Normal Truck Passes vs. Heavy Truck Passes (Tirado et al. 2010)

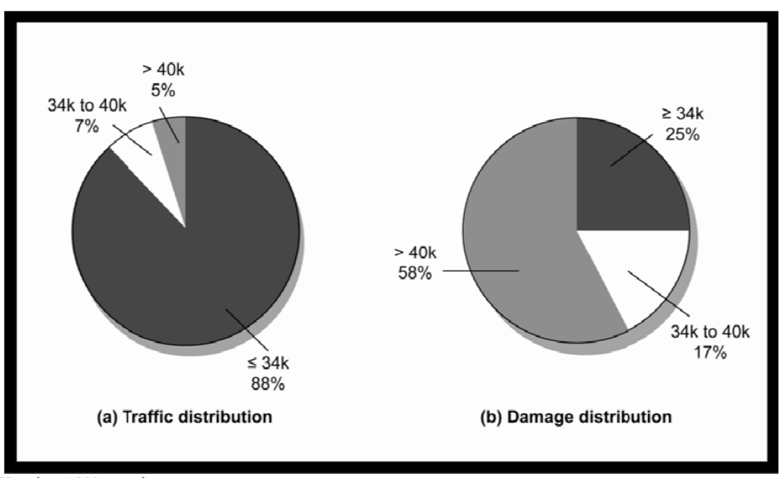
Acimovic et al. (2007) conducted an investigation of pavement failure on Vazquez Boulevard, which is an OSOW truck relief route in Colorado for I-25. The route carries high volumes of truck traffic to Commerce City, mainly an industrialized area. In 2001 a major rehabilitation project took place by milling the existing surface layer and paving with 2 in. of stone matrix asphalt (SMA). The previous HMA surface layer was 6 in. The pavement performance was monitored closely, and after a year there was a significant amount of rutting. There were areas of 0.25 to 3 in. rutting over the rehabilitated site, causing concern due to the distresses appearing in such a short period of time. Figure 2.8 shows the severe rutting in the pavement, approximately 2 in. within the observed wheel path.

Figure 2.8: Rutting along Vazquez Boulevard in Commerce City, CO (Acimovic et al. 2007)

The design of the pavement for the rehabilitation did not take into concern that Vazquez Blvd. is a main OSOW relief route. Acimovic et al. (2007) concluded that the pavement failure was due to excessive and constant loading from OSOW trucks.

2.3 Weight Limit Increase Studies

The Federal Highway Administration (FHWA) (2010) conducted a pilot study in the states of Vermont and Maine regarding increasing vehicle weight limits. The 2010 U.S. Consolidated Appropriations Act (P.L. 111-117) authorized a one-year pilot study to assess the feasibility of raising truck weight limits on interstate highways. Maine applied a state weight limit of 100,000 lbs GVW (over six axles) and up to 46,000 lbs per tandem axle and 54,000 lbs per tridem axle, and Vermont applied a state limit of 99,000 lbs GVW (over six axles), 39,600 lbs per tandem axle, and 54,000 lbs per tridem axle. The pilot study report used the National Pavement Cost Model (NAPCOM) to estimate pavement damage effects of different vehicle configurations and axle loads (FHWA 2010). NAPCOM is a complex simulation model that uses the federal Highway Performance Monitoring System (HPMS) database of pavement sections and performance to estimate pavement performance (USDOT 2000). The NAPCOM model does not use AASHTO's fourth power law – the ESAL approach – but includes similar exponential functions for a variety of pavement distress types based on axle loads. Most NAPCOM distress model exponents are slightly below the AASHTO exponent value of four (USDOT, 2000). The Vermont and Maine pilot study report estimated that only 5% of tandem axles exceeded 40,000 lbs, but those 5% of axles caused 58% of the total damage due to tandem axles. Additionally, tandem axles greater than 34,000 lbs up through 40,000 lbs accounted for 7% of tandem axles, yet were estimated to cause 17% of damage from tandem axles. 88% of tandem axles were 34,000 lbs and lower, yet those 88% only caused the remained 25% of pavement damage, as shown in Figure 2.9 FHWA (2010).



Key: k = 1,000 pounds.

Figure 2.9: Traffic Distribution by Tandem Axle Groups and the Corresponding Damage Distribution (FHWA 2010)

The FHWA (2011) conducted a pilot study in Vermont to determine the impact of trucks when there was shift in the allowable GVW. The pilot study reported noticeable shifts in truck class spectra on both interstate and non-interstate highways. Of particular note is that some traffic (approximately 1.5% of total traffic) shifted from non-interstates to interstates, especially class 7, 11, and 12 vehicles. The weight spectra shifts were estimated to cause an increase in pavement damage (approximately 12%) on interstates due to the increased number of vehicles. Once again the NAPCOM model was used to determine the effects of the pilot trucks on the life cycle costs of the pavement. Table 2.2 shows the changes in pavement damage due to the shift of traffic between the two highway types. Pavement wear on non-interstates was expected to remain constant as the decrease in number of vehicles was accompanied by an increase in GVW and axle loadings (FHWA 2011).

FHWA Vehicle Class	Interstate Pavement Changes (Pilot Versus Control) 2010	Non-Interstate Pavement Changes (Pilot Versus Control) 2010
7	686.2%	-15.0%
8	-5.1%	2.7%
9	1.7%	-5.7%
10	63.9%	18.4%
11	65.5%	9.1%
12	144.0%	-25.9%
Other	0.0%	0.0%
All Trucks	11.4%	-0.4%

Table 2.2: Summary of changes in pavement damage from Vermont Pilot Study (FHWA 2011)

Peters and Timm (2008) used a MEPDG analysis and a layered elastic pavement analysis using WESLEA, a linear elastic multi-layer program to analyze a pavement structure under complex loads, to assess the potential impact of increasing the U.S. GVW limit from 80,000 lbs to 97,000 lbs via the addition of a 6th axle to the trailer of a class 9 truck. The analysis assumed that various percentages of tandem axles currently loaded to 34,000 lbs would be converted to a tridem axle of 34,000 + 17,000 = 51,000 lbs to accommodate the increase in GVW limits. The conversion percentage analyzed were 0% (control), 5%, 25%, 50%, and 100%. Two pavement typical sections were analyzed - flexible and rigid - and an Alabama climate file was assumed. Pavement thicknesses were selected at four different AADTTs (250; 1,000; 4,500; and 8,000) at a minimum sufficient level based on current traffic distributions as calculated by MEPDG. Simulations were performed for each pavement type and across the four AADTT levels and five levels of GVW shift. Both the MEPDG and WESLEA models predicted that an increase in the federal weight limit to 97,000 lbs for six-axle vehicles would not result in additional fatigue cracking, assuming that the total weight of the traffic remained constant. However, this analysis used an Alabama climate profile (no freeze-thaw cycles), four distinct traffic levels, and only considered one rigid and one flexible pavement typical sections. While it analyzed multiple scenarios for percentage of total truck traffic converting to the six-axle 97,000 lbs format, it also assumed that the additional 17,000 lbs load would be borne entirely by the addition of a sixth axle to form a rear tridem axle, and the authors acknowledged that more research was needed to determine probable axle spectra under a 97,000 lbs GVW limit.

Cohen et al. (2003) looked at the possible shift of GVW laws and regulations and how carriers would adapt to the changes. In 1983, the GVW limit in Arkansas increased from 73,280 lbs (approximately 312.5 kN) to the now current 80,000 lbs (approximately

337.5 kN). Figure 2.9 displays that the peak frequency of trucks drastically shifted towards the new GVW limits. The carriers took advantage of being able to transport heavier loads by filling up trailers.

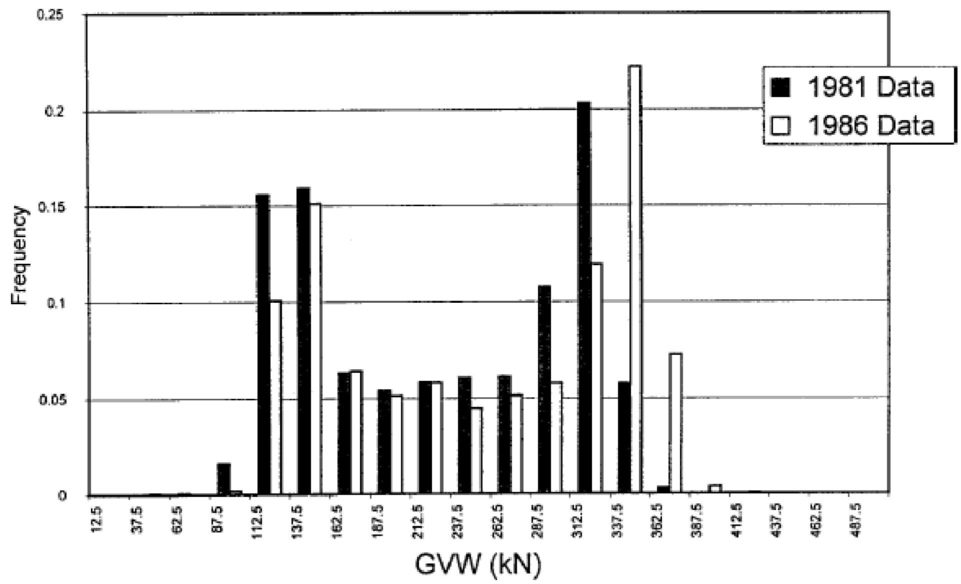


Figure 2.10: Comparison of truck weights in Arkansas from 1981 to 1986 (Cohen et al. 2003)

Fiorillo (2014) conducted research on developing a data mining tool to use the Automatic Vehicle Identification infrastructure integrated with the Weigh-In-Motion (WIM) systems to easily find out which vehicles are the OSOW trucks. They will then be able to identify which trucks are operating illegally. The state of New York consistently found trucks that were running overweight, and in one of their studies, 49.6% were illegal trucks. The results showed that only about 2% to 5% are running over the state 80,000 lb limit.

2.4 The Impact and Cost of OSOW Trucks

Strauss (2006) in a study conducted a study for the Arizona Department of Transportation (ADOT) and stated reported that overweight vehicles cause an extra $12-53 million per year in pavement damage in Arizona. This figure was derived from a top-down analysis of Arizona summary data based on ADOT's own Highway Cost Allocation Model and from national-scale FHWA highway cost statistics. ADOT's model estimated that approximately $210 million per /year in pavement damage could be attributed to heavy vehicles. Additionally, the analysis included a 2005 multi-state survey of DOT truck weight monitoring and enforcement efforts. Informal estimates from 11 states of the percentage of truck traffic exceeding axle or GVW limits ranged from less than 0.5% (South Dakota) to 30% (Arizona), with most estimates less than 10%, and an estimate of 7% from Wisconsin. Only 2 out of 23 states were able to report specific estimates of annual cost of damages from overweight vehicles: $36 million/year in Maryland, and $0.7 million/year in Montana. The report authors note a "truly disappointing" lack of information quantifying these costs. Additionally, there was large variation in the reported number of trucks weighed per year, ranging from 1,000 trucks per /year in Wisconsin and North Dakota, to millions of trucks per /year in Arizona, California, Georgia, and Utah (Straus 2006).

2.5 Moving Ahead for Progress in the 21st Century Act

On July 6, 2012, President Barack Obama signed the Moving Ahead for Progress in the 21st Century Act (MAP-21). The bill covers many transportation related policies such as improving safety, infrastructure maintenance, protecting the environment, developing an efficient system for freight movement, and reducing congestion on the roadways (FHWA 2012).

House Resolution 4348 §167 (2012) is the legislative document authorizing the MAP-21 initiative. Section 1115 ("National Freight Policy") of the MAP-21 Act highlights seven important goals:

1. "to invest in infrastructure improvements and to implement operational improvements that strengthen the contribution of the national freight network, reduce congestion, and increase productivity for domestic industries and businesses that create high value jobs;
2. to improve the safety, security and resilience of freight transportation;
3. to improve the state of good repair of the national freight network;
4. to use advanced technology to improve the safety and efficiency of the national freight network;
5. to incorporate concepts of performance, innovation, competition, and accountability into the operation and maintenance of the of the national freight network;
6. to improve the economic efficiency of the national freight network;
7. to reduce the environmental impacts of freight movement on the national freight network"

Section 32801 of the bill authorizes a comprehensive truck size and weight limits study to replace the most recent study published in 2000 (USDOT 2000). One component of the study is to "evaluate the impacts to the infrastructure in each state that allows a vehicle to operate with size and weight limits that are in excess of the federal law and regulations, or to operate under a Federal exemption or grandfather right, in comparison to vehicles that do not operate in excess of federal law and regulations (other than vehicles with exemptions and grandfather rights)."

The MAP-21 Significant Freight Positions Overview (2013) highlights the steps to be taken in the comprehensive truck study. MAP-21's provisions call for an assessment of pavement damage in alternate load spectra scenarios as well as an assessment of the cost of adequately maintaining the existing highway infrastructure over time. A heavily discussed alternate scenario is the increase of the GVW for six-axle trucks to 97,000 lbs. MAP-21 initiates will also research the safety and economic consequences of the proposed increase in truck weight limits.

MAP-21 may benefit SHAs by leading to an increase in the share of federal funding of projects to 95% on the Interstate Highway System (IHS), a significant rise from the current federal contribution level of 80% (FHWA 2012). The summation of the comprehensive truck size and weight study is to be reported to the U.S. Congress by October 1, 2014 (FHWA 2013).

2.6 Mechanistic-Empirical Pavement Design Guide Development History

The standards for highway pavement design in the United States are set by the American Association of State and Highway Transportation Officials (AASHTO). The data used in developing practical methodologies for pavement design under the AASHTO design guides have remained essentially unchanged following the American Association of State Highway Officials (AASHO) Road Tests carried out in Ottawa, Illinois in the late 1950s. Based on AASHO Road Test observation, the concept of the equivalent single axle load (ESAL) was introduced as a 'unit of damage' caused by a loaded axle relative to a base

18,000 pound single axle load, which was chosen to represent 1.0 ESALs of damage. Load equivalency factors (LEF) were formulated to translate all loaded axle configurations into ESALs. The LEF are functions of axle loads, axle group type (single, tandem, etc.), loss of serviceability, and pavement parameters (structural number for flexible pavements, and slab thickness for rigid pavements). Combined with average annual daily truck traffic (AADTT) and truck type distribution information, the damage imparted upon a pavement can be expressed as the summation of ESALs of the trucks which used the design lane of a highway during the specified timeframe. The estimated cumulative ESALs during the design life of the pavement is used as a design parameter in the AASHTO pavement design guides through the 1993 guide, allows designers to estimate pavement layer thicknesses (Haider and Harichandran 2007). The first AASHTO Pavement Design Guide was introduced in 1972. Changes to the design methods were made over the years in 1986 and again in 1993. All three of these versions produced a pavement design through empirical methods using the ESAL method. However, these methodologies give little consideration to the engineering properties and load responses of the material through time and seasonal variations in traffic and pavement layer conditions. The methodologies were developed using data conducted in Illinois, and therefore do not account for on-the-ground conditions in all areas of the country. Additionally, the AASHO Road Tests used a limited material selection (and 1950s materials), the testing was accelerated, and low traffic levels were used for the tests (Wooden 2012).

In 1996, the National Cooperative Highway Research Program (NCHRP) initiated Project 1-37a: “Development of the 2002 Guide for the Design of New Rehabilitated

Pavement Structures." The project produced a Mechanistic-Empirical Pavement Deign Guide (MEPDG) in 2004 which is slowly replacing the previous AASHTO design guides for state highway transportation agencies. The MEPDG methodology is wholly different from the previous methodologies which used ESALs and the AASHO Road Test data, and the switch represents a significant technical advance in the field of pavement design and analysis.

The MEPDG methodology uses detailed traffic and vehicle measurements to develop axle load distributions (ALS). Consideration is given to load magnitude and the number of load repetitions imparted on a pavement structure by each axle configuration (single, tandem, tridem, or quad) within each truck class. This information is added to the analysis via axle load distribution factors, which are the percentage of axles carrying a given load by a particular axle load configuration within a particular truck class. The use of axle load spectra also introduces a probabilistic approach to quantifying traffic load over time with appropriate growth consideration, and differentiates unloaded and loaded vehicles in each truck class, which the 1993 guide did not. Additional traffic parameters considered in the MEPDG include vehicle class distribution factors, hourly and monthly truck distribution factors, and growth factors (Ishak et. al 2010). MEPDG can estimate the progression of pavement performance criteria across a pavement's design life. It also uses climate information collected at numerous weather stations across the country, as well as detailed material specifications such as asphalt binder type and subgrade modulus (Daniel et. al 2012). Local climate data is included in the analysis via the Enhanced Integrated Climatic Model (EICM). The distress models built into the MEPDG software analyze the traffic data in the context of changing loads distributions and variable climatic effects such as sun exposure, rain and snow events which affect the ground water table and subgrade properties and create freeze-thaw cycles. The MEPDG methodology is implemented in the AASHTOWare MEDPG.

2.7 MEPDG Traffic Characterization and Axle Load Spectra

The data to create the detailed traffic and axle load distributions can most accurately be obtained from weigh-in-motion (WIM) records. WIM stations are the preferred traffic monitoring system due to the ability to measure axle loads as well as counts. The orientation of the sensors also allows the axle configurations to be determined directly, in addition to yielding more technical axle data including wheelbase and axle spacing. The WIM output data can be easily converted into vehicle class distributions, hourly distribution factors, monthly distribution factors, and axle load spectra for use with the MEPDG software.

The MEPDG also allows for the characterization of traffic data by monthly and hourly distribution factors. A summary of MEPDG traffic input parameters obtainable from WIM data is outlined below (Smith and Diefenderfer 2010):

- Axle Load Spectra (ALS)
- Axle Configurations, Spacings, Wheelbase
- Monthly Distribution Factors
- Hourly Distribution Factors
- AADTT
- Traffic Volume by Vehicle Class

The AASHTOWare MEPDG software uses separate ALS for each vehicle class (4 through 13) and for each month of the year. The axle weight distribution factors are specified for axles within the following weight ranges, and axle weights are grouped based on the corresponding intervals:

- Single Axle 3,000 lbs - 41,000 lbs @ 1,000 lbs
- Tandem Axle 6,000 lbs - 82,000 lbs @ 2,000 lbs
- Tridem/Quad Axle 12,000 lbs – 102,000 lbs @ 3,000 lbs

Unfortunately, WIM stations and other weighing devices are often not installed near a given site or are not cost-effective to implement. To account for practical constraints on the availability of site-specific traffic and soils data, the MEPDG utilizes three hierarchical levels of data input. The general traffic data requirements for Levels 1-3 of input are as follows:

- Level 1: Site-Specific Data
- Level 2: Statewide and Regional Data
- Level 3: Nationwide Data

States can develop calibrated ALS with available WIM data to provide a general traffic characterization for pavement design in a state or region, which facilitates the implementation of the MEPDG software at expense of some accuracy due to local variations in truck traffic characteristics.

2.8 Federal Highway Administration Vehicle Classes with Definitions

Truck classes are defined by the number and spacing of axles on the vehicle and by the configuration of tractor and trailer(s); WIM data can be used to categorize vehicles into their respective classes, or visual counts can be conducted. The FHWA uses a standard 13 category classification system as shown in Figure 2.11.

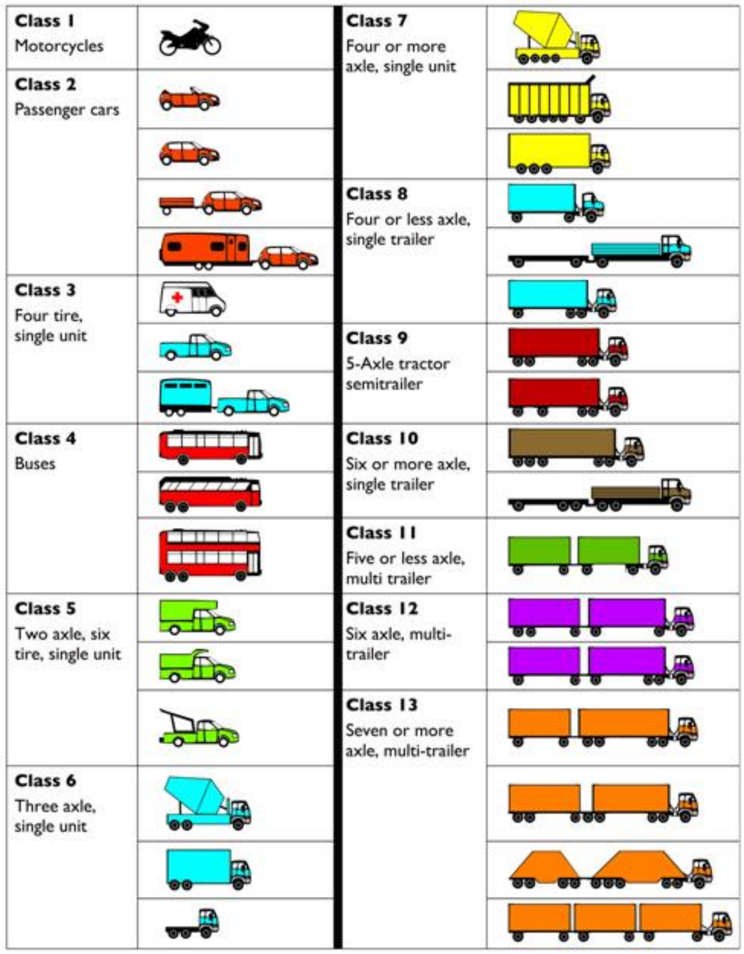


Figure 2.11: FHWA 13 category vehicle **classifications (**Boriboonsomsin 2013**)**

All trucks are considered classes 4 through 13. The typical OSOW trucks are class 10 and thirteen due to the addition of the extra axle or axles.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter describes the research methodology employed in this study. Analysis of oversize/overweight single permit truck traffic in Wisconsin and the identification of heavily trafficked highway segments for field investigation are discussed. In addition, field research conducted to verify traffic data, pavement condition surveys executed, as well as pavement performance analysis using AASHTOWare MEPDG software performed are described in detail.

3.1 Wisconsin Oversize Overweight Trucks Single Trip Permit Database

The Wisconsin Department of Transportation (WisDOT) allows truck carriers to apply for permits when their load exceeds weight and size dimensions. Vehicles with permits to exceed these limits are classified as Oversize/Overweight (OSOW). Vehicles with a GVW of at least 270,000 lbs are classified as superheavy loads (SHL), necessitating a detailed route analysis for bridge and pavement structural capacity and possibly for size or turning restrictions. WisDOT keeps records of all these permits since the department grants permission to the carrier to move the load with a specified route.

Titi et al. (2014) conducted routing analysis of single truck permits in Wisconsin. Six years of permit records were obtained from WisDOT. The original spreadsheets provided by WisDOT contained axle-level records as well as vehicle-level data. After removing duplicate and oversize-only records, approximately 96,000 unique oversize permits encompassing 726,000 axle records remained. Personal communication with WisDOT confirmed that the remaining records could be expected to contain very few duplicates, and also that the dataset represented the full number of single-trip oversize permits issued during the study's six-year scope. The single trip permit records collected range from May 17, 2007 to June 19, 2013. The data obtained spanned 2,221 days (Titi et al. 2014).

Figure 3.1 depicts a Microsoft Excel record for one single trip permit as acquired from WisDOT. Each row in the Excel spreadsheet represents a single axle on a permit vehicle, and contains axle-level as well as vehicle-level data, which is repeated across all axle records. WisDOT grants the carrier a two week window to move the load for single trip permits (Titi et al. 2014).

The routes, dimensions, axle spacing, and axle weights are the most important information available in the dataset for the purposes of pavement analysis. Each row in the dataset included the number of tires per axle and the weigh per axle. The axle spacing was also critical since if the axles were close to one another, they could be a tandem, tridem, or quad configuration. This information allows the axle groupings to be determined, which allows the vehicles to be categorized and provides for the development of ALS. The components of the route information included a start location, end location, and route description.

Report Title

OSOW Permit Number	Permit Class Code	Permit Copy Type Code	Permit Issued Year Number	Permit Effective Date	Permit Expiration Date	Nstd Load Desc	Vehicle Overall Length	Vehicle Overall Width	Vehicle Overall Height	Vehicle Overall Weight	Vehicle Axle Number	Vehicle Axle Tire Count	Vehicle Axle Gross Wgt	Vehicle Axle Spacing	Permit Route Start Location	Permit Route End Location	Permit Roadway Route	Permit Fee Amt
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	1	2	12,000	16.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	2	4	20,000	4.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	3	4	20,000	38.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	4	4	19,000	4.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	5	4	19,000	4.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20112622	S	3	2011	09/19/2011	10/01/2011	FORKLIFT	900.00	108.00	118.00	109,000	6	4	19,000	0.00	MILWAUKEE	IL STATE LINE	START WI-59 W MP MILWAUKI	$45
001CP20113495	S	3	2011	12/16/2011	12/30/2011	CRANE	881.00	105.00	145.00	99,760	1	2	10,000	12.00	MN LINE	MI LINE	START US-8 E MP POLK 0.00	$65
001CP20113495	S	3	2011	12/16/2011	12/30/2011	CRANE	881.00	105.00	145.00	99,760	2	4	15,000	4.00	MN LINE	MI LINE	START US-8 E MP POLK 0.00	$65
001CP20113495	S	3	2011	12/16/2011	12/30/2011	CRANE	881.00	105.00	145.00	99,760	3	4	15,000	36.00	MN LINE	MI LINE	START US-8 E MP POLK 0.00	$65

(a) Original Excel sheet

PermitNumber	Load	IssuedD	Effective	ExpirationDa	FHWA	VLength	VWidth	VHeight	GVW	StartLocatio
001CP20120937	cat 988 loader	4/2/2012	4/2/2012	4/16/2012	10	950	143	186	170000	GREEN BAY

AxleNumbe	Tires	AxleWeight	AxleSpacing	AxleGroup	Click to Add
1	2	14000	16	1	
2	4	22000	4	2	
3	4	22500	4	2	
4	4	22500	35	2	
5	4	22250	4	5	
6	4	22250	4	5	
7	4	22250	5	5	
8	4	22250	0	5	

(b) Access database following vehicle classification and axle grouping

Figure 3.1: Screenshots of single trip OSOW permit records from WisDOT

Titi et al. (2014) developed oversize-overweight truck single trip permit database in Wisconsin (see Figure 3.2). A VBA script was used to categorize vehicles based on FHWA guidelines and the FHWA's recommendation that vehicle classification algorithms be customized to match a project's end use – in this case the creation of data inputs for AASHTOWare MEPDG pavement analysis (FHWA Vehicle Types). The 2012 Census TIGER shapefile of primary and secondary highways was used as the network base layer. The shapefile was processed manually and using ArcGIS tools to fix cartographic errors, combine vertices located within 1,000 feet of each other, and ensure all highway routes were continuous and linear without spurs or loops. The feature names were standardized using VBA to match the highway designation scheme in the WisDOT permits database.

After the processing was complete, a total of 9,026 individual highway segments representing 175 numbered highways remained in the shapefile, with an average segment length of 1.5 miles (Titi et al. 2014). An algorithm was developed to match the route information in the permit dataset to the GIS highways shapefile. The route descriptions of 99% of the permits were successfully matched to the shapefile and are included in this study's analysis. Aggregated permit vehicle data were tabulated for each segment and linked to the shapefile, including the number of permits, number of SHL permits, and cumulative flexible and rigid ESALs.

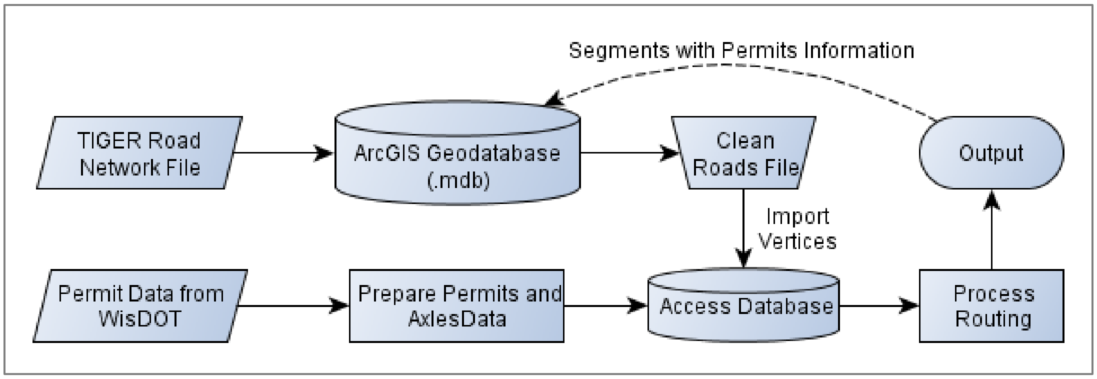


Figure 3.2: Flowchart of the development of the OSOW permit routes analysis (Titi et al. 2014)

3.2 Identification of Highways for Field Investigation

The OSOW single trip permit trucks database was used to identify routes heavily trafficked by OSOW trucks. The output is presented in map with routes that have line thicknesses to indicate the OSOW traffic volume, as depicted in Figure 3.3. The route analysis is discussed further in Chapter 4.

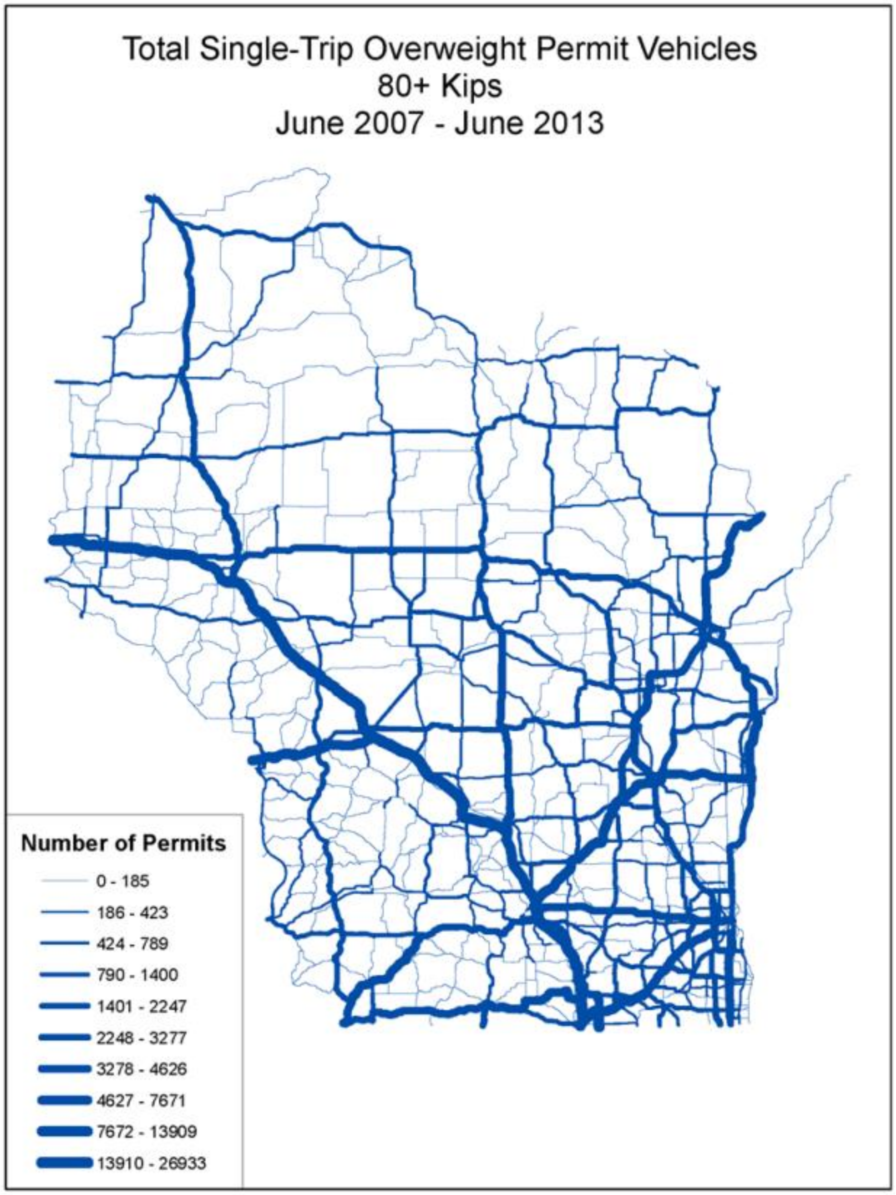


Figure 3.3: Intensity of highways usage by OSOW single trip permit trucks in Wisconsin based on the number of permits issued (Titi et al. 2014)

Based on this analysis, four state trunk highways were identified for field investigation including traffic counting, current pavement condition evaluation, and pavement performance estimation using the AASHTOWare MEPDG software. The selected highways are listed in Table 3.1. The criteria for selecting these highways include ease of site accessibility, ability to provide traffic control and safety of the researchers while performing the field work including visual distress surveys. In addition, these highways exhibited significant levels of distresses and are heavily trafficked by regular and OSOW trucks.

Field work conducted at each highway segment included 6-hour traffic counts and visual distress survey for a representative 150-ft section. The average annual daily truck traffic data was obtained from WisDOT databases. The traffic count process including the observation and characterization of the OSOW trucks in terms of vehicle class, axles, and type of load carried. Figure 3.4 depicts the researchers performing field work at STH 140 south of Clinton.

Table 3.1: Highway and corresponding field work performed at each highway

Highway		**WI-140**	**WI-11**	**WI-23**	**WI-26**
Location		Clinton	Delavan	Plymouth	Waupun
Segment ID		11870	9851	14709	15141
Field Investigation	**Traffic Count**	✓	✓	✓	✓
	Visual Distress Survey	✓	✓	✓	✓
	Rutting Measurement	✓	✓	✓	✓

Figure 3.4: The researchers preforming field work at STH 140

3.3 Mechanistic – Empirical Pavement Performance Evaluation

WisDOT was contacted to obtain information about the pavement typical sections of the four investigated highways. The information provided included pavement rehabilitation history. It should be noted that some information was no longer available in the files due to the age of the pavements. Information pertaining to the pavement layer materials properties, climate conditions, and other inputs needed to the AASHTOWare

MEPDG analysis were obtained from WisDOT and other resources. For examples, information on the resilient modulus of subgrade soils was obtained for Wisconsin Highway Research Program Study by Titi and English (2011).

Mechanistic-Empirical pavement performance evaluation for all investigated highway segments was conducted at the Pavement Research Laboratory at the University of Wisconsin-Milwaukee. Figure 3.5 depicts the workstation that was used to run the analysis. The AASHTOWare MEPDG analysis was conducted using normal traffic load inputs obtained from WisDOT and load inputs that are developed from the OSOW single trip permit trucks plus the normal traffic loads.

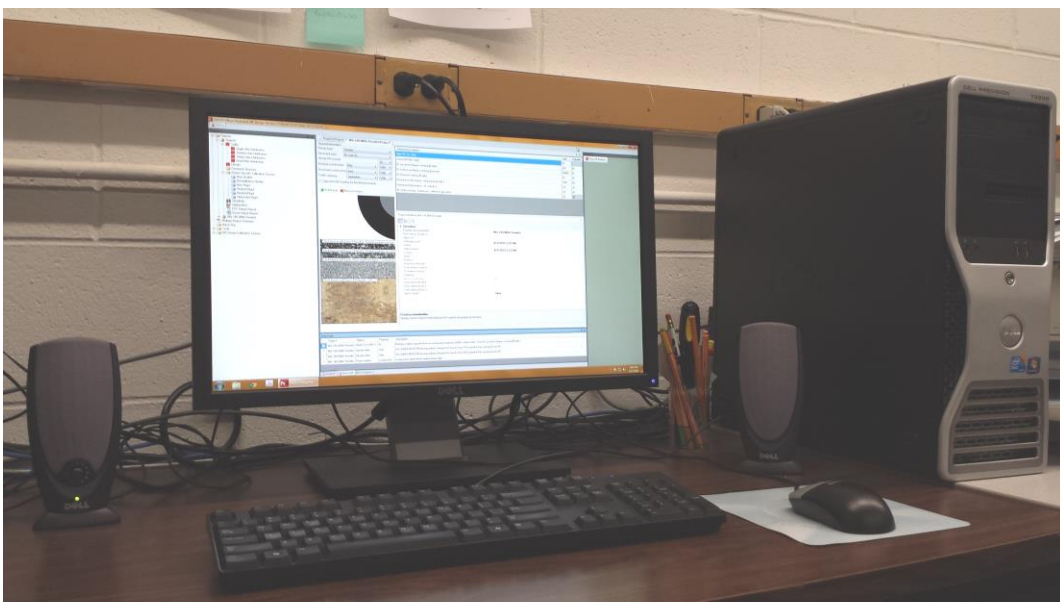


Figure 3.5: The workstation used to perform the AASHTOWare MEPDG at UW-Milwaukee Pavement Research Lab

CHAPTER 4

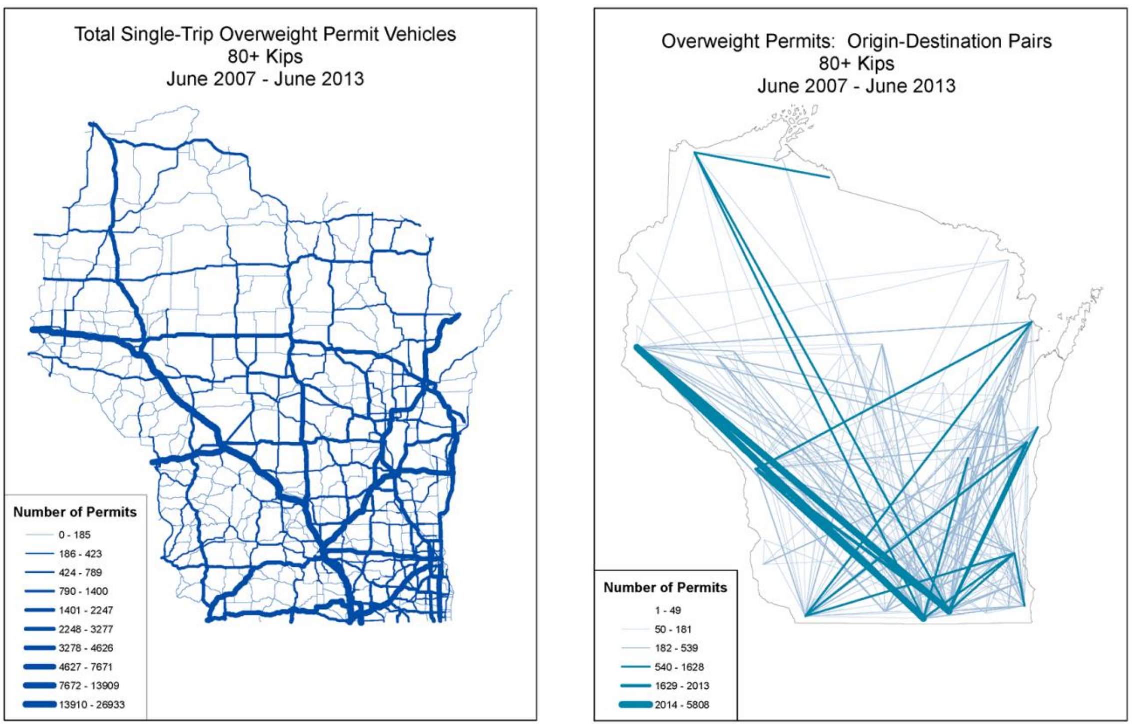
RESULTS AND ANALYSES

This chapter presents the results from the multiphase study conducted on four Wisconsin highway segments heavily travelled by OSOW single trip permit vehicles. Pavement surface visual distress surveys, traffic and OSOSOW truck counts and verification, and evaluation of pavement performance at normal as well as OSOW traffic loads are discussed in detail. A critical analysis and evaluation of the results in terms of pavement performance as predicted by the AASHTOWare MEPDG software in relation to the OSOW traffic load is presented.

4.1 Wisconsin's OSOW Single Trip Permit Truck Database

Titi et al. (2014) and Coley et al. (2014) conducted a comprehensive analysis on OSOW single trip permit truck traffic in Wisconsin. The database used for the analysis contained approximately 96,000 unique single-trip OSOW permit records, representing all single trip overweight vehicle permits issued in Wisconsin from June 2007 through June 2013, a period of 2,221 days. The analysis identified Wisconsin routes used by this traffic as depicted Figure 4.1a. The relative intensity of the OSOW traffic movement on the national and state highway networks is indicated by the thickness of the line representing the highway in the map. Different segments along the same numbered highway may have variable line thickness depending on which parts of the highway were most heavily used by the OSOW trucks. The length of the highway segments used in the analysis generally ranges between one and five miles. For example, the IH 90 is one of the most heavily used highways by OSOW trucks. The types of highways shown in the map are:

the interstate highways (IH), U.S. highways (USH), and state trunk highways (STH). Inspection of the origin-destination map shown in Figure 4.1b demonstrates the existence of significant OSOW truck traffic that moves across the state lines with Illinois, Iowa and Minnesota. Approximately 77% of OSOW permits routes either began or ended in a neighboring state; 33% of OSOW permits began in Wisconsin and ended at the state border, 26% of OSOW permits began at the state border and ended in Wisconsin, and 18% of permits travelled across the state from border to border. The remaining 23% of permit routes both began and ended in Wisconsin.

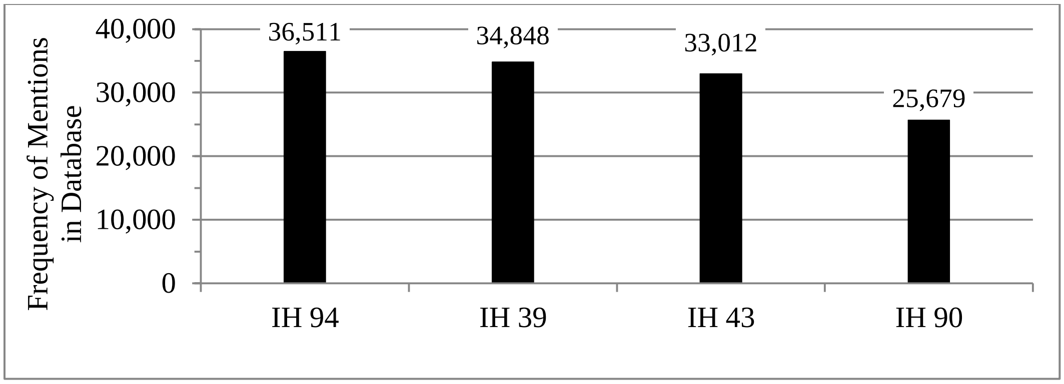


(a) Total number of permits (b) Trip origin-destination

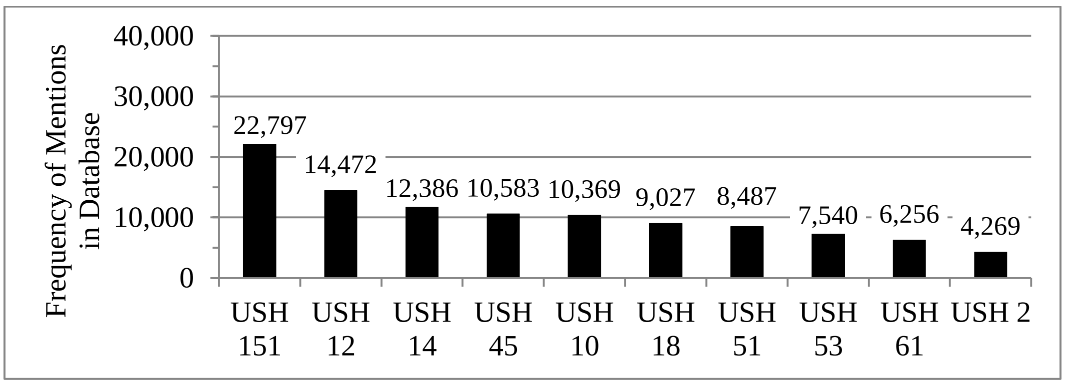
Figure 4.1: Intensity of highways usage by OSOW single trip permit trucks in Wisconsin based on the number of permits issued (Titi et al. 2014).

The analysis of Wisconsin OSOW database identified the highways shown in Figure 4.2 as the most heavily used numbered highways by single trip permit trucks. The frequencies presented in Figure 4.2 represent the number of times a highway is mentioned in the permit routing database regardless of where the permit vehicle travelled along the highway's length. The figure indicates that IHs are generally the most heavily utilized by OSOW trucks followed by the USHs and STHs, which have a comparable level and distribution of OSOW volumes.

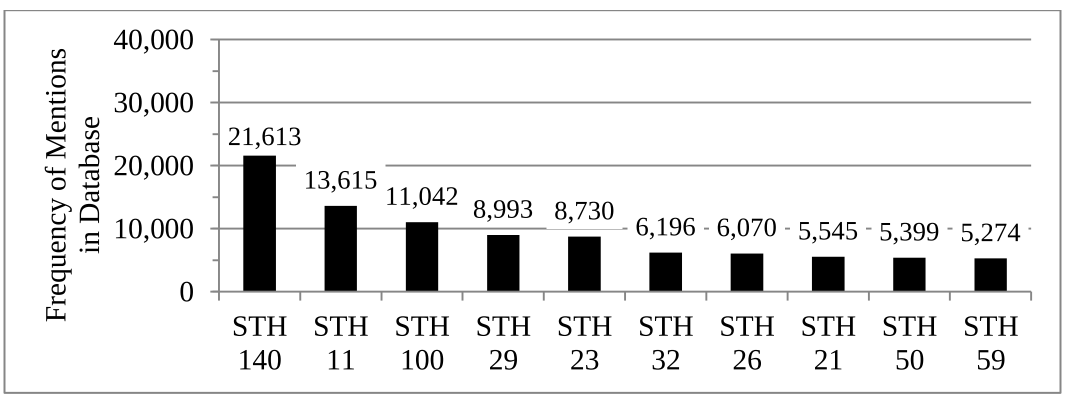
Analysis of the OSOW single trip permit database demonstrated that the vast majority of the trucks are carrying indivisible loads, which is consistent with Wisconsin's permit regulations. The types of these indivisible loads vary from heavy farm equipment, cranes, and excavators to wind turbine components, large beams and trusses, generators, and manufacturing equipment. Figure 4.3 shows the most common categories of commodities transported by OSOW single trip permit trucks in Wisconsin.



(a) Interstate Highways



(b) United States Highways



(c) State Trunk Highways

Figure 4.2: The most heavily trafficked highways in Wisconsin as identified by the OSOW single trip permit database based on the segment frequency (Titi et al. 2014).

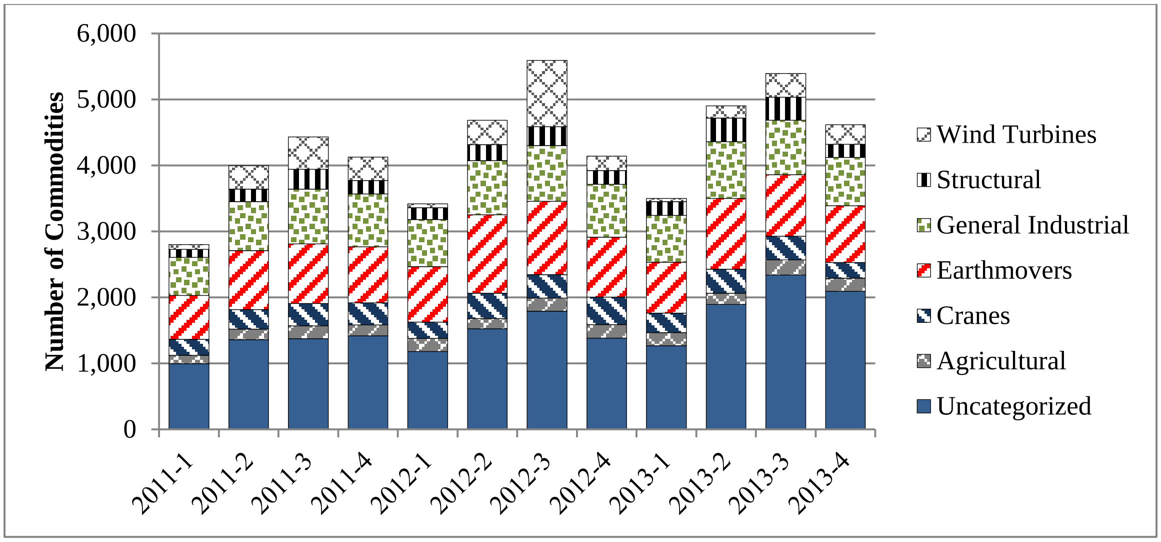


Figure 4.3: Most common commodities moved in Wisconsin using OSOW single trip permit trucks by quarter (after Coley et al. 2014)

The objective of this study is to evaluate pavement condition and estimate pavement performance due to the OSOW single trip permit truck traffic. The results of the route analysis were used to identify and select STHs with significant OSOW truck traffic for field investigation, which are presented in Table 4.1 and shown on the map in Figure 4.4. The primary selection parameters included high levels of OSOW traffic, site accessibility, and the ability to provide traffic control and safety for the researchers while performing the visual distress surveys. In addition, these highways exhibited significant levels of distresses and are heavily trafficked by regular and OSOW trucks.

STH 140 was identified as a unique route for OSOW trucks with 21,294 permits during the six-year dataset timeframe; this number is more than three times the number of permits issued for the second highest used route, STH 23, with 5,951 permits. The number of SHL permits is also presented in Table 4.1, which is a very small fraction of the total number of permits issued. STH 140 also experienced the largest number of SHL permits with a total of 103 over six years.

Table 4.1: State trunk highways with significant records of OSOW single trip permits selected for pavement performance investigation.

Highway	STH 140	STH 11	STH 23	STH 26
Total number of OSOW permits issued (GVW> 80,000 lb.)	21,294	4,778	5,951	3,684
Average number of permits per day	9.59	2.15	2.68	1.66
Number of SHL permits (GVW $\geq$ 270,000 lb.)	103	29	13	12
Percent of permits that are SHL (%)	0.48	0.61	0.22	0.33

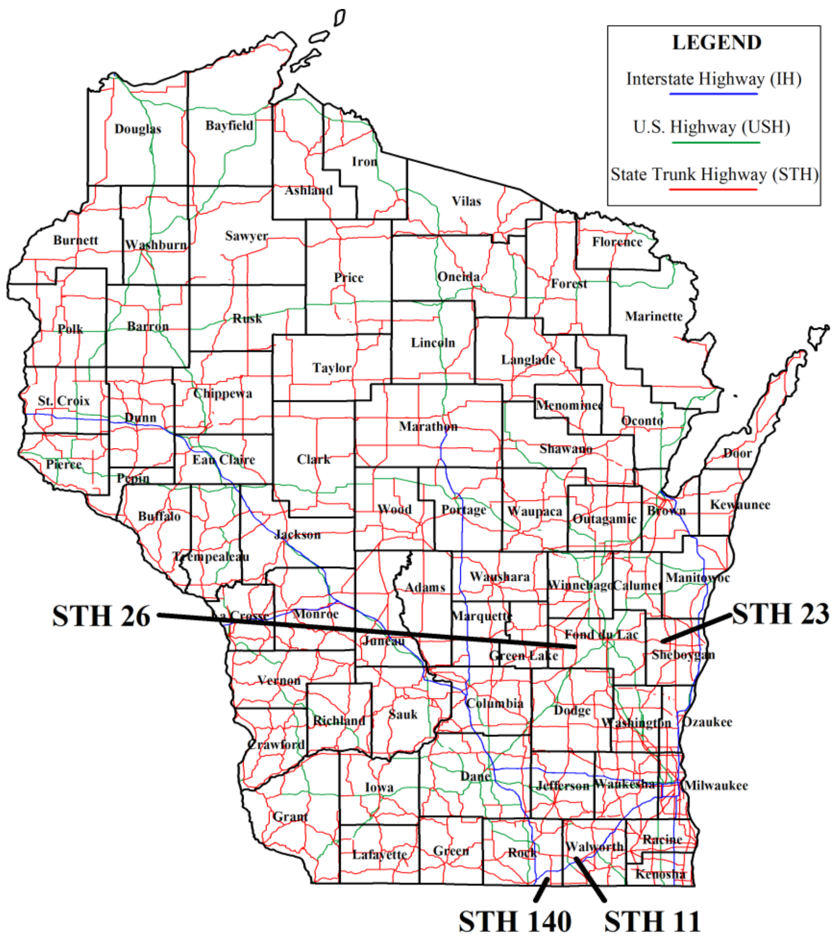


Figure 4.4: Location of highways selected for field investigation.

4.2 Field Investigation

Comprehensive field work was conducted on the four selected highway segments to evaluate the current condition of the pavement surface and provide a verification/observation to the OSOW single trip permit trucks reported in the database.

4.2.1 Traffic Characterization

State Trunk Highway 140

As shown in Figure 4.2, STH 140 is a 12 mile north-south highway beginning at the Illinois border in southern Wisconsin as an extension of Illinois state highway IL 76, intersecting IH 43 at milepoint 5, and terminating at STH 11. It is roughly five miles east of IH 90/IH 39, a major interstate corridor and a toll road in Illinois with the first toll station located four miles south of the Illinois-Wisconsin border. The route analysis shows that the majority of permit trucks crossing the Illinois-Wisconsin border at IH 90/IH 39 and STH 140 choose STH 140, as depicted in Figure 4.1. Of the 35,648 total permits in the dataset, which crossed Illinois-Wisconsin border using either highway, 21,294 (59.7%) used STH 140, while only 14,354 (40.3%) used IH 90/IH 39. Although weight and size restrictions at the toll plazas may account for some of these diversions, an informal sample of the dataset demonstrated that many significantly OSOW vehicles used IH 90/IH 39 across the dataset’s timeframe, suggesting that size and weight limitations on IH 90/IH 39 were not the cause of the diversions. Rather, the STH 140/IL 76 route provides a bypass around the IH 90/IH 39 tollway, a slightly shorter route to the Chicago metro area, and also a rural route with fewer passenger vehicles and easier access to Illinois and local highways compared with the tollway.

Field work at STH 140 consisted of two trips; in the first one, a pavement surface visual distress and traffic count survey were conducted, while the second trip only included a traffic count. The primary purpose of the traffic counts was to verify the trend of abnormally high OSOW truck traffic observed in the permit database and. The first trip was a preliminary 2.5-hour traffic count, which provided a rough description of the segment's truck traffic and confirmed the high number of trucks and visually identifiable permit vehicles utilizing this segment. Out of 337 vehicles counted, 103 were visually identified as FHWA classes 4 through 13 (30.6% truck), much higher than expected on a typical rural state highway. 11 of the trucks (11% of trucks) were marked as oversize loads and may also have been overweight. The second trip was a 6-hour traffic count and generated similar results as the first trip. A total of 779 vehicles were counted, and 264 (33.89% truck) were trucks, with 14 visibly identifiable as oversize and possibly overweight (5.3% of trucks). The traffic count data is summarized in Table 4.2.

Table 4.2: Traffic count at the investigated STHs for a duration of 6 hours

FHWA Vehicle Class	STH 140			STH 11			STH 23			STH 26		
	SB	NB	Total	WB	EB	Total	WB	EB	Total	SB	NB	Total
1	0	1	1	0	0	0	0	0	0	1	1	2
2	172	212	384	286	335	621	509	596	1105	760	790	1550
3	64	66	130	247	191	438	160	181	341	155	200	355
4	2	0	2	6	3	9	0	4	4	2	7	9
5	22	3	25	28	30	58	64	37	101	62	65	127
6	20	23	43	28	27	55	17	14	31	13	18	31
7	3	2	5	4	6	10	4	9	13	0	7	7
8	2	1	3	0	3	3	3	4	7	2	3	5
9	74	90	164	23	16	39	144	157	301	317	320	637
10	4	6	10	6	1	7	3	2	5	4	4	8
11	3	2	5	0	0	0	1	3	4	0	1	1
12	1	3	4	0	0	0	1	0	1	0	0	0
13	2	1	3	1	0	1	0	1	1	0	1	1
Total	369	410	779	629	612	1,241	906	1,008	1,914	1,316	1,417	2,733

Farm equipment was also observed using this segment during the traffic counts; 10 large farm implements – tractors and combines – were observed during the second count. Figure 4.5 depicts two of the OSOW trucks that were observed traveling along the highway during the field investigation. Both trucks have eight axles, confirming them as OSOW trucks. In addition, Figure 4.5 depicts four of the large farm equipment trucks observed travelling on the highway. A number of these trucks are wide enough that their wheels were travelling on the paved shoulder and sometimes at edge of the paved shoulder.

WisDOT assigns a functional classification for all state highways, which depends on the traffic volumes as well as the population density in the surrounding areas. The Average Annual Daily Traffic (AADT) obtained from a volume count site on STH 140 was 3,175 vehicles/day (WI TOPS 2014). With such low traffic volumes, this specific segment of STH 140 is classified as a rural minor arterial. A vehicle class distribution (VCD) was calculated through the 6-hour traffic count for STH 140; in addition, a typical VCD for this functional class of highways was obtained from WisDOT (WisDOT 2008). A comparison of the VCD obtained from the field traffic count with the VCD obtained from WisDOT is presented in Figure 4.6. The field count showed higher traffic levels for class 9 trucks, but lower levels for class 8 trucks when compared to the WisDOT typical VCD. The field count also confirmed the presence of class 10 and class 13 truck traffic, which are usually used to move OSOW loads. To verify the OSOW permit volumes on this highway, the expected daily rate of permit vehicles was compared with the observed number of visibly OSOW vehicles from the traffic counts. The total number of overweight permits issued for this segment over 6 years was 21,294, approximately 10 trucks per day. This is consistent with the field investigation count of 11 trucks during the first count and 14 trucks during the second count, considering that not all visibly oversize vehicles were also overweigh. Table 4.3 presents a comparison of general truck traffic data obtained by the field counts and data reported by WisDOT for STH 140 and the other investigated highways.

Table 4.3: Traffic characterization of the investigated STHs

Highway		**STH 140**	**STH 11**	**STH 23**	**STH 26**
Functional Class		Rural Minor Arterial	Rural Minor Arterial	Rural Principal Arterial	Rural Principal Arterial
AADT	Count	3,175	3,102	7,443	6,952
	Vehicle Counter Type	Volume	Volume	Volume	Class
	WisDOT Site Number	530266	640107	591422	200124
AADTT	% Trucks Counted in Field	33.89	14.67	24.45	30.22
	% Trucks from Nearest WisDOT Site (Year)	15.41 (2006)	11.03 (2006)	18.09 (2000)	31.10 (2007)
	Approximate Distance to WisDOT Site (mi)	5	15	< 1	< 1
	% Trucks used for Analysis	20	12	18.1	31.1
	Daily No. of Trucks for AASHTOWare MEPDG	635	372	1,346	2,162

Figure 4.5: Observed OSOW and farm equipment trucks travelling on STH 140 during field investigations.

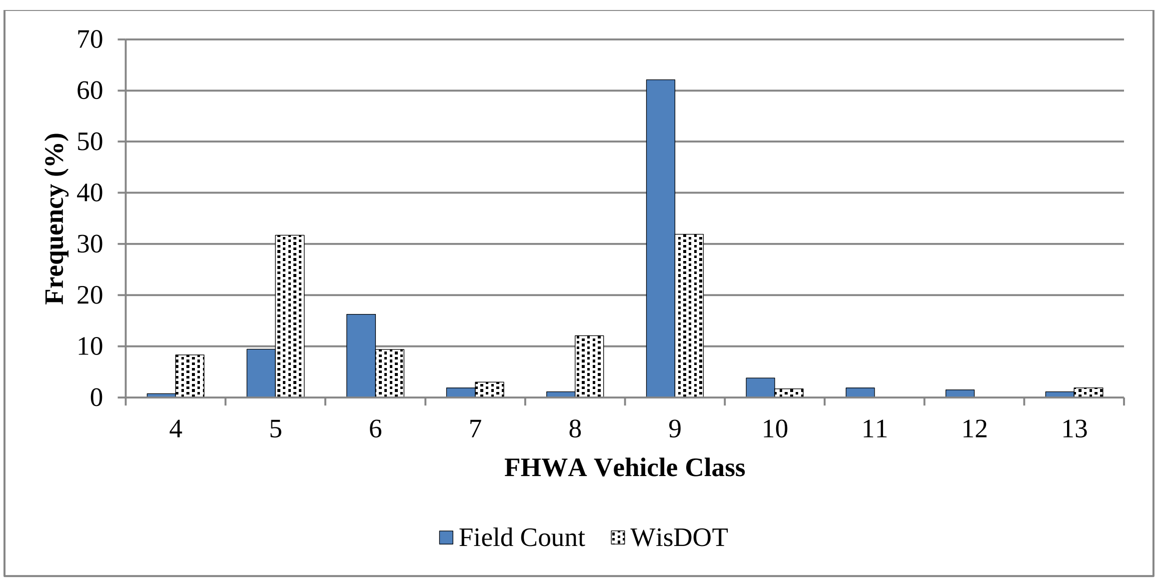


Figure 4.6: Comparison of VCD obtained from traffic count at STH 140 and WisDOT VCD for rural minor arterial

State Trunk Highway 11

The second route selected for analysis is STH 11, a 158 mile long highway crossing Wisconsin east to west in the southern portion of the state. The highway begins in Racine and stretches west to the southwest corner of the state, merging with USH 151/USH 61 just before entering Dubuque, Iowa (Bessert 2009). As shown in Figure 4.2, USH 151 is the most heavily used USH in Wisconsin by OSOW single trip permit trucks. STH 11 potentially has a high amount of trucks due to the intersection with USH 151. Figure 4.2 also shows that STH 11 is the second most used route by the single trip OSOW trucks. One of the most heavily used highway segments by the OSOW trucks along the 158 mile stretch of STH 11 is in the vicinity of Delavan. The segment on STH 11 selected for analysis is located between STH 89 and STH 50. Table 4.1 shows that for this STH 11 segment, a total of 4,778 OSOW single trip permits were issued over the 6 years of records (35% of total permits on any segment of STH 11), with a daily volume of 2.15 trucks per day. 29 of the permits were for SHLs.

The results of the 6-hour traffic count at STH 11 are summarized in Table 4.2. A total of 1,241 vehicles were counted of which 182 were identified as FHWA classes 4 through 13 (14.67% truck), which is consistent with WisDOT traffic counts (see Table 4.3). The majority of the trucks were classes 5 and 6 (single unit trucks). Field work also demonstrated the presence of OSOW single trip permit traffic where three trucks were observed, which is consistent with the average number of OSOW trucks permitted on this segment from the database (2.15 per day). Seven trucks were class 10 vehicles, which are often heavier than 80,000 lb due to the addition of the sixth axle. Figure 4.7 depicts two of the OSOW trucks that were observed traveling along the highway during the field investigation. The first truck has 13 axles while the second has seven, confirming them as OSOW trucks.

The AADT obtained from a volume count site on STH 11 was 3,102 vehicles/day (WI TOPS 2014), classifying the highway as a rural minor arterial. The vehicle class distribution was calculated through the 6-hour traffic count for STH 11 and compared with the VCD obtained from WisDOT in Figure 4.8.

Figure 4.7: Observed OSOW trucks traveling on STH 11 during field investigations

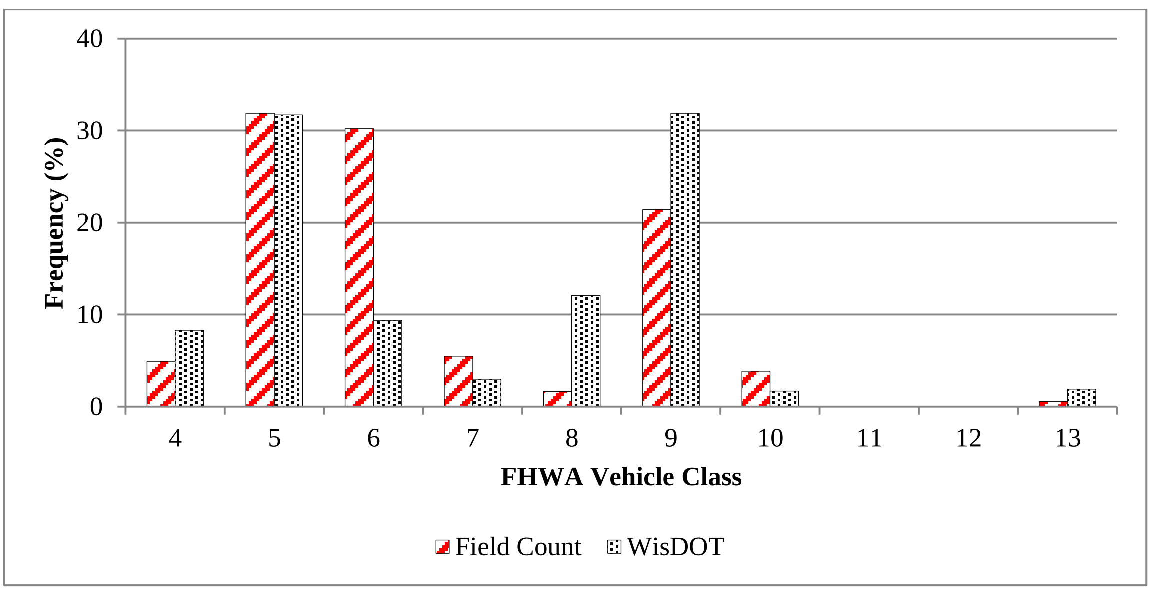


Figure 4.8: Comparison of VCD obtained from traffic count at STH 11 and WisDOT VCD for rural minor arterial

State Trunk Highway 23

The third route selected for analysis is STH 23, which is approximately 211 miles long running east and west in the central portion of the state then changing direction southbound ending near the Wisconsin-Illinois border. The highway begins in Sheboygan and ends at the junction of STH 11 in Darlington (Bessert 2009). STH 23 is the fifth most used route for the single trip OSOW trucks on state trunk highways in Wisconsin, as shown in Figure 4.2. One of the most heavily concentrated segments of the OSOW trucks along the 211 mile stretch was in Plymouth, east of the junction of STH 57 and STH 23. Table 4.1 shows that the segment was exposed to 5,951 OSOW trucks over the 6 years of records (68% of total permits on any segment of STH 23), with approximately 2.68 trucks per day. Thirteen of the OSOW permitted trucks were SHLs, the fewest of all the state trunk highways investigated.

Summarized in Table 4.2 are the results of the 6-hour traffic count for STH 23. Out of 1,914 vehicles counted over the six hours, 468 vehicles were identified as FHWA classes 4 through 13 (24.45% truck). The nearest WisDOT traffic count site had a truck percentage of 18.09% as seen in Table 4.2, slightly less than the field count of 24.45% (WisDOT 2008). The majority of trucks observed were class 9. Three of the trucks were marked as OSOW, which is consistent with the average number of OSOW trucks traveling on this segment obtained from the database (2.68 per day). Five trucks were class 10. A class 13 truck was also observed, which can also be assumed to be an OSOW vehicle.

The AADT obtained from a volume count site on STH 23 was 7,443 vehicles/day (WI TOPS 2014), classifying the highway as a rural principal arterial. The vehicle class distribution was calculated through the 6-hour traffic count for STH 23 and compared with the VCD obtained from WisDOT in Figure 4.9.

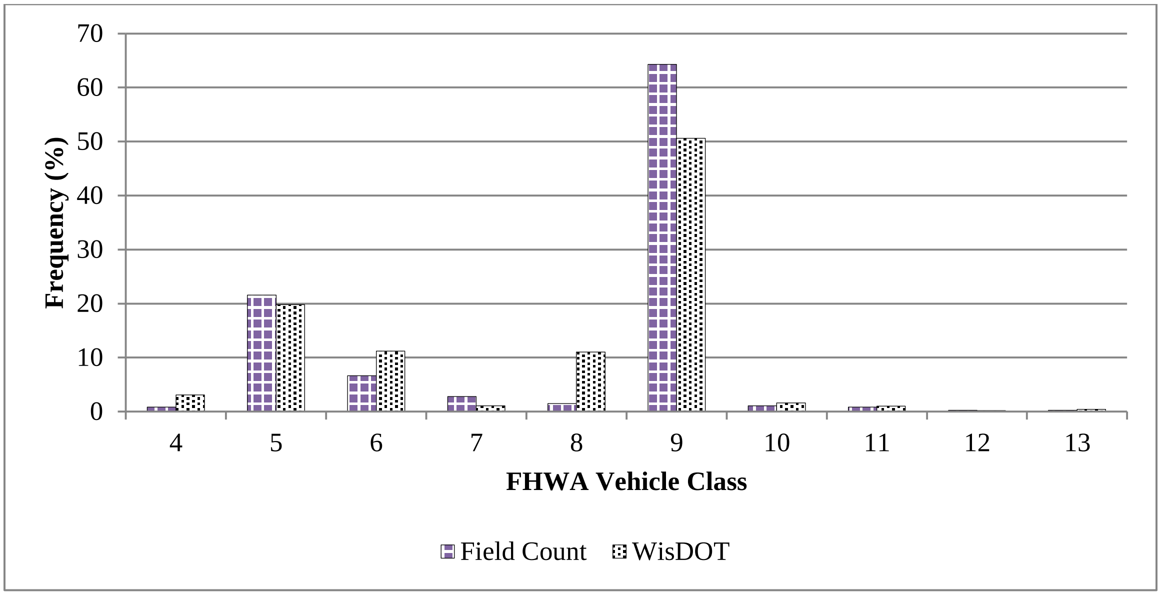


Figure 4.9: Comparison of VCD obtained from traffic count at STH 23 and WisDOT VCD for rural principal arterial

<u>State Trunk Highway 26</u>

The final route selected for analysis is STH 26, which is 98 miles long crossing Wisconsin north to south in the east central portion of the state. The highway begins near Janesville and ends at USH 41 south of Oshkosh (Bessert 2009). Figure 4.2 shows that STH 26 ranks as the seventh most used route for the single trip OSOW trucks in Wisconsin. One of the most heavily used segments by the OSOW trucks was identified near Waupun. This segment of STH 26 is considered a shortcut for trucks traveling north on USH 151. USH 151 is a heavily trafficked route and joins with USH 41, which leads to Oshkosh and Appleton. Trucks travelling north will have to use USH 151 east, then travel west on USH 41, which is longer than the shorter the route via STH 26. The STH 26 segment analyzed is located between USH 151 and STH 23. Table 4.1 shows that the segment was used by 3,684 OSOW trucks over the 6 years or records (61% of total permits on any segment of STH 26), with approximately 1.66 trucks per day. 29 of the OSOW trucks were SHLs.

During the 6-hour traffic count, 2,733 vehicles were observed of which 826 were identified as FHWA classes 4 through 13 (30.22% truck). Truck percent from the traffic count is consistent with the number published by WisDOT (31.10%) (WisDOT 2008). Over 75% of the trucks were class 9. Seven trucks were marked as OSOW, which is much higher than the average of 1.66 OSOW truck/day obtained from the permit database. Eight trucks were class 10. There was also a class 13 truck which can also be assumed to be OSOW. The results of traffic count for STH 26 are summarized in Table 4.2. Figure 4.10 depicts the largest OSOW truck observed on STH 26 during the field investigation. It is a seven axle class 10 truck carrying a large piece of construction equipment.

Figure 4.10: Observed OSOW trucks traveling on STH 26 during field investigations.

Based on AADT obtained for STH 26, which is 6,952 vehicles/day (WI TOPS 2014), the highway is classified a rural principal arterial. The vehicle class distribution was calculated from the 6-hour traffic count for STH 26 and compared with the VCD obtained from WisDOT in Figure 4.11.

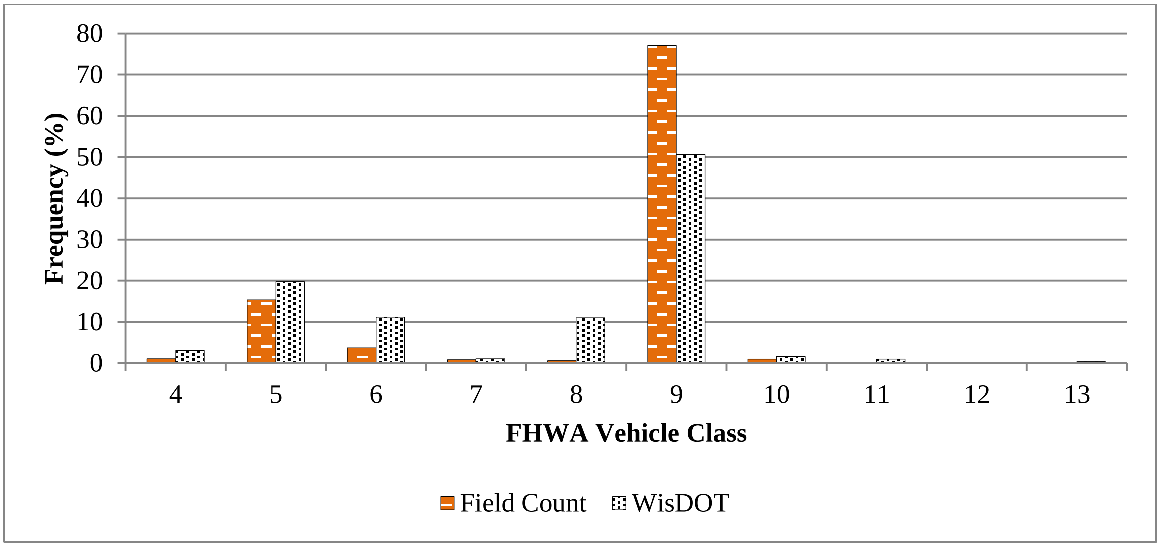


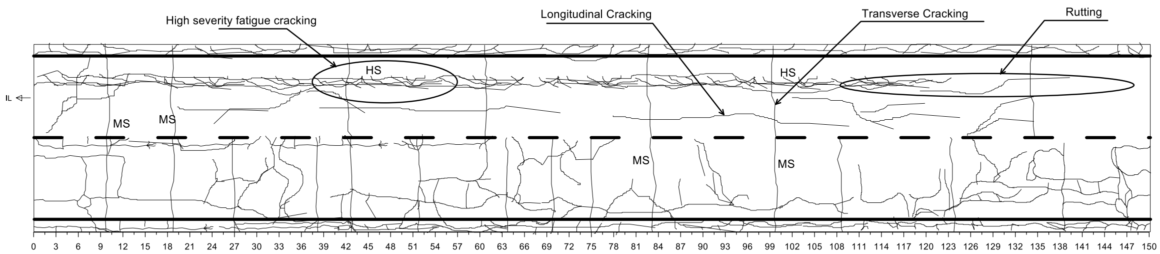
Figure 4.11: Comparison of VCD obtained from traffic count at STH 26 and WisDOT VCD for rural principal arterial

4.2.2 Pavement Condition Evaluation

The visual distress survey performed on the 150-ft section representing the current pavement condition of STH 140 is depicted in Figure 4.12a. The pavement surface distresses include fatigue cracking of high and medium severities, medium and high severity longitudinal and transverse cracking, raveling, potholes, polished aggregate, edge cracking and rutting. Figure 4.12b depicts the pavement surface showing majority of the observed distresses. In order to further emphasize the level of pavement surface deterioration, the measured pavement surface rutting in the wheel path is depicted in Figure 4.13a and a contour map of rutting within the test section is presented in Figure

4.13b. Pavement surface rutting measured in the outside wheel path varies between 0.2 and 1.0 in, which is larger than rutting measured in the inside wheel path which ranges from 0.0 to 0.25 in.

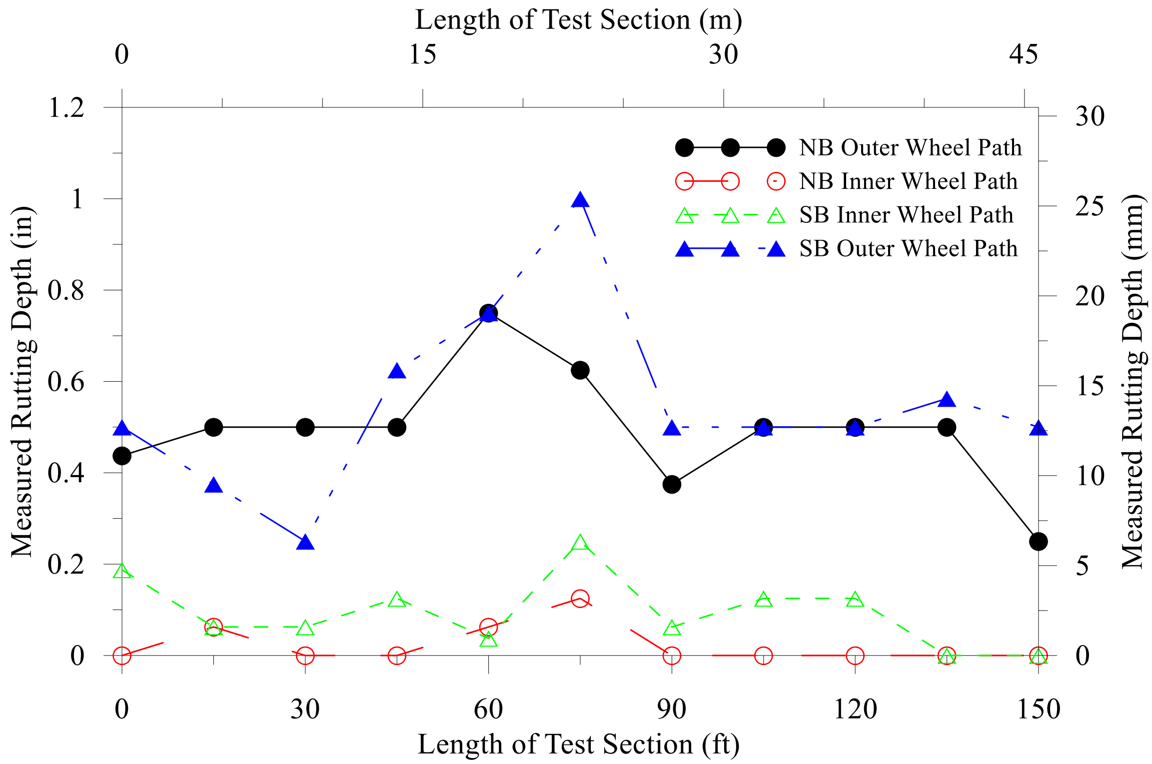
The survey was conducted in accordance with ASTM D6433: "*Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys,"* in order to calculate the pavement condition index (PCI) for this section, which is assumed to represent the condition of STH 140. Pavement distress data was analyzed using the computer program MicroPAVER and the corresponding PCI values were calculated. Table 4.4 presents a summary of the measured distresses, the calculated PCI values, and the corresponding pavement condition classification for all investigated highway including STH 140. Inspection of Figure 4.12 and Table 4.4 demonstrates the presence of significant deterioration of the pavement within the driving lanes as well as within the shoulder. For example, the area of fatigue damage was measured as 12.7%, and the maximum measured rutting was 1.0 in. The calculated PCI values of the investigated section are 13 for NB and 17 for SB lanes, which classifies the pavement condition as seriously deteriorated, as can be seen in the pictures shown in Figure 4.12b. It should be noted that for all investigated highways in this research, no profile measurements were taken or obtained from previous records. All results and measurements presented herein are based on a 150-ft section of each that was considered as representative of the investigated highway segments.



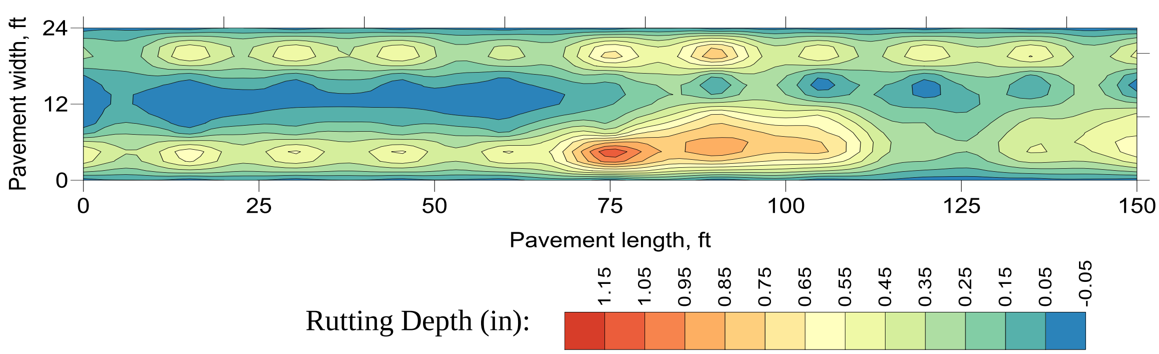
(a) Map of the observed distresses

(b) Picutres of variuos pavement surface distresses

Figure 4.12: Pavement surface distresses observed on STH 140 (HS: high severity; MS: medium severity)



(a) Variation of rutting with distance



(b) Contour of measured rutting

Figure 4.13: Rutting measured on the wheel path along the 150-ft investigated pavement section on STH 140

Table 4.4: Summary of the pavement distress surveys conducted on the investigated STHs

Pavement Surface Distress		STH 140	STH 11	STH 23	STH 26
Fatigue Cracking (%)		12.7	7.6	4.1	10.2
Total Length of Longitudinal and Transverse Cracking (ft)	High Severity	173	35	10	156
	Medium Severity	396	335	110	408
	Low Severity	82	102	143	93
Max Rutting Depth Measured (in)	Outer Wheel Path	1.00	0.82	0.38	1.25
	Inner Wheel Path	0.31	0.88	0.50	0.56
Pavement Condition Index (PCI)	Direction (NB or EB)	13	40	63	14
	Direction (SB or WB)	17	52	66	15
PCI Rating	Direction (NB or EB)	Serious	Very Poor	Fair	Serious
	Direction (SB or WB)	Serious	Poor	Fair	Serious

The pavement surface of STH 11 exhibited various types of distresses as depicted in Figure 4.14. Distresses of a selected 150-ft section representative of the highway investigated segment are mapped and presented in Figure 4.15a. In addition, measured rutting on the wheel path of the inside and outside wheel paths for both lanes was measured along the 150-ft section and plotted in Figure 4.15 b. The maximum measured rut depth is 0.88 in for the inside wheel path, while the minimum rut depth measured is 0.44 in. STH 11 pavement surface condition was described as very poor to poor based on the calculated PCI values of 40 and 52.

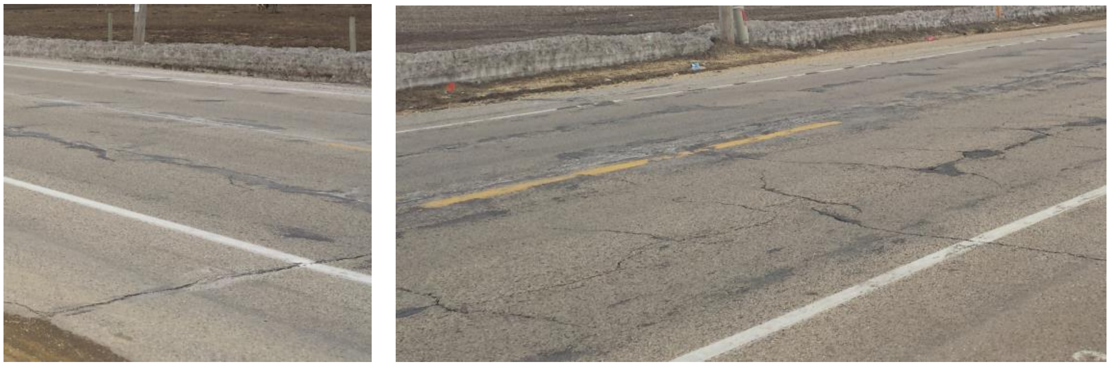
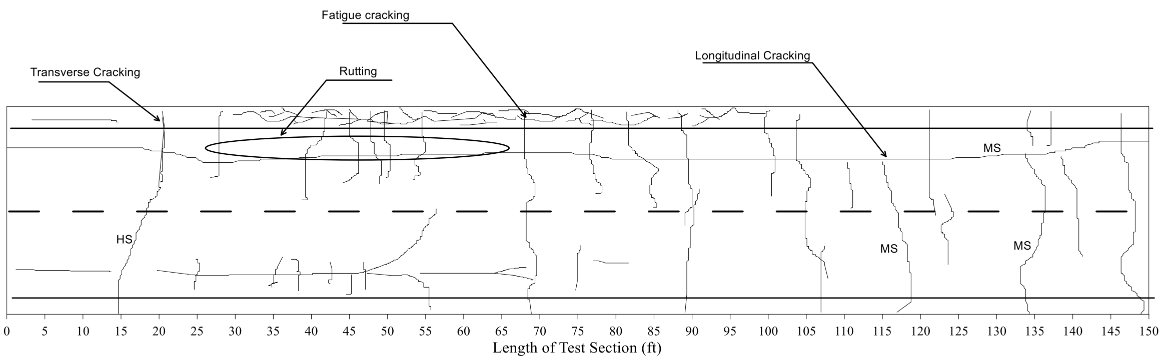
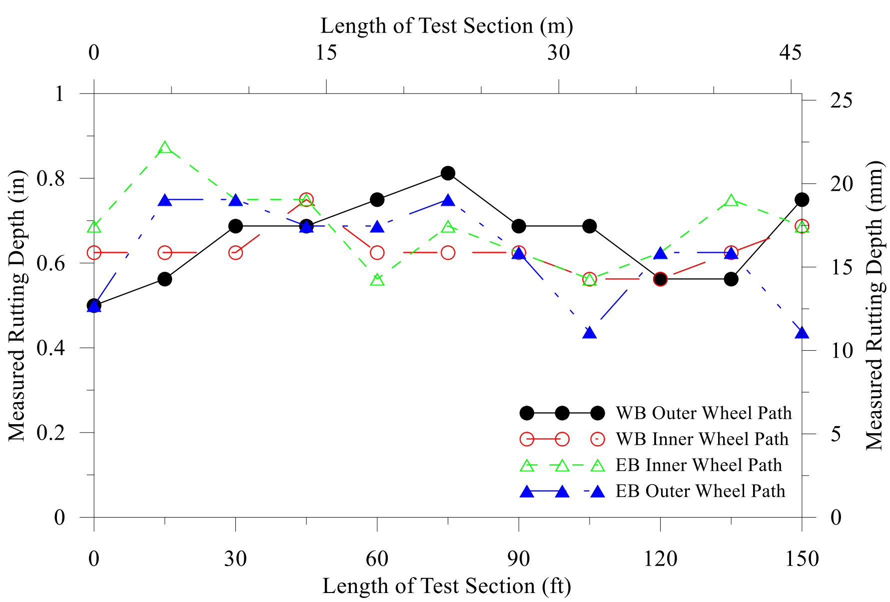


Figure 4.14: Pavement surface distresses observed on STH 11



(a) Map of the observed distresses

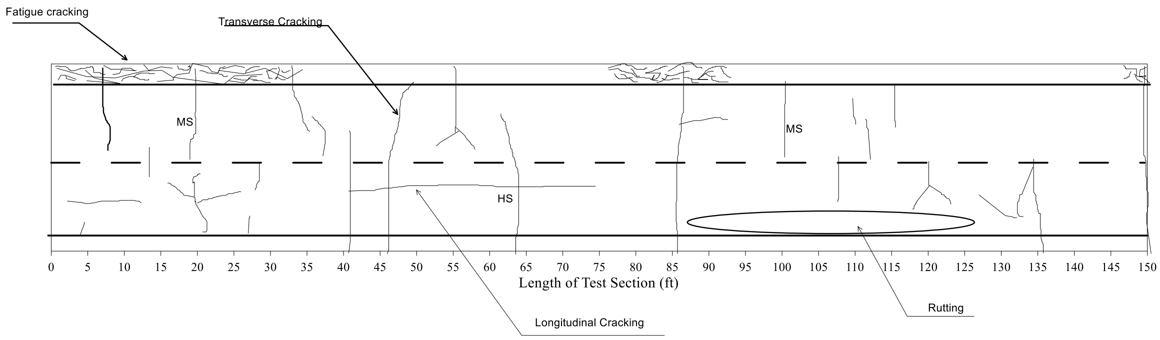


(b) Variation of rutting with distance

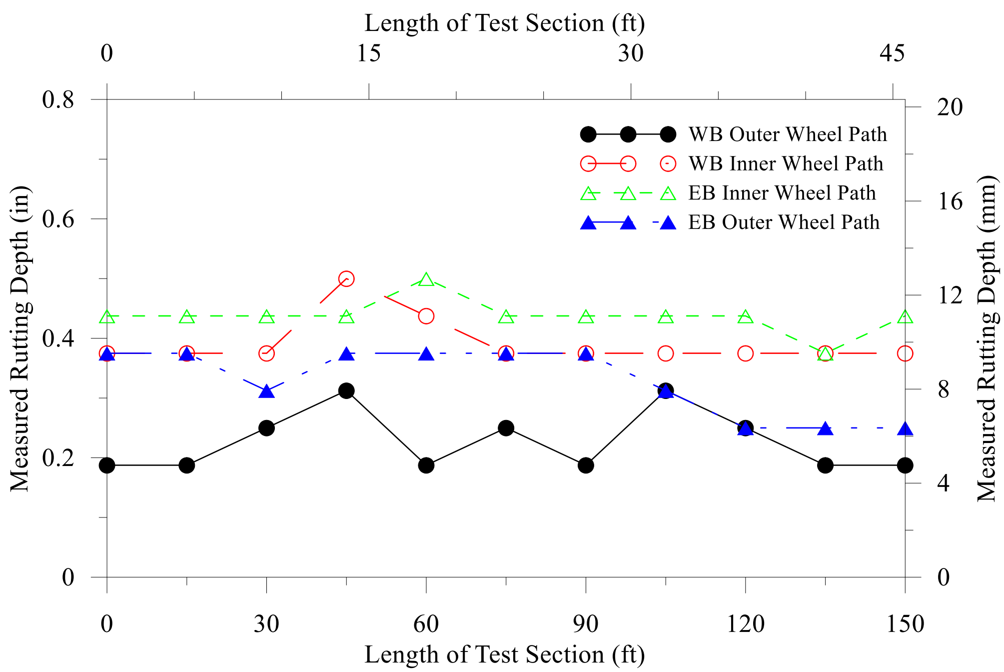
Figure 4.15: Pavement surface distresses observed on a representative 150-ft section on STH 11 (HS: high severity; MS: medium severity)

Figure 4.16 shows the various distresses observed on STH 23. High, medium, and low severity cracks were observed among other distresses mapped from a 150-ft section and depicted in Figure 4.17a. The measured rut depth on the wheel path varies between 0.19 and 0.50 in as shown in Figure 4.17 b. The calculated PCI values for STH 23 are 63 and 66 rating the pavement surface as fair. Compared with the other investigated state trunk highways, STH 23 had the least distressed pavement surface.

Figure 4.16: Pavement surface distresses observed on STH 23



(a) Map of the observed distresses

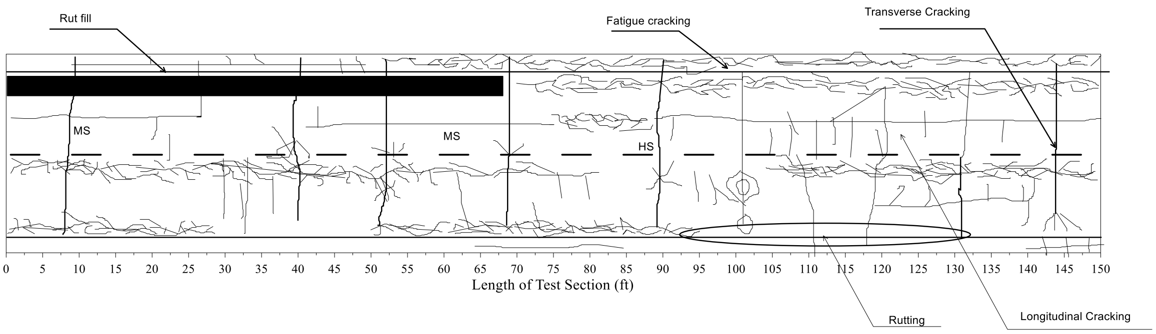


(b) Variation of rutting with distance

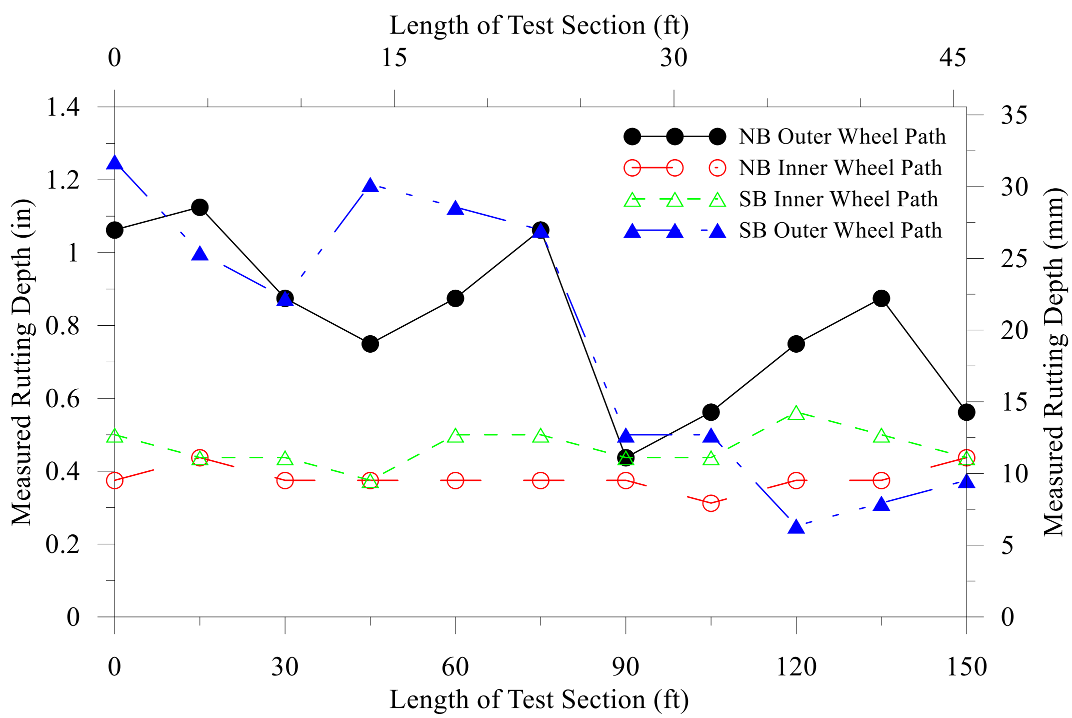
Figure 4.17: Pavement surface distresses observed on a representative 150-ft section on STH 23 (HS: high severity; MS: medium severity)

The pavement surface condition at the investigated segment of STH 26 showed the most deterioration among the investigated highways. As shown in Figure 4.18, significant cracking, raveling, and rutting were observed. The total length of longitudinal and transverse cracks of high and medium severity, measured in a 150-ft section, was 156 and 408 ft, respectively. Rut depth was also the highest among all investigated sites with a range of 0.25 to 1.25 in. Figure 4.19a presents a map of the various distresses observed on 150-ft section on STH 26 and Figure 4.19b shows the variation of pavement surface rut depth along the surveyed section. Based on PCI calculated values of 14 and 15, STH 26 was rated as serious with respect to pavement surface condition.

Figure 4.18: Pavement survey distresses observed on a representative 150-ft section on STH 26.



(a) Map of the observed distresses



(b) Variation of rutting with distance

Figure 4.19: Pavement surface distresses observed on a representative 150-ft section on STH 26 (HS: high severity; MS: medium severity)

4.3 Mechanistic-Empirical Pavement Performance Evaluation

The pavements at the four investigated STHs exhibited various levels of distresses that ranges between poor and serious based on the visual distress surveys of a representative 150-ft section and the corresponding PCI values. During the course of conducting the research project, data and information were obtained and included traffic from regular vehicles/trucks as well as single trip permit OSOW trucks, pavement typical sections, rehabilitation history since construction and climate conditions in the areas of close proximity to the highways. The data was used in the AASHTOWare MEPDG software to estimate pavement performance under normal traffic loads (termed as baseline traffic herein) and under normal traffic plus single trip permit OSOW truck loads to assess the long term pavement performance and to attempt to quantify pavement damages/deterioration resulting from the single trip permit OSOW truck loads.

4.3.1 Axle Load Spectra for Normal and Single Trip Permit OSOW Trucks

Axle load spectra are among the main input parameters for AASHTOWare MEPDG design and analysis. WisDOT developed ALS for normal (baseline) traffic in Wisconsin. The ALS developed by WisDOT is a Level 2 statewide input, which can be used as a baseline traffic input for pavement analysis. The axle load spectra provided by WisDOT for statewide traffic are shown in Figure 4.20. The single axle load distributions are generally centered around 12,000 lbs, the tandem axle distributions between 20,000 and 34,000 lbs, the tridem axle distributions between 30,000 and 55,000 lbs, and the quad axle distributions between 40,000 lbs and 70,000 lbs.

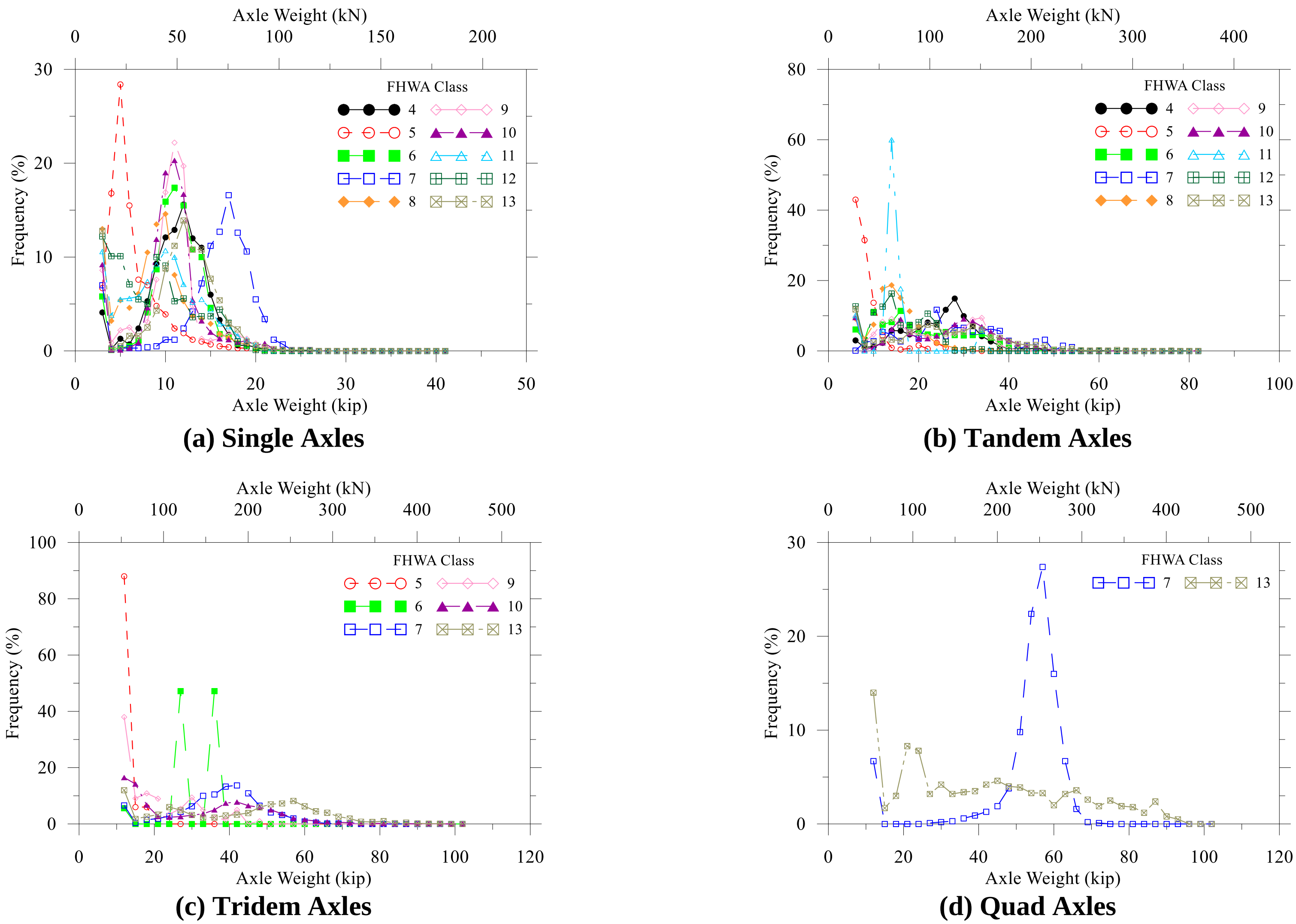


Figure 4.20: Baseline statewide axle load spectra provided by WisDOT.

In order to account for loads from OSOW single trip permit trucks, ALS from the permit database needed to be integrated with the Wisconsin baseline ALS for each of the investigated highways. The ALS for OSOW trucks were created in the database through the information provided by the single trip permit records. Queries were created in the database by isolating the specific highway segments where the site investigations were conducted. The query provided the number of axle occurrences based on the load, vehicle class, and configuration over the investigated period (i.e. 2,221 days).

Figure 4.21 illustrates the process of how the ALS and traffic data for the baseline traffic and OSOW traffic were merged. The traffic input parameters created for the baseline traffic analyses were specific for each highway segment based on AADT, percent of trucks, and functional class of highway. The AADT values for the investigated highways were obtained from WisDOT database WisTransportal website using the nearest traffic counting site. The WisDOT statewide ALS were used in all baseline analyses. For the analyses with OSOW permits integrated with baseline traffic, Microsoft Excel was used to back-calculate vehicle and axle weight counts from the baseline traffic parameters and statewide ALS; the segment-specific OSOW vehicle and axle weight counts were then added to the baseline counts, and the VCD, ALS, and AADTT were recalculated from the meshed counts. The ALS for only the OSOW single trip permit trucks and the ALS for the baseline traffic integrated with the OSOW single trip permit trucks are shown in Figures 4.22 through 4.29, respectively. Additionally traffic data such as the VCD obtained from WisDOT are presented in Appendix A.

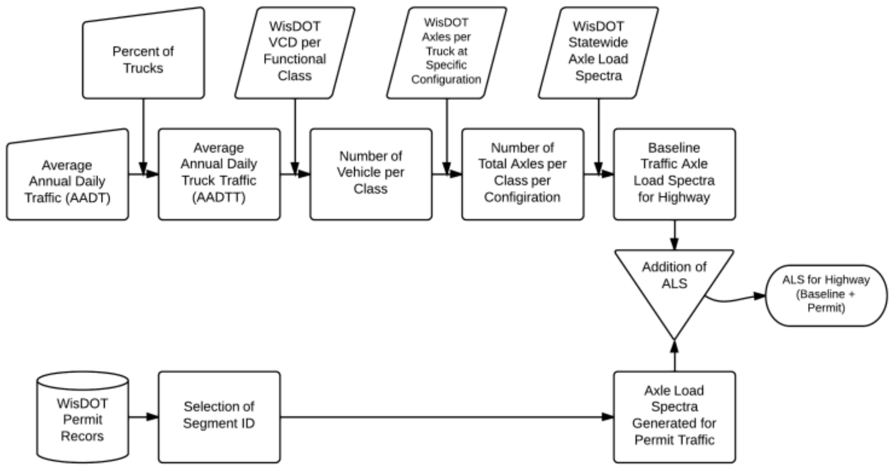


Figure 4.21: Flow chart for development of baseline plus permit traffic

The ALS for the OSOW single trip permit vehicles show higher overall axle weights than the WisDOT baseline ALS presented earlier. For example, the OSOW permit ALS for STH 140 show that single axle weights are centered around 12,000 lbs but with a skew towards higher weights up to 20,000 lbs; the tandem axle weight distribution is centered around 40,000 lbs (vs. 20,000 - 34,000 lbs); most tridem axles are between 40,000 and 60,000 lbs with a peak at 60,000 lbs (vs. 30,000 to 55,000 lbs); and quad axles range from 60,000 lbs to 100,000 lbs with a peak at 80,000 lbs (vs. 40,000 to 70,000 lbs).

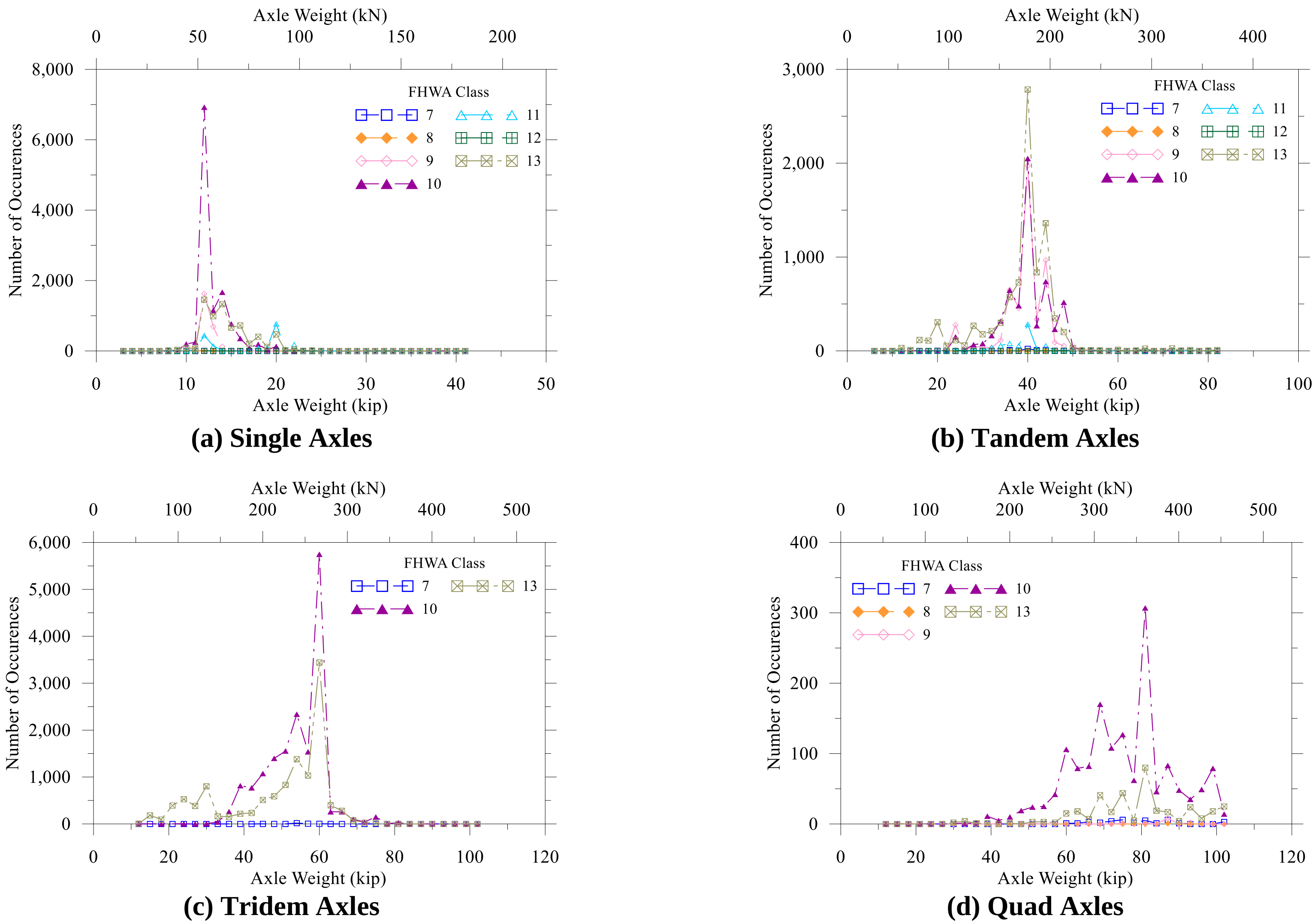
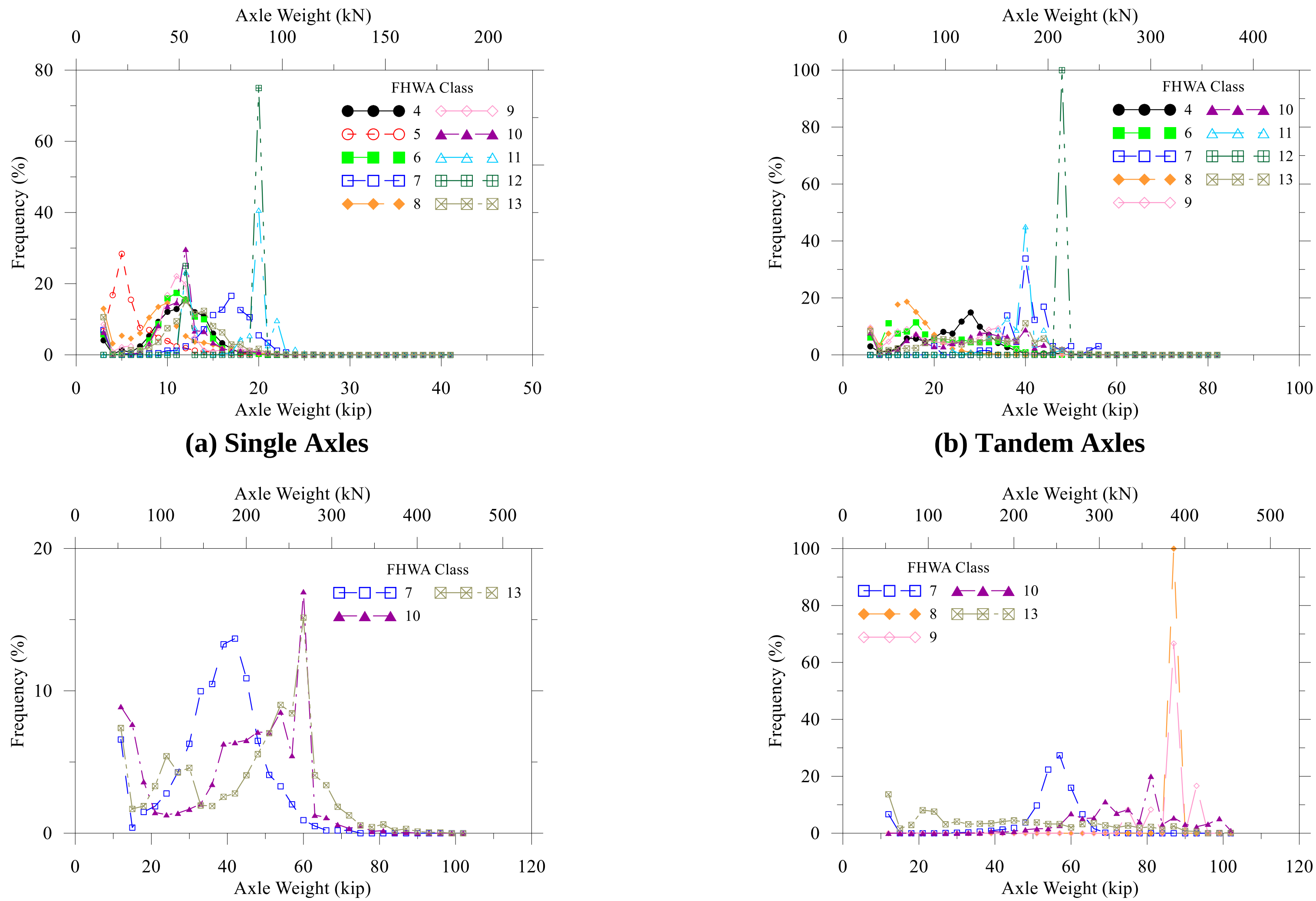


Figure 4.22: Axle load spectra (ALS) for OSOW single trip permit trucks on STH 140 (All GVWs)



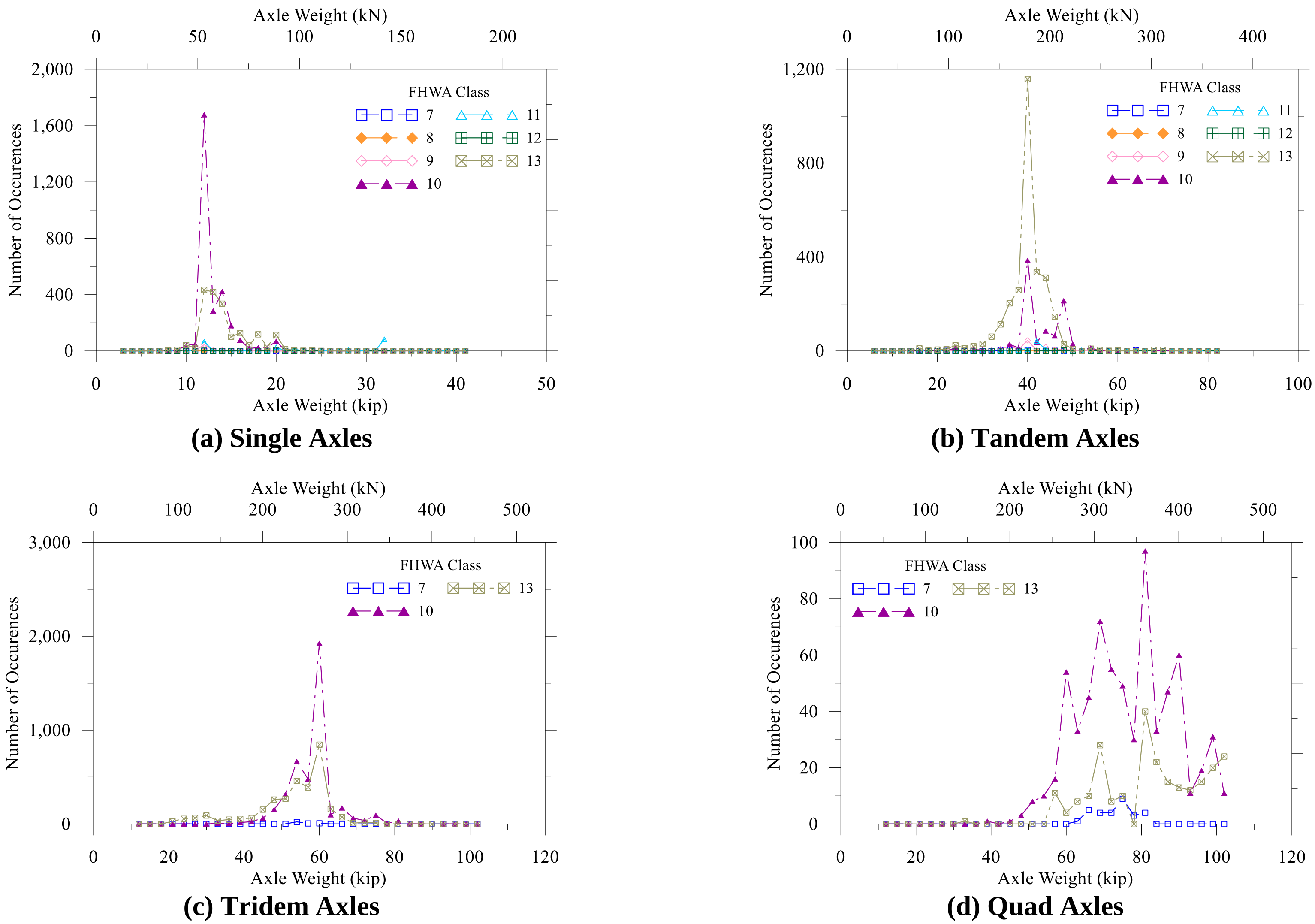
(a) Single Axles

(b) Tandem Axles

(c) Tridem Axles

(d) Quad Axles

Figure 4.23: Axle load spectra for all truck traffic using WisDOT baseline plus OSOW single trip permit trucks on STH 140



(a) Single Axles

(b) Tandem Axles

(c) Tridem Axles

(d) Quad Axles

Figure 4.24: Axle load spectra (ALS) for OSOW single trip permit trucks on STH 11 (All GVWs)

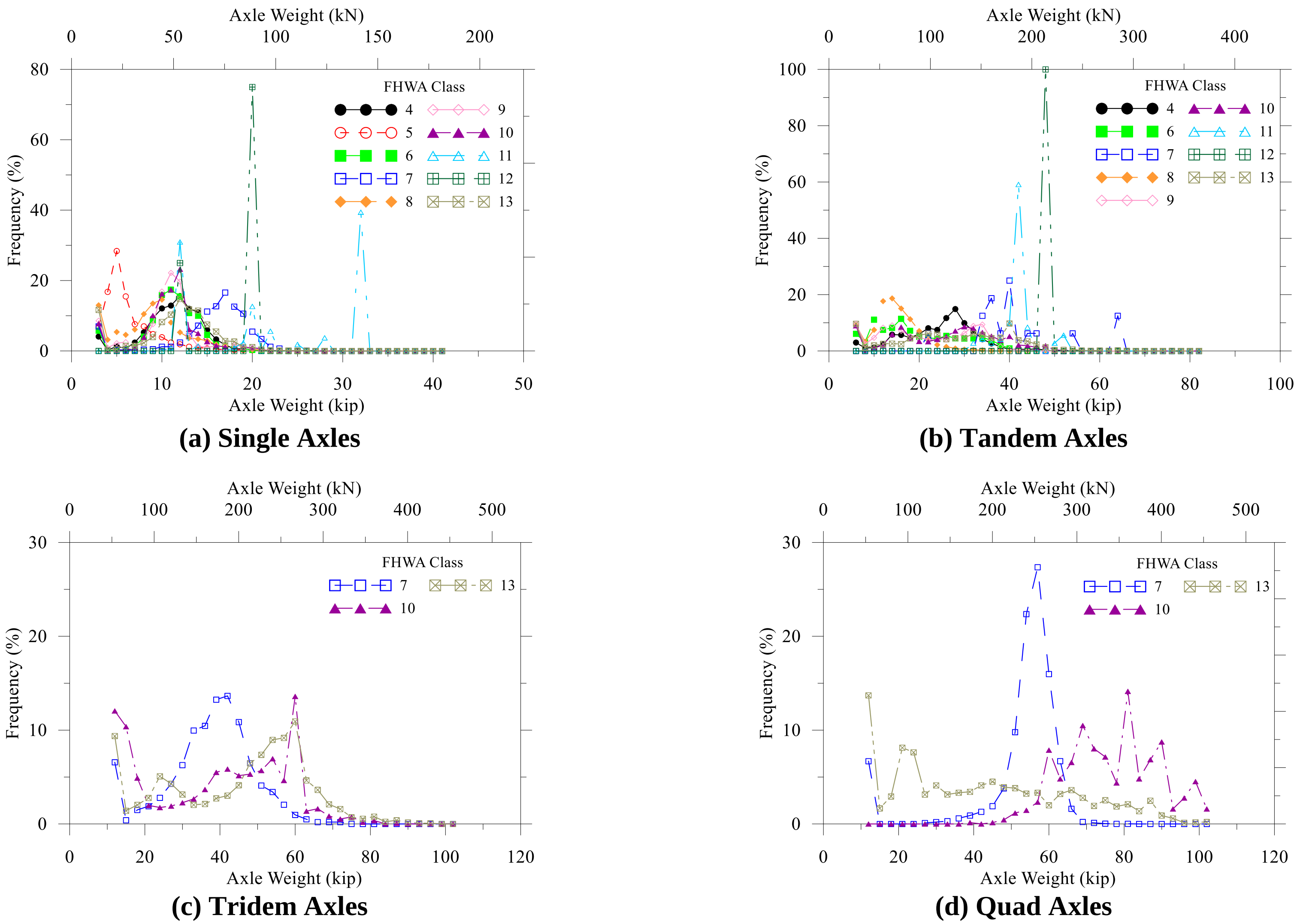
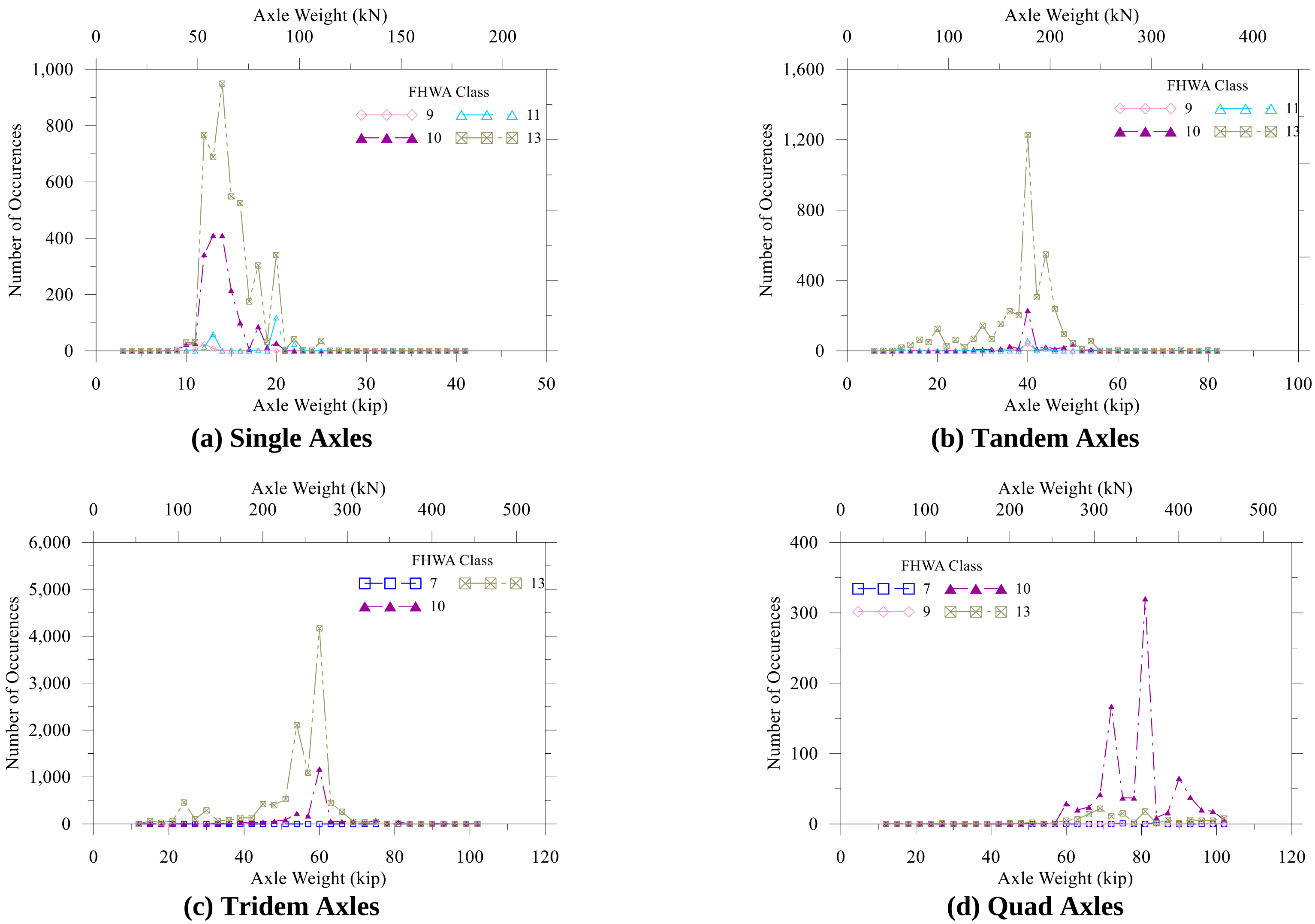


Figure 4.25: Axle load spectra for all truck traffic using WisDOT baseline plus OSOW single trip permit trucks on STH 11



(a) Single Axles

(b) Tandem Axles

(c) Tridem Axles

(d) Quad Axles

Figure 4.26: Axle load spectra (ALS) for OSOW single trip permit trucks on STH 23 (All GVWs)

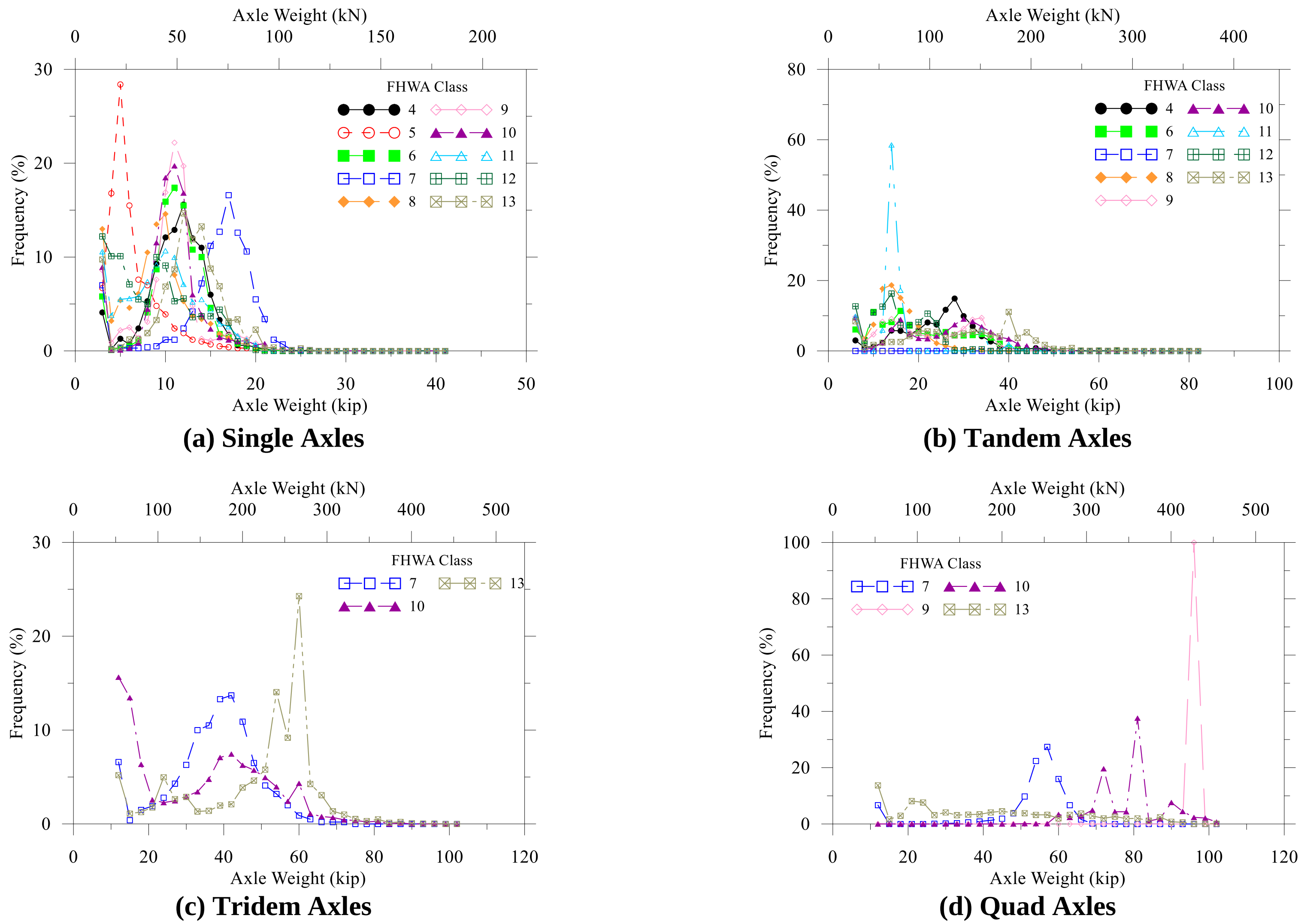
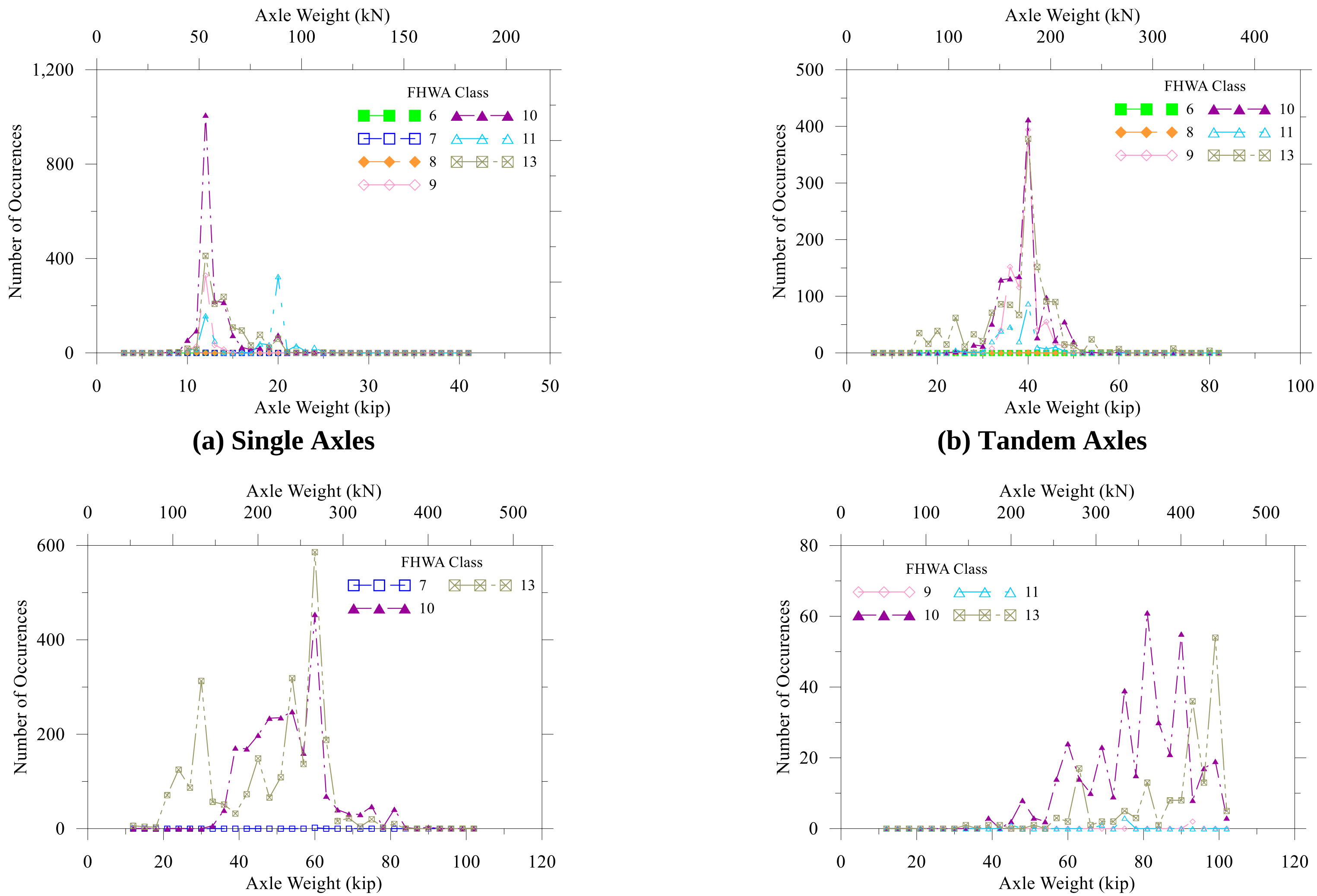


Figure 4.27: Axle load spectra for all truck traffic using WisDOT baseline plus OSOW single trip permit trucks on STH 23



(a) Single Axles

(b) Tandem Axles

(c) Tridem Axles

(d) Quad Axles

Figure 4.28: Axle load spectra (ALS) for OSOW single trip permit trucks on STH 26 (All GVWs)

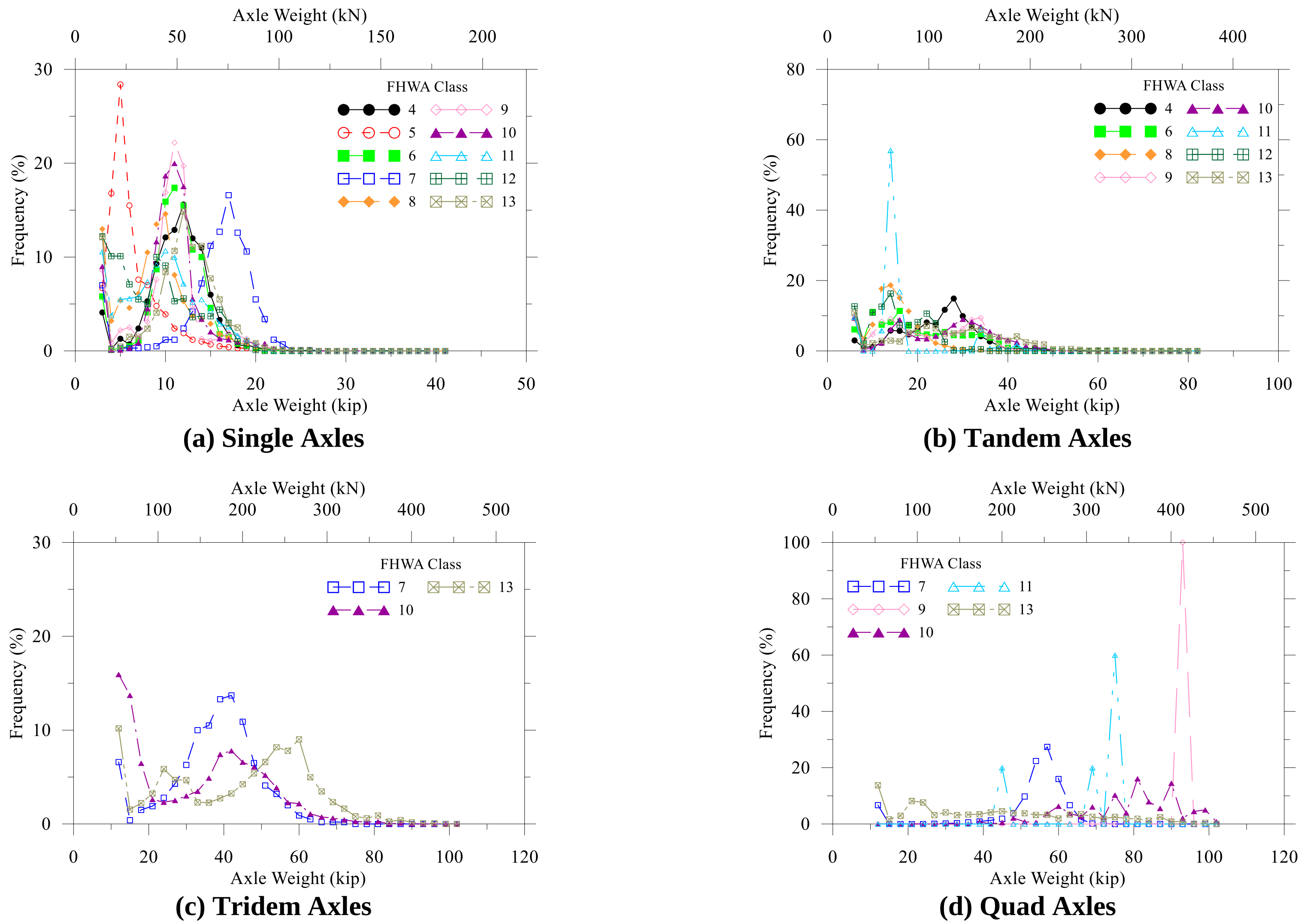


Figure 4.29: Axle load spectra for all truck traffic using WisDOT baseline plus OSOW single trip permit trucks on STH 26

4.3.2 MEPDG Pavement Performance

The AASHTOWare MEPDG software was used to evaluate pavement performance at the investigated STHs under baseline traffic as well as under baseline plus OSOW single trip permit traffic. It should be noted that there are limitations to the analyses and results of this research. These limitations include issues with the software models in predicting certain distresses such as top down cracking and thermal cracking, the use of default (and possibly inaccurate) calibration factors, and the fact that the empirical equations and calibrations were created based on typically loaded trucks and therefore have not been validated for overweight trucks and axles. This analysis used nationally calibrated models due to the novelty of the software and the general lack of time-tested local calibration factors in Wisconsin, although efforts to develop local calibration factors are underway across the state. The author believes that using models calibrated based on Wisconsin data may yield different results, although the differences could be insignificant. Moreover, there were limitations on the available historical information regarding pavement sections and rehabilitation measures. Other limitations included the lack of confirmation that permitted vehicles actually made the physical trips, as well as the lack of quantification of the loads or potential pavement damage resulting from agricultural equipment sharing the highways with truck and car traffic.

The originally constructed pavement typical sections and rehabilitation measures for the highway segments analyzed are summarized in Table 4.5. For example, as presented in the table, STH 140 typical pavement sections consists of 4 in HMA surface layer above a 4.5 in of crushed aggregate base course. The typical sections as well as estimates of material properties and the traffic parameters discussed earlier were used as inputs for the AASHTOWare MEPDG software in order to estimate pavement performance under baseline (normal) traffic loads and under all traffic loads including the OSOW single trip permit truck traffic loads. Table 4.6 summarizes the pavement layer material properties for STH 140 and other investigated STHs used in the AASHTOWare MEPDG analysis. Part of the data used includes general default values, but were considered reasonable estimates for the region. The failure criteria used to evaluate pavement performance were those threshold values for pavement distresses and damage and ride quality adopted by WisDOT. These values are presented in Table 4.7.

Table 4.5: Pavement typical section inputs used in the AASHTOWare MEPDG to estimate pavement performance

Highway	Location	Original Typical Section Thickness and Type (in)		Rehabilitation	AC Overlay Thickness	Most Recent Construction Year
		Surface	Base			
STH 140	Clinton, Rock Co.	4" HMA	4.5" Crushed Aggregate Base Course	Milling of 2" HMA Surface	2"	1996
STH 11	Delavan, Walworth Co.	6.5" PCC	-	Cracking and Seating of PCC	4.5"	1987
STH 23	Plymouth, Sheboygan Co.	5" HMA	13" Crushed Aggregate Base Course	Milling of 1" HMA Surface	2.5"	2004
STH 26	Waupun, Fond du Lac Co.	6.25" HMA	6" Crushed Aggregate Base Course	Milling of 3" HMA Surface	3"	1997

Table 4.6: Pavement input parameters used in the AASHTOWare MEPDG to estimate pavement performance

Highway		STH 140	STH 11	STH 23	STH 26
HMA Surface Layer(s)	Unit Weight (pcf)	143			
	Poisson's Ratio	0.35			
	Reference Temperature (°F)	70			
	Effective Binder Content (%)	11.6			
	Air Voids (%)	7			
	Thermal Conductivity (BTU/hr-ft-°F)	0.67			
	Heat Capacity (BTU/lb-°F)	0.23			
	Grade	Superpave Performance Grade			
	Binder Type	58-28			
Base Course	Resilient Modulus (psi) (*Input Level 3*)	30,000	40,000	30,000	30,000
	Poisson's Ratio	0.35			
	Coefficient of Lateral Earth Pressure (k_o)	0.5			
Subgrade	AASHTO Soil Classification	A-6	A-6	A-7-5	A-7-5
	Resilient Modulus (psi) (*Input Level 3*)	5,000	5,000	8,000	8,000
	Poisson's Ratio	0.4			
	Coefficient of Lateral Earth Pressure (k_o)	0.5			
Climate Station		Madison	Racine	Fond du Lac	Oshkosh

Table 4.7: WisDOT pavement failure criteria for AASHTOWare MEPDG

Performance Criteria	Threshold	Reliability
Initial IRI (in/mi)	55	-
Terminal IRI (in/mi)	200	85
AC Top-Down Fatigue Cracking (ft/mi)	2,000	85
AC Bottom-Up Fatigue Cracking (%)	20	85
AC Thermal Cracking (ft/mi)	2,000	85
Permanent Deformation - Total Pavement (in)	0.50	85
Permanent Deformation - AC Only (in)	0.50	85

Due to the lack of long-term experience with the AASHTOWare MEPDG software and possibly insufficient historical pavement rehabilitation data, there is uncertainty regarding the sensitivity of the analysis to existing pavement condition and to prior rehabilitation activities. The analysis initially considered two construction scenarios for STH 140: a newly constructed pavement, and a rehabilitated pavement. The author's experience with the software and personal communication with other users indicated that the current HMA pavement rehabilitation analysis is very sensitive to the existing condition of the pavement (i.e. poor, fair, etc.). In addition, an issue was encountered during the analysis of the rehabilitated pavement in which the pavement's milled surface did not appear in the output report, necessitating that the author input the HMA surface as a milled surface. However, the pavement damage results from that analysis were significantly lower than what was observed during field work on the investigated highways. For example, an analysis was conducted using STH 140 comparing baseline traffic to baseline traffic plus permit traffic, which predicted significantly different results than the observed pavement condition. The analysis attempting to simulate a rehabilitated pavement (as described previously) predicted a rutting depth that was more than one whole inch less than the analysis with the same traffic data which treated the pavement as newly constructed (see Table 4.8). Ultimately, because the field distress surveys provided quantifications of the pavement condition that were consistent with the results of MEPDG analysis treating the pavement as newly constructed, the newly constructed analysis mode was adopted in this study instead of the rehabilitated mode. The results of the MEPDG analysis are presented in Table 4.8.

Table 4.8: Comparison of AASHTOWare MEPDG analysis using new with rehabilitated pavement for STH 140

State Trunk Highway 140		Baseline Traffic		Baseline Traffic + Permit Traffic	
AASHTOWare MEPDG Analysis Scheme		New	Rehabilitated	New	Rehabilitated
IRI (in/mi)	Total (85% Reliability)	158.6	126.8	159.3	127.5
Rutting Depth (in)	Total (85% Reliability)	1.296	0.28	1.337	0.29
	Subtotal HMA	0.2456	0.1739	0.2521	0.1853
	Subtotal Base	0.0752	0.0002	0.0769	0.0003
	Subtotal Subgrade	0.8289	0.029	0.8592	0.0331
	Total	1.15	0.2085	1.188	0.2187
Fatigue Cracking (%)	Bottom-Up HMA Cracking	35.645	1.17	37.145	1.17
	Bottom-Up HMA Damage	33.7	0.0005	36.4	0.0006

The results of the AASHTOWare MEPDG analysis for STH 140 are presented in Figures 4.30 to 4.34. The analysis was conducted over a 20 year performance period for the baseline traffic data as well as baseline plus OSOW permits. The results are also summarized in Table 4.9. The analysis results indicate that there is a 0.44% increase in IRI over the 20 years of predicted pavement performance due to the addition of the OSOW trucks into the traffic data, which is considered an insignificant increase results from OSOW truck traffic due to the small margin. In addition, the ride quality of the pavement did not reach the threshold of 200 in/mile specified by WisDOT, as shown in Figure 4.30

At an 85% reliability level, the total pavement rutting was predicted to reach 1.296 in under baseline traffic, but this increased to 1.337 in when permit vehicles were included, a 3.16 % increase as shown in Figure 4.31. It was also observed that the pavement was predicted to reach the rutting threshold of 0.50 in, as specified by WisDOT, after less than one year for both cases of traffic loading. Furthermore, the pavement exhibited bottom-up fatigue cracking of 35.6% under baseline traffic load and 37.1% due to OSOW single permit truck traffic loading, a 4.21% increase.

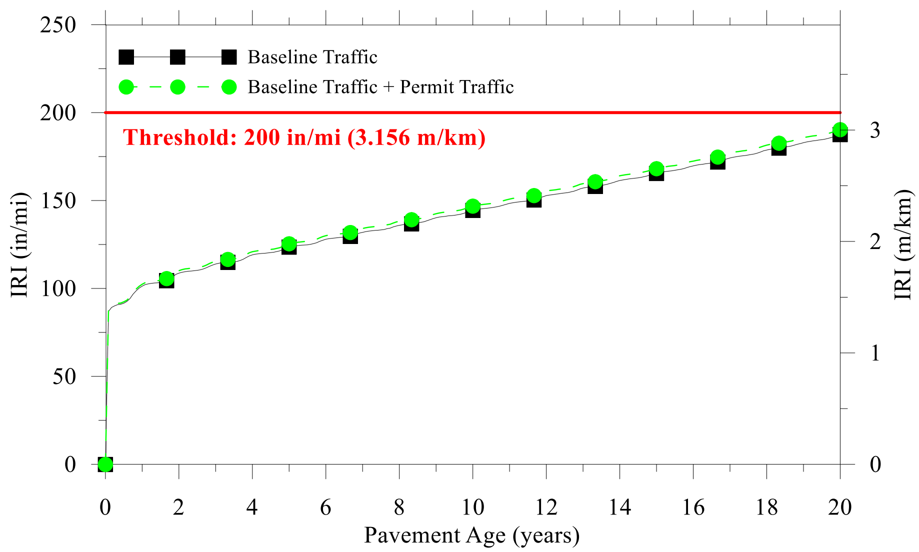


Figure 4.30: Comparison of ride quality performance over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 140 (85% Reliability)

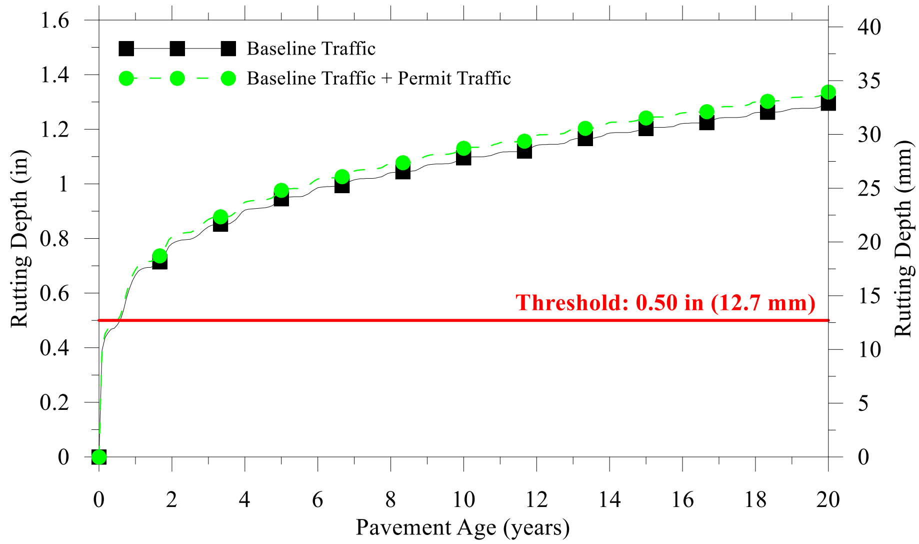


Figure 4.31: Comparison of total permanent deformation over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 140 (85% Reliability)

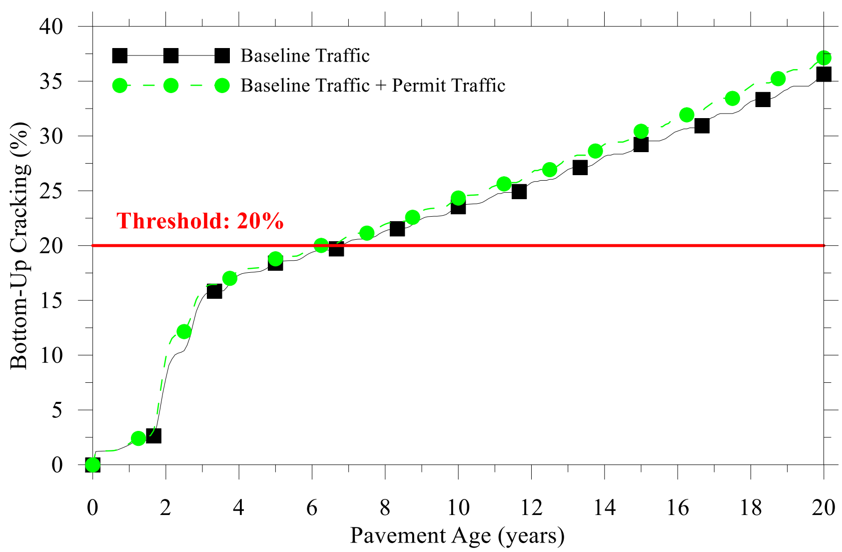


Figure 4.32: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 140 (85% Reliability)

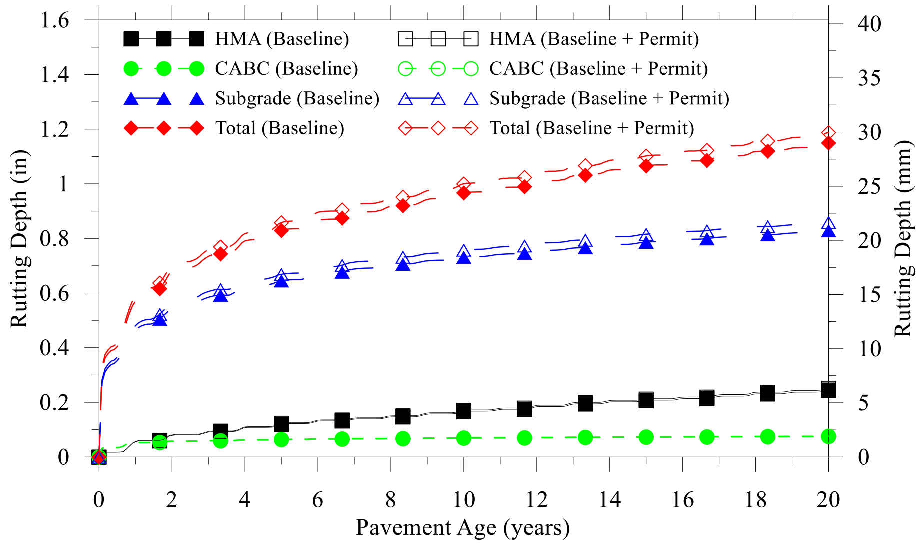


Figure 4.33: Pavement layer rutting over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 140 (50% Reliability)

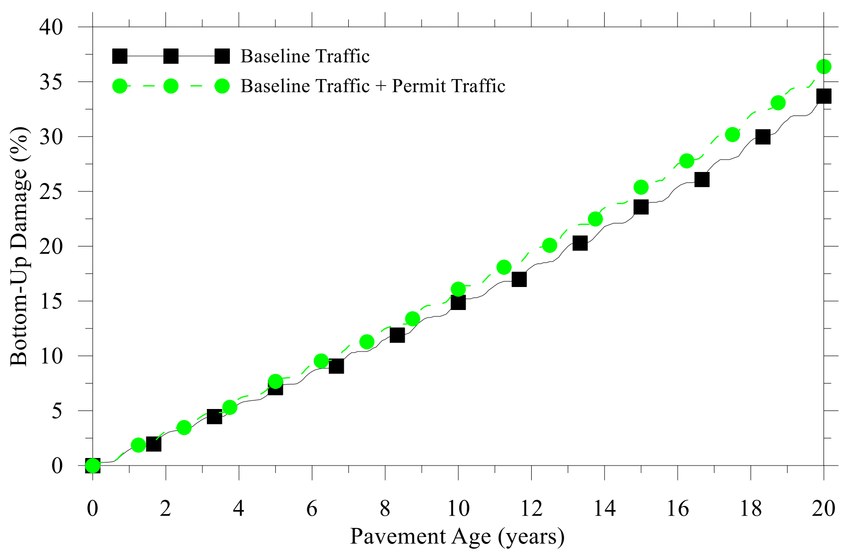


Figure 4.34: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 140 (50% Reliability)

Figures 4.35 to 4.39 show the AASHTOWare MEPDG analysis results for STH 11. Of the highways segments analyzed in this study, the second highest increase of rutting at 85% reliability occurred on this highway due to the addition of the OSOW permit trucks. It also experienced the largest increase in bottom-up damage in the HMA layer (3.88%).

The AASHTOWare MEPDG analysis results for STH 23 are shown in Figures 4.40 to 4.44. Of the highways segments analyzed in this study, the most significant increase in distress from bottom-up cracking in the HMA layer from the addition of the OSOW permit traffic was noted at this segment (4.64%). The maximum rutting observed on STH 23 from field investigations was 0.5 in, which is 0.3 in less than the predicted rutting with the OSOW traffic.

The AASHTOWare MEPDG analysis results for STH 26 are shown in Figures 4.45 to 4.49. The rutting at 85% reliability level for STH 26 after 20 years was 0.95 in from the normal plus OSOW traffic. The maximum rutting exhibited is consistent with the maximum rutting depth measured in the field at 1.25 in. The increase in rutting due to the addition of OSOW permit vehicle traffic was only 0.45% above the baseline results, which is viewed as insignificant.

All of the pavement analyses using the AASHTOWare MEPDG software predicted rutting levels that exceeded WisDOT’s 0.5 in threshold for rutting under both baseline traffic and baseline traffic with the OSOW truck loads. As summarized in Table 4.9, all of the investigated highways exhibited minor increases in damages due to the addition of the OSOW permit truck traffic. One of the pavement distresses that remained consistent with all four highways was the rutting of the base layer. STH 23 experienced the greatest rutting depth of the base layer, 0.96 in, for the traffic analysis with the OSOW traffic. However, this was only a 0.73% increase from the rutting predicted under normal traffic.

In general, the analyses conducted on the investigated segments did not result in a significantly large increase in pavement damage and deterioration due to the addition of OSOW single trip permit vehicles into the traffic data. The author believes that such insignificant increases in pavement damage levels could be accurate predictions, since the field measurements were generally consistent with the analyses obtained from the AASHTOWare MEPDG software. For example, the maximum measured rutting depth at STH 140 was 1.0 in, which is consistent with the predicted rutting depth of 1.34 in obtained from the AASHTOWare MEPDG software. A contributing factor leading to lower-than-expected differential damage levels due to the OSOW vehicles could be the fact that when permits are issued, WisDOT requires OSOW to include sufficient numbers of axles and tires to ensure that the maximum allowable load per axle for various axle configurations are not exceeded due to uneven load distributions along the vehicle. Therefore, most on-the-ground axle loadings are probably less than the declared axle loading as recorded by WisDOT. As a result, the loads carried by OSOW trucks will almost always be distributed over a larger pavement area than strictly necessary to comply with WisDOT regulations, reducing pavement stresses and leading to less pavement damage than would be predicted based on the nominal axle loadings.

Table 4.9: Summary of AASHTOWare MEPDG analysis for STHs in Wisconsin

Highway		STH 140			STH 11			STH 23			STH 26		
Traffic		Baseline Traffic	Baseline Traffic + Permit Traffic	% Change due to OSOWs	Baseline Traffic	Baseline Traffic + Permit Traffic	% Change due to OSOWs	Baseline Traffic	Baseline Traffic + Permit Traffic	% Change due to OSOWs	Baseline Traffic	Baseline Traffic + Permit Traffic	% Change due to OSOWs
IRI (in/mi)	Total (85% Reliability)	158.6	159.3	0.44	158.6	159.6	0.63	150.6	151	0.27	160.8	160.9	0.06
Rutting Depth (in)	Total (85% Reliability)	1.296	1.337	3.16	0.976	0.996	2.05	0.791	0.799	1.01	0.949	0.952	0.32
	Subtotal HMA	0.2456	0.2521	2.65	0.1506	0.1525	1.26	0.285	0.2867	0.6	0.3547	0.3548	0.03
	Subtotal Base	0.0752	0.0769	2.26	0.0734	0.0744	1.36	0.0954	0.0961	0.73	0.0766	0.0768	0.26
	Subtotal Subgrade	0.8289	0.8592	3.66	0.6321	0.6479	2.5	0.2901	0.2958	1.96	0.3799	0.3816	0.45
	Total	1.15	1.188	3.3	0.8561	0.8748	2.18	0.6706	0.6786	1.19	0.8111	0.8132	0.26
Fatigue Cracking (%)	Bottom-Up HMA Cracking	35.645	37.145	4.21	16.454	16.746	1.77	8.966	9.382	4.64	20.557	20.567	0.05
	Bottom-Up HMA Damage	33.7	36.4	8.01	4.64	4.82	3.88	2.95	3.00	1.69	8.22	8.24	0.24

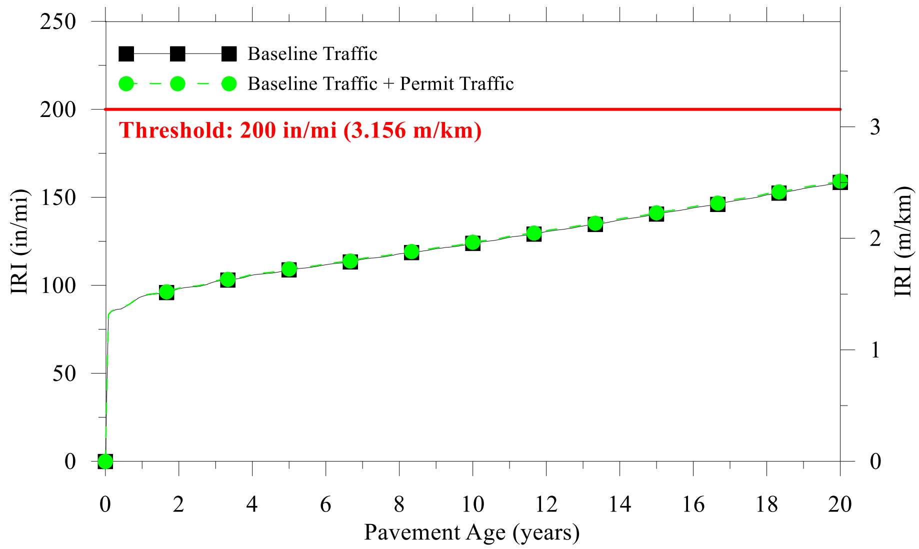


Figure 4.35: Comparison of ride quality performance over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 11 (85% Reliability)

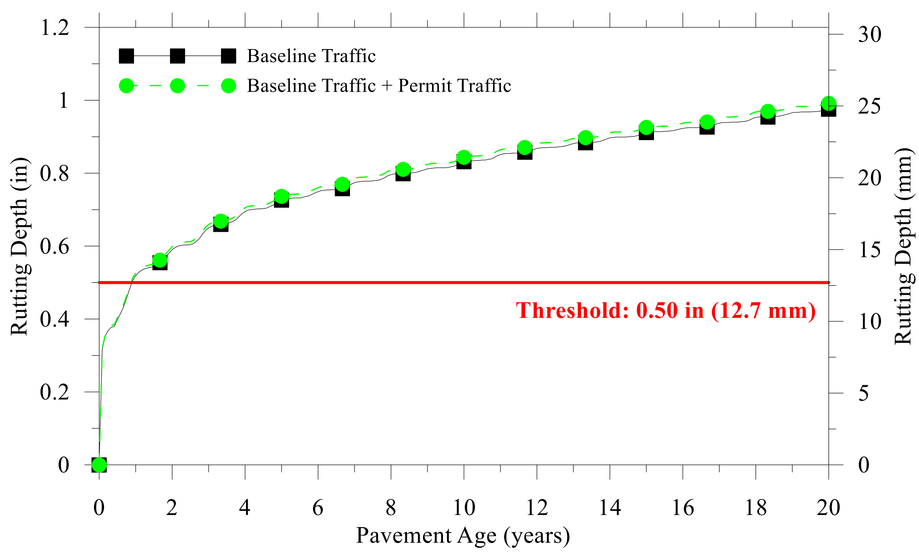


Figure 4.36: Comparison of total permanent deformation over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 11 (85% Reliability)

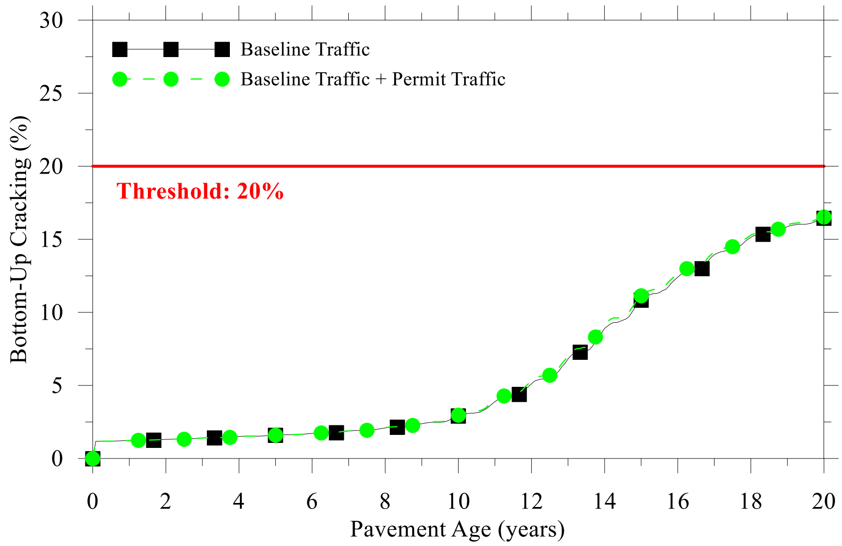


Figure 4.37: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 11 (85% Reliability)

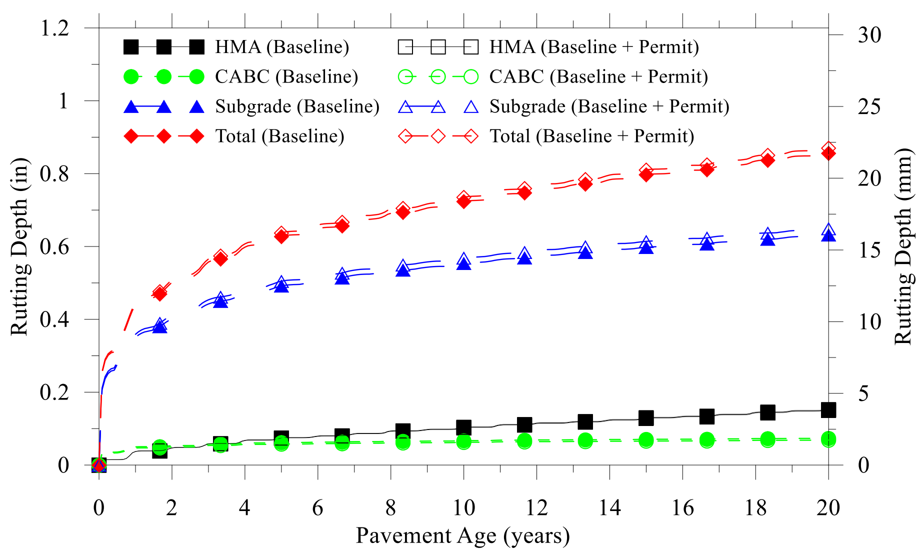


Figure 4.38: Pavement layer rutting over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 11 (50% Reliability)

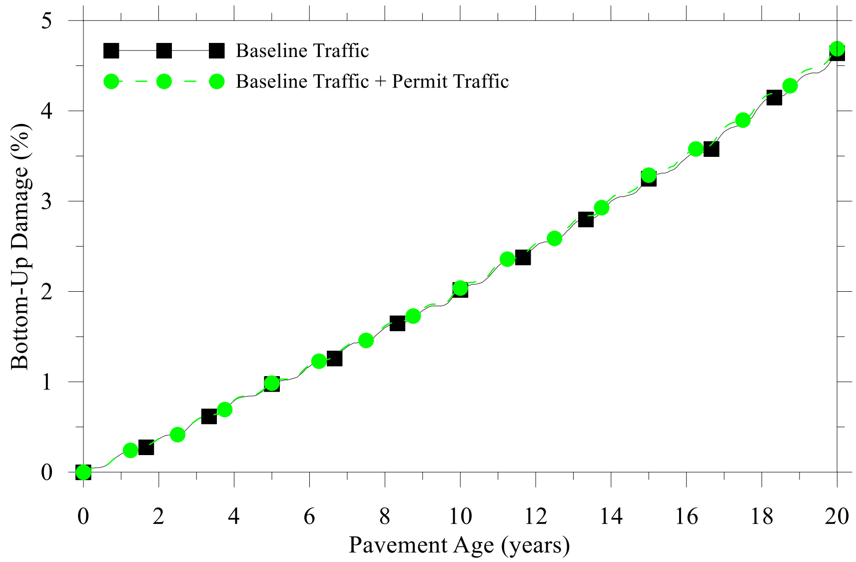


Figure 4.39: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 11 (50% Reliability)

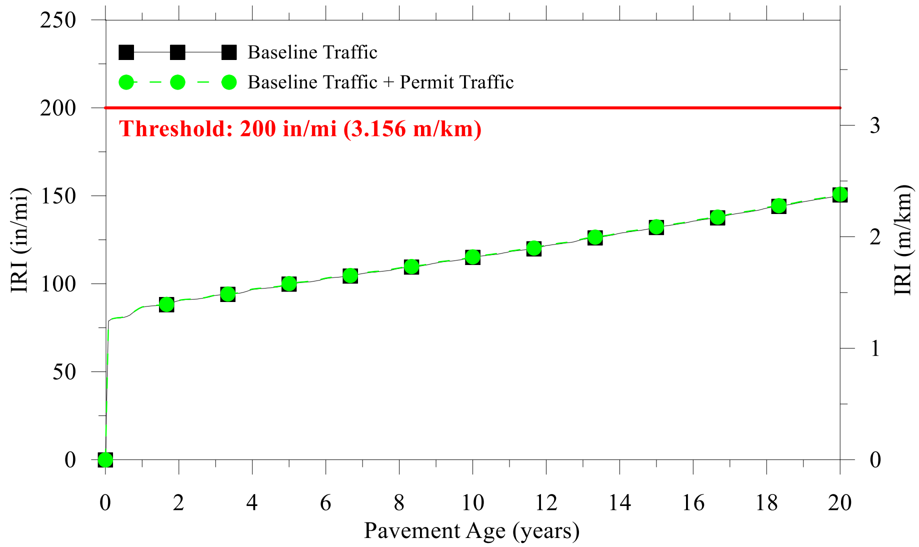


Figure 4.40: Comparison of ride quality performance over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 23 (85% Reliability)

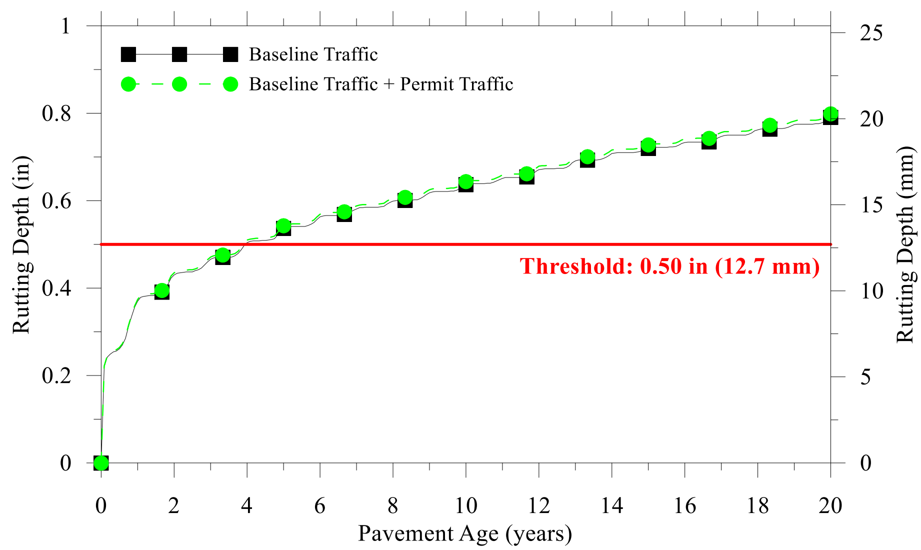


Figure 4.41: Comparison of total permanent deformation over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 23 (85% Reliability)

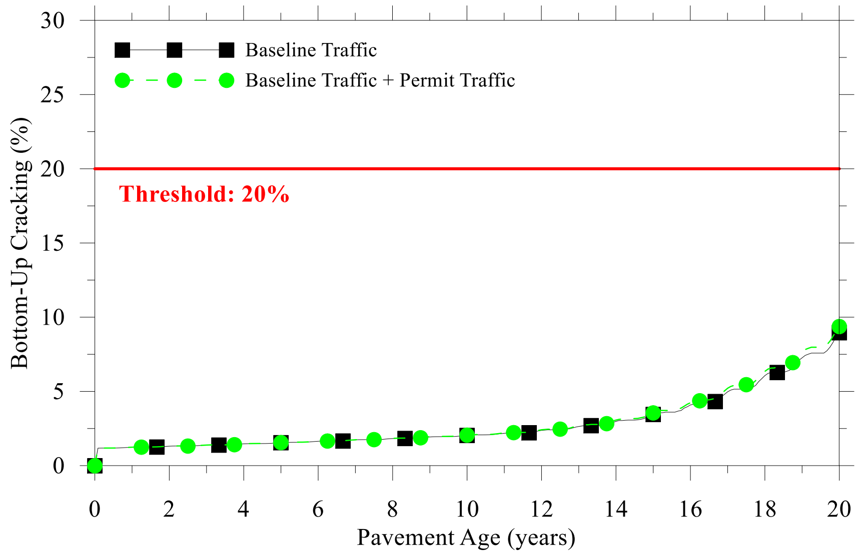


Figure 4.42: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 23 (85% Reliability)

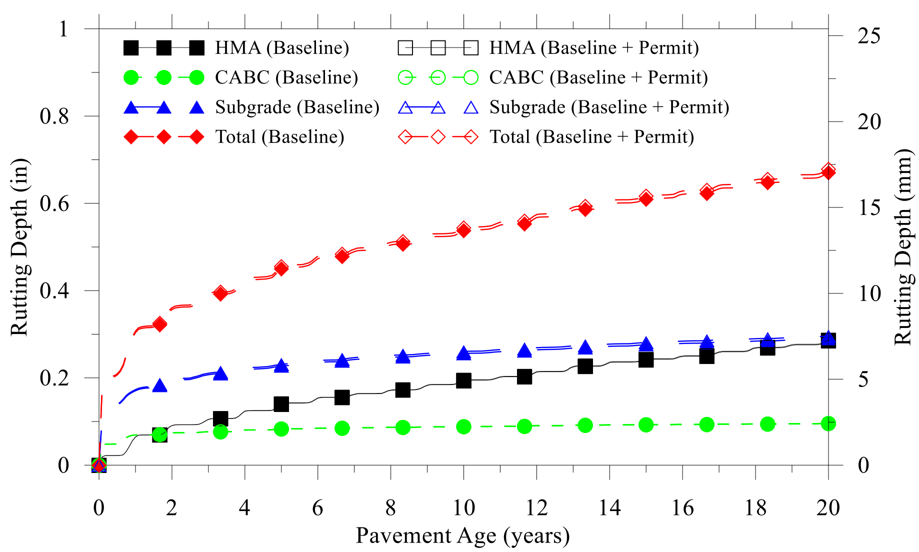


Figure 4.43: Pavement layer rutting over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 23 (50% Reliability)

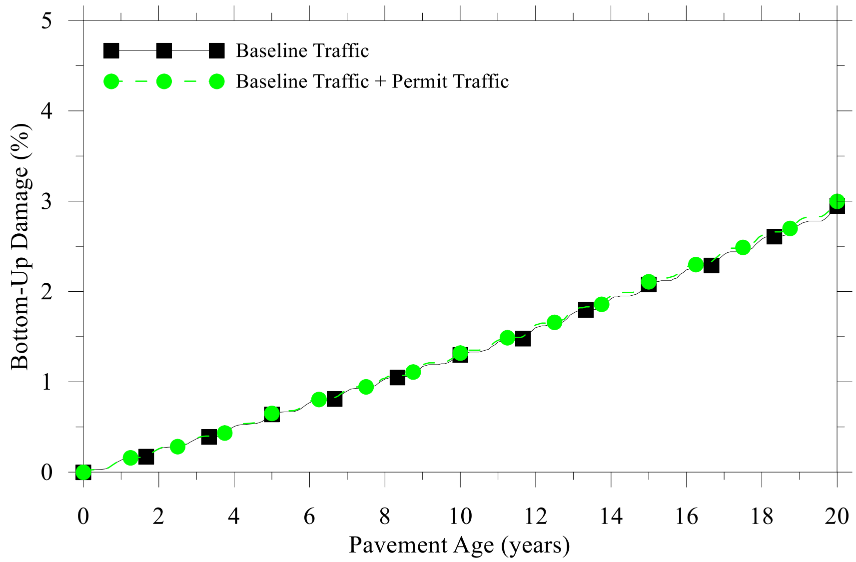


Figure 4.44: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 23 (50% Reliability)

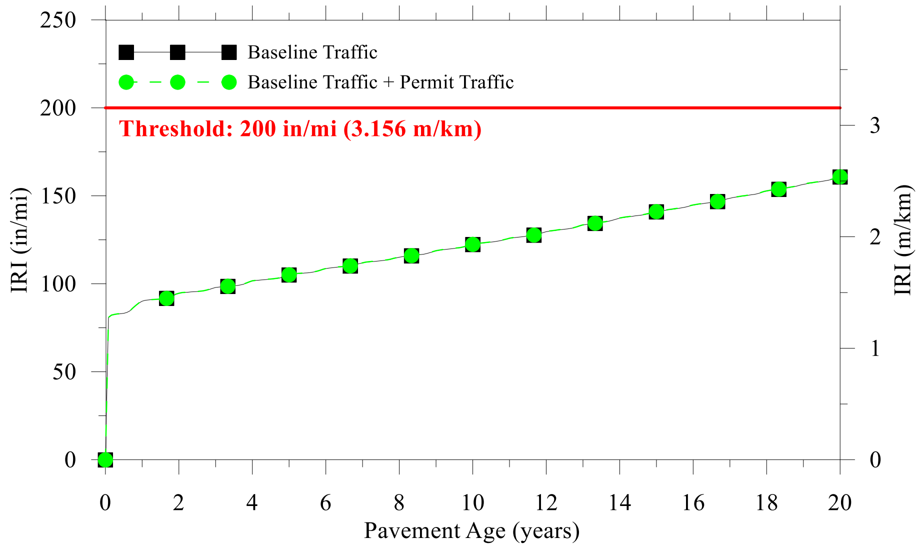


Figure 4.45: Comparison of ride quality performance over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 26 (85% Reliability)

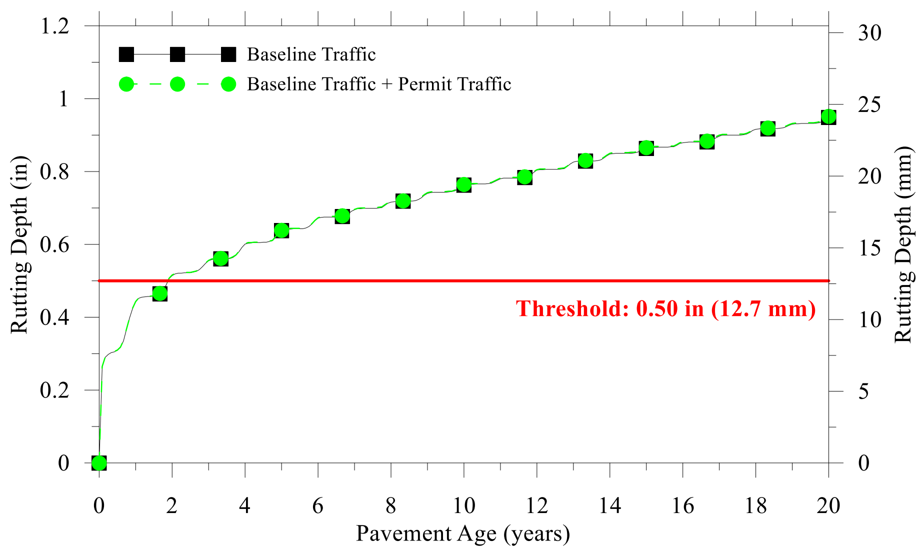


Figure 4.46: Comparison of total permanent deformation over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 26 (85% Reliability)

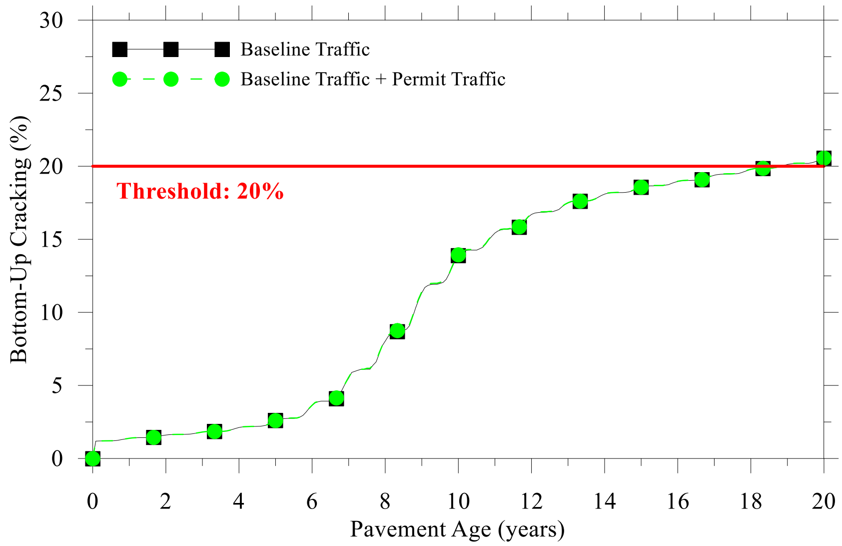


Figure 4.47: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 26 (85% Reliability)

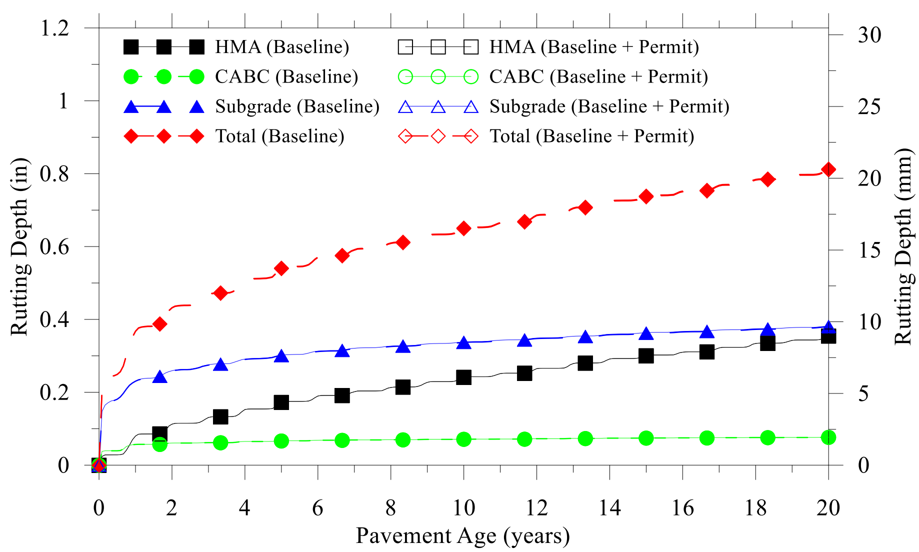


Figure 4.48: Pavement layer rutting over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 26 (50% Reliability)

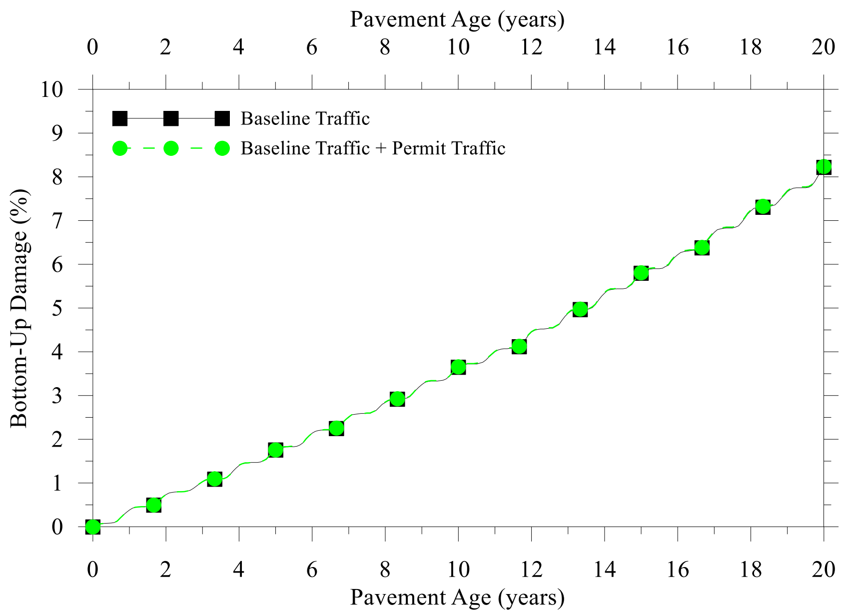


Figure 4.49: Comparison of fatigue over pavement life resulted from normal traffic and normal traffic plus OSOW single trip permit truck loads for STH 26 (50% Reliability

CHAPTER 5

CONCLUSIONS

The objective of this research was to characterize pavement damage and deterioration induced by oversize overweight single permit truck traffic on selected hot mix asphalt pavements in Wisconsin. A database of OSOW single trip permit truck records was analyzed and provided a network of Wisconsin corridors heavily trafficked by OSOW trucks. Four Wisconsin state trunk highways were selected for investigation due to a high level of OSOW truck traffic. The research included traffic counts to confirm the levels of truck traffic on these segments and to verify the high numbers of permits issued for OSOW trucks. Furthermore, the field work included the identification and quantification of pavement surface distresses by executing visual distress surveys allowing for the current pavement surface conditions to be rated using the pavement condition index.

In addition, comprehensive analyses were conducted to evaluate pavement performance due to normal traffic loads as well as normal traffic loads plus the OSOW truck traffic loads. The use of AASHTOWare MEPDG analyses presented a potential methodology for determining the portion of pavement deterioration attributable to OSOW truck traffic. Large amounts of data were developed including the axle load spectra for the OSOW trucks for each investigated highway segment. This data was required for the traffic load input for the AASHTOWare MEPDG analysis. Moreover, inputs pertaining to the typical pavement sections and pavement layer materials were obtained for the investigated highway segments from WisDOT and other available references. The

AASHTOWare MEPDG analysis was conducted and pavement performance was predicted for each investigated highway under baseline traffic loads as well as under baseline traffic loads plus OSOW truck traffic loads. Based on these analyses, the following conclusions were reached:

1. The OSOW dataset provided by WisDOT contains records of approximately 96,000 unique single-trip overweight permits issued between June 2007 and June 2013 and includes detailed information such as route descriptions and axle loads and spacings. This allowed for the mapping and identification of highway corridors, which are heavily used by OSOW trucks.
2. Field studies verified the existence of high volumes of OSOW truck traffic on STHs 140, 11, 23, and 26 at the segments selected for detailed investigation. The number of observed OSOW trucks during the field work was generally consistent with the expected OSOW volumes obtained from the permits database.
3. Visual distress surveys conducted at the selected segments of STHs 140, 11, and 26 rated the pavement surface conditions as serious to poor, ranging from a PCI value of 13 on STH 140 to a PCI value of 52 on STH 11. Across these three segments, the maximum measured rutting depth along the outer wheel paths ranged from 0.82 in to 1.25 in, which exceeded WisDOT's threshold for acceptable rutting of 0.50 in. Only the segment of STH 23 exhibited a fair pavement surface condition due to PCI values of 63 and 66 in the two lanes, with a maximum rutting depth of 0.50 in. The generally poor pavement conditions across the sampled segments included significant

pavement surface damage and distresses such as rutting, longitudinal and transverse cracking, significant fatigue cracking, and potholes.

4. The AASHTOWare MEPDG software, within the limitations discussed in Chapter 4, predicted pavement deterioration levels that were generally consistent with the levels of deterioration observed during the site investigations. However, the proportion of pavement damage and deterioration attributable to OSOW truck traffic was predicted to be fairly insignificant, with most distress indices showing relative increases of approximately 0.5% to 4%, with a few outliers. The addition of OSOW truck traffic to the baseline truck traffic volumes resulted in a small increase in the amount of pavement damage, rutting depths, and loss of ride quality compared with the predicted deterioration levels due to only the baseline traffic.

REFERENCES

Acimovic, B., Rejaseker, L., and Akhavan, R. (2007). "Forensic Investigation of Pavement Failure on Vasquez Boulevard." *Report CDOT-2007-7*, Colorado Department of Transportation, Denver, CO.

Adams, T., Malaikrisanachlee, S., Blazquez, C. and Vonderohe, A.P. (2002). "GIS-Based Oversize/Overweight Vehicle Routing System." *Report 0092-45-19*, University of Wisconsin-Madison, Madison, WI.

Adams, T. M., Bittner, J., and Wittwer, E. (2009). "Wisconsin Truck Size and Weight Study." *Report CFIRE 02-0,* National Center for Freight and Infrastructure Research and Education, University of Wisconsin-Madison, Madison, WI.

American Society for Testing and Materials (ASTM). (2011), "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys." D6433-11, West Conshohocken, PA.

Bessert, C.J. (2009). "Wisconsin Highway Listings." Wisconsin Highways, <http://www.wisconsinhighways.org/listings/index.html/> (Apr. 10, 2014).

Boriboonsomsin, K., Scora, G., Wu, G., and Barth, M. (2011). "Improving Vehicle Fleet, Activity, and Emissions Data for On-Road Mobile Sources Emissions Inventories." Federal Highway Administration, Washington D.C.

Chen, D.H., Bilyeu, J., and Chang, J.R. (2005). "A Review of the Superheavy Load Permitting Programme in Texas." *International Journal of Pavement Engineering*, 6(1), 47-55.

Chen, D.H., Bilyeu, J., and Li, Z. (2009). "Field Evaluation of Damages from Super Heavy Load Moves." GeoHunan International Conference, 187-192.

Chen, X., Lambert, J. R., Tsai, C., and Zhongjie, Z. (2013). "Evaluation of Superheavy Load Movement on Flexible Pavements." *International Journal of Pavement Engineering*, 14(5), 440-448.

Cohen, H., Fu, G., Dekelbab, W., and Moses, F. (2003). "Predicting Truck Axle Load Spectra Under Weight Limit Changes and its Application to Steel Bridge Fatigue Assessment." *Journal of Bridge Engineering*, 8(5), 312-322.

Coley, N., Latifi, V., and Titi, H. (2014). "Analysis of Heavy Freight Trends in Wisconsin using Overweight Permit Data." Poster presented at the Logistics, Trade and Transportation Symposium, February 26-27, 2014, Gulfport, MS.

Daniel, J., Chehab, G. R., Ayyala, D., and Nogaj, I. M. (2012). "New England Verification of National Cooperative Highway Research Program (NHCRP) 1-37A Mechanistic-Empirical Pavement Design Guide (MEPDG)." Report NETCR87, University of New Hampshire, Department of Civil Engineering, Durham, NH.

Federal Highway Administration (FHWA). (2003). “Commercial Vehicle Size and Weight Program.” Freight Management and Operations, <http://ops.fhwa.dot.gov/freight/sw/overview/index.htm> (Jul. 28, 2013).

Federal Highway Administration (FHWA). (2010). "Maine and Vermont Interstate Highway Heavy Truck Pilot Program 6-Month Report." Federal Highway Administration, Washington D.C.

Federal Highway Administration (FHWA). (2011). "Vermont Truck Interstate Pilot Study." Federal Highway Administration, Washington D.C.

Federal Highway Administration (FHWA). (2012). "Moving Ahead for Progress in the 21st Century Act (MAP-21)." <http://www.fhwa.dot.gov/map21/docs/presentation_082012.pdf> (Feb. 5, 2014).

Federal Highway Administration (FHWA). (2013a). “Significant Freight Provisions.” MAP-21 - Moving Ahead for Progress in the 21st Century, <http://www.fhwa.dot.gov/map21/factsheets/freight.cfm> (Feb. 5, 2014).

Fiorillo, G., and Ghosn, M. (2014). "Procedure for Statistical Categorization of Overweight Vehicles in a WIM Database." Journal of Transportation Engineering, 140(5).

Gillespie, T. D., Karamihas, S. M., Cebon, D., Sayers, M. W., Nasim, M. A., Hansen, W., and Ehsan, N. (1992). "Effects of Heavy Vehicle Characteristics on Pavement Response and Performance." Report UMTRI 92-2, University of Michigan Transportation Research Institute, Ann Arbor, MI.

Haider, S. W., and Harichandran, R. S. (2007). "Relating Axle Load Spectra to Truck Gross Vehicle Weights and Volumes." *Journal of Transportation Engineering*, 133(12), 696-705.

House Resolution 4348, 112th Congress. §167 (2012).

Ishak, S., Shin, H.-C., Sridhar, B. K., and Zhang, Z. (2010). "Characterization and Development of Truck Axle Load Spectra for Implementation of New Pavement Design Practices in Louisiana." *Transportation Research Record: Journal of the Transportation Research Board*, *2153*, 121-129.

Jooste, F. J., and Fernando, E. G. (1994). "Victoria Superheavy Load Move: Report on Route Assessment and Pavement Modeling." *Report FHWA/TX-94/1335-1*, Texas A&M University, Texas Transportation Institute, College Station, TX.

Kraus, E., Oh, J. and Fernando, E. (2014). “Impact of Repeat Overweight Truck Traffic on Buried Utility Facilities.” *Journal of Performance Constructed Facilities*, in press.

Oh, J. H., Fernando, E. G., and Lytton, R. L. (2007). "Evaluation of Damage Potential for Pavements Due to Overweight Truck Traffic." *Journal of Transportation Engineering*, 133(5), 308-317.

Oh, J. H., and Wimsatt, A. J. (2010). "Seal Coat Damage Evaluation Due to Superheavy Load Moves Based on a Mechanistic-Empirical Approach." Report FHWA/TX-10/0-5270-1, Texas A&M University, Texas Transportation Institute, College Station ,TX.

Owusu-Ababio, S., and Schmitt, R. (2005). "Effects of Heavy Loading on Wisconsin's Concrete Pavements." *Report WHRP 05-06*, University of Wisconsin-Platteville, Department of Civil and Environmental Engineering, Platteville, WI.

Smith, B. C., and Diefenderfer, B. K. (2010). "Analysis of Virginia-Specific Traffic Data for Use with Mechanistic-Empirical Pavement Design Guide." *Transportation Research Record: Journal of the Transportation Research Board*, 2154, 100-107.

Straus, S. H., and Semmens, J. (2006). "Estimating the Cost of Overweight Vehicle Traffic on Arizona Highways." Report FHWA-AZ-06-528, Arizona Department of Transportation, Phoenix, AZ.

Tirado, C., Carrasco, C., Mares, J. M., Gharaibeh, N., Nazarian, S., and Bendana, J. (2010). "Process to Estimate Permit Costs for Movement of Heavy Trucks on Flexible Pavement." *Transportation Research Record: Journal of the Transportation Research Board*, 2154, 187-196.

Titi, H. H., Coley, N., Latifi, V. and Matar, M. (2014). “Characterization of Overweight Permitted Truck Routes and Loads in Wisconsin,” *Journal of the Transportation Research Board, National Research Council,* Washington, D.C., in press.

Titi, H.H., and English, R. (2011). "Determination of Resilient Modulus Values for Typical Plastic Soils in Wisconsin." *Report WHRP 11-04*, University of Wisconsin-Milwaukee, Department of Civil Engineering and Mechanics, Milwaukee, WI.

United States Department of Transportation (USDOT). (2000). Comprehensive Truck Size and Weight Study. *Report FHWA-PL-00-029*, Washington D.C.

Wisconsin Department of Transportation. (2008). *2007 Wisconsin Vehicle Classification Data.* Madison, WI.

Wisconsin Department of Transportation. (2013). "AASHTOWare Pavement ME Design Training." Workshop conducted by the WisDOT BTS Pavements and Subsurface Exploration Unit, Madison, WI. June 4-6.

Wisconsin Department of Transportation. (2013). "Oversize-Overweight Permits." Doing Business, <http://www.dot.wisconsin.gov/business/carriers/osowgeneral.htm.> (Jul 30, 2013).

Wisconsin Traffic Operations and Safety Laboratory (WI TOPS). (2014). "Wisconsin Hourly Traffic Data Index Page." The WisTransPortal System, <https://transportal.cee.wisc.edu/products/hourly-traffic-data/bysiteid/> (Mar. 25, 2014).

Woodson, R. D. (2012). *Concrete Portable Handbook*. 1st Ed., Elsevier.

APPENDIX A: AASHTOWare MEPDG DEFAULT TRAFFIC INPUTS FOR WISCONSIN

Table A1: WisDOT standard vehicle class distribution

FHWA Vehicle Class	Rural Principal Arterial - Interstate	Rural Principal Arterial - Other	Rural Minor Arterial	Urban Principal Arterial - Other
4	1.3	3.1	8.3	1.3
5	25.8	19.8	31.7	23.4
6	6.1	11.2	9.4	3.7
7	0.3	1.1	3	2.5
8	7.2	11	12.1	3.7
9	55.5	50.6	31.9	62.6
10	0.8	1.6	1.7	2.2
11	1.3	1	0	0.2
12	0.5	0.2	0	0.1
13	1.2	0.4	1.9	0.3

Table A2: WisDOT standard monthly adjustment factors for AASHTOWare MEPDG

Month	FHWA Vehicle Class									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
January	1.06	0.7	0.7	0.76	0.72	0.92	0.83	0.67	0.8	0.55
February	0.92	0.79	0.75	0.78	0.77	0.95	0.86	0.84	0.79	0.72
March	0.91	0.82	0.77	0.81	0.81	0.97	0.88	0.94	0.81	0.84
April	0.99	0.95	0.93	0.92	0.93	0.98	0.98	0.85	0.95	1.12
May	0.89	1.08	1.13	1	1.05	1	1	1.07	0.78	1.01
June	1.08	1.17	1.23	1.22	1.26	1.05	1.21	1.28	1.23	0.97
July	1.02	1.28	1.2	1.05	1.41	1	1	1.08	0.89	1.24
August	1.02	1.21	1.2	1.21	1.33	1.05	1.16	1.2	1.59	1.08
September	1.08	1.14	1.14	1.32	1.18	1.06	1.1	1.01	1.79	1.2
October	1.21	1.11	1.23	1.08	1	1.07	1.06	1.06	0.93	1.51
November	0.96	0.94	0.93	1.15	0.8	1	1.08	1.01	0.92	1.09
December	0.86	0.81	0.79	0.7	0.74	0.95	0.84	0.99	0.52	0.67

Table A3: WisDOT standard hourly classification distribution

Time of Day (Hour)	Rural and Urban Highways
0	1.02
1	0.93
2	1.25
3	1.58
4	2.39
5	3.46
6	5.19
7	6.12
8	6.59
9	6.93
10	7.09
11	7.3
12	7.3
13	7.09
14	6.82
15	6.23
16	5.44
17	4.44
18	3.58
19	2.67
20	2.14
21	1.79
22	1.56
23	1.09

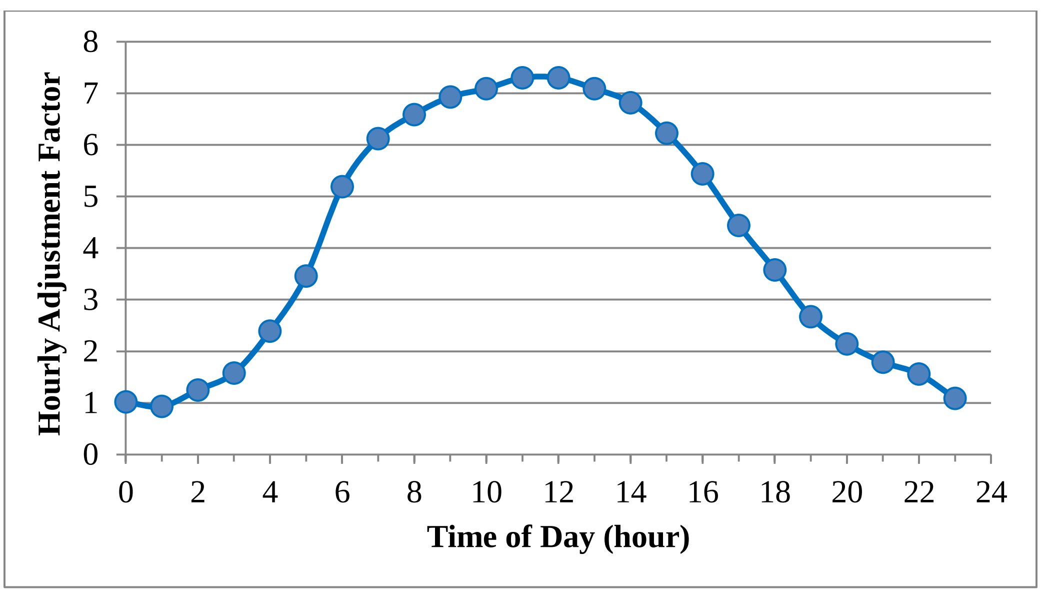


Figure A1: Plot of WisDOT hourly adjustment factors

Table A4: WisDOT standard for axles per truck

FHWA Vehicle Class	Axle Type			
	Single	Tandem	Tridem	Quad
4	1.3	0.7	0	0
5	2.2	0	0	0
6	1	1	0	0
7	1	0	0.4	0.8
8	2.4	0.6	0	0
9	1.3	1.9	0	0
10	1.1	1.1	0.8	0
11	4.9	0.1	0	0
12	4	1	0	0
13	1.2	0.8	0.7	0.6

Table A5: WisDOT standard ALS for single axle configuration

	FHWA Vehicle Class									
Axle Load (lbs)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
3,000	4.1	6.7	5.8	7.0	13.0	8.6	9.2	10.6	12.2	12.8
4,000	0.2	16.8	0.1	0.2	3.2	0.9	0.1	3.8	10.1	0.3
5,000	1.3	28.4	0.3	0.3	5.4	2.2	0.1	5.5	10.1	0.5
6,000	0.7	15.5	0.5	0.3	4.6	2.5	0.3	5.6	7.1	1.6
7,000	2.4	7.6	1.1	0.3	6.1	1.4	0.9	5.8	5.5	1.6
8,000	5.3	7.0	4.1	0.4	10.5	3.1	4.6	7.4	5.0	2.5
9,000	9.3	4.8	8.7	0.5	13.5	7.6	11.9	9.2	10.0	4.3
10,000	12.1	3.9	15.9	1.2	14.6	16.9	19.0	10.7	9.1	8.8
11,000	12.9	2.4	17.4	1.2	8.1	22.2	20.3	10.0	5.3	11.2
12,000	15.6	1.9	15.5	2.4	5.3	19.7	16.7	7.1	5.6	13.9
13,000	12.0	1.2	10.8	4.2	3.7	4.8	5.4	5.2	3.6	10.8
14,000	11.0	1.0	10.0	7.2	3.4	1.3	3.2	5.5	3.7	10.8
15,000	6.0	0.7	4.6	11.2	2.9	1.1	2.0	4.4	3.7	7.7
16,000	3.3	0.5	1.8	12.7	1.8	1.3	1.3	2.9	4.4	5.4
17,000	1.7	0.4	1.5	16.6	1.4	1.9	1.2	2.6	3.0	2.9
18,000	0.6	0.3	0.8	12.6	0.9	1.6	0.9	1.6	1.0	2.3
19,000	0.6	0.3	0.6	10.6	0.7	1.3	1.1	1.2	0.5	1.0
20,000	0.4	0.2	0.3	5.5	0.4	0.8	0.6	0.6	0.1	0.6
21,000	0.2	0.2	0.1	3.4	0.3	0.5	0.8	0.2	0.0	0.4
22,000	0.1	0.1	0.1	1.2	0.1	0.2	0.2	0.0	0.0	0.2
23,000	0.1	0.1	0.0	0.7	0.1	0.1	0.1	0.1	0.0	0.1
24,000	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1
25,000	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
26,000	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
27,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	100	100	100	100	100	100

Table A6: WisDOT standard ALS for tandem axle configuration

		FHWA Vehicle Class									
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Axle Load (lbs)	**6,000**	3.0	43.0	6.1	0.1	9.2	9.7	9.5	10.1	12.7	11.8
	8,000	1.0	31.5	3.1	2.5	3.3	2.5	0.3	0.0	2.1	1.4
	10,000	1.2	13.7	11.1	2.8	7.5	4.7	1.0	0.0	10.9	2.4
	12,000	2.3	4.4	7.5	5.4	17.7	8.3	2.3	6.1	12.6	3.1
	14,000	5.8	0.9	8.2	4.7	18.7	9.1	6.2	60.0	16.3	3.2
	16,000	5.7	0.4	11.4	2.7	15.1	7.2	9.0	17.7	7.3	2.9
	18,000	4.7	0.7	7.2	5.2	11.3	5.3	4.9	0.0	7.4	5.4
	20,000	6.0	1.6	5.1	3.5	7.1	4.7	3.6	0.0	8.2	6.7
	22,000	8.1	0.6	4.7	7.5	4.1	4.1	3.5	0.0	10.6	7.5
	24,000	7.5	2.3	4.3	11.7	2.2	3.9	4.3	0.0	7.9	6.9
	26,000	11.7	0.9	5.4	4.3	1.5	4.1	5.4	0.0	2.6	5.0
	28,000	14.9	0.0	4.5	6.6	0.9	4.8	7.5	0.0	0.2	5.4
	30,000	9.9	0.0	4.4	6.6	0.5	6.3	9.1	0.0	0.2	5.4
	32,000	7.0	0.0	4.5	5.5	0.4	8.9	8.4	0.0	0.5	7.0
	34,000	4.2	0.0	4.8	5.7	0.3	9.4	6.9	6.1	0.5	6.1
	36,000	2.7	0.0	3.8	6.2	0.1	4.2	5.4	0.0	0.0	4.0
	38,000	1.5	0.0	2.1	5.7	0.1	1.6	3.9	0.0	0.0	3.7
	40,000	0.5	0.0	0.9	2.9	0.0	0.7	3.0	0.0	0.0	2.7
	42,000	0.7	0.0	0.4	0.5	0.0	0.3	2.0	0.0	0.0	2.0
	44,000	0.5	0.0	0.2	1.4	0.0	0.1	1.4	0.0	0.0	1.7
	46,000	0.8	0.0	0.1	2.7	0.0	0.1	0.9	0.0	0.0	1.7
	48,000	0.2	0.0	0.1	3.2	0.0	0.0	0.6	0.0	0.0	1.4
	50,000	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.4
	52,000	0.0	0.0	0.0	1.5	0.0	0.0	0.2	0.0	0.0	0.5
	54,000	0.0	0.0	0.0	1.1	0.0	0.0	0.1	0.0	0.0	0.6
	56,000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
	58,000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	60,000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
	62,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	64,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	66,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	68,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	70,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72,000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	74,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	76,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	78,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	80,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	82,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100	100	100	100	100	100	100	100	100	100

Table A7: WisDOT standard ALS for tridem axle configuration

		FHWA Vehicle Class									
		4	5	6	7	8	9	10	11	12	13
Axle Load (lbs)	12,000	0.0	88.0	5.6	6.6	0.0	38.0	16.5	0.0	0.0	12.0
	15,000	0.0	6.0	0.0	0.4	0.0	9.1	14.2	0.0	0.0	1.8
	18,000	0.0	6.0	0.0	1.5	0.0	10.9	6.7	0.0	0.0	2.6
	21,000	0.0	0.0	0.0	1.9	0.0	9.0	2.7	0.0	0.0	3.3
	24,000	0.0	0.0	0.0	2.8	0.0	3.5	2.4	0.0	0.0	6.0
	27,000	0.0	0.0	47.2	4.3	0.0	5.4	2.6	0.0	0.0	4.9
	30,000	0.0	0.0	0.0	6.3	0.0	9.4	3.1	0.0	0.0	3.2
	33,000	0.0	0.0	0.0	10.0	0.0	5.0	3.6	0.0	0.0	2.3
	36,000	0.0	0.0	47.2	10.5	0.0	2.2	5.0	0.0	0.0	2.3
	39,000	0.0	0.0	0.0	13.3	0.0	1.5	7.4	0.0	0.0	3.0
	42,000	0.0	0.0	0.0	13.7	0.0	5.0	7.8	0.0	0.0	3.3
	45,000	0.0	0.0	0.0	10.9	0.0	0.0	6.5	0.0	0.0	3.9
	48,000	0.0	0.0	0.0	6.5	0.0	1.0	5.9	0.0	0.0	5.9
	51,000	0.0	0.0	0.0	4.1	0.0	0.0	5.0	0.0	0.0	7.0
	54,000	0.0	0.0	0.0	3.2	0.0	0.0	3.6	0.0	0.0	7.3
	57,000	0.0	0.0	0.0	2.0	0.0	0.0	2.1	0.0	0.0	8.2
	60,000	0.0	0.0	0.0	0.9	0.0	0.0	1.5	0.0	0.0	6.3
	63,000	0.0	0.0	0.0	0.5	0.0	0.0	1.0	0.0	0.0	4.5
	66,000	0.0	0.0	0.0	0.2	0.0	0.0	0.7	0.0	0.0	4.0
	69,000	0.0	0.0	0.0	0.2	0.0	0.0	0.6	0.0	0.0	2.6
	72,000	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0	1.9
	75,000	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.8
	78,000	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.7
	81,000	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	1.0
	84,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	87,000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5
	90,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	93,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	96,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	99,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	102,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		0	100	100	100	0	100	100	0	0	100

Table A8: WisDOT Standard Statewide ALS for quad axle configuration

		FHWA Vehicle Class									
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Axle Load (lbs)	**12,000**	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	14.0
	15,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
	18,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
	21,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
	24,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8
	27,000	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.2
	30,000	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	4.2
	33,000	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	3.2
	36,000	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	3.4
	39,000	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	3.5
	42,000	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	4.2
	45,000	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	4.6
	48,000	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	4.0
	51,000	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0	3.9
	54,000	0.0	0.0	0.0	22.4	0.0	0.0	0.0	0.0	0.0	3.3
	57,000	0.0	0.0	0.0	27.4	0.0	0.0	0.0	0.0	0.0	3.3
	60,000	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	2.0
	63,000	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	3.2
	66,000	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	3.6
	69,000	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.6
	72,000	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	1.9
	75,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	78,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
	81,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
	84,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
	87,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4
	90,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	93,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	96,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	99,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	102,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		0	0	0	100	0	0	0	0	0	100

APPENDIX B: FULL RESULTS OF FIELD TRAFFIC COUNTS

Table B1: Summary of 6 hour traffic count in field for STH 140

FHWA Vehicle Class	South Bound (SB)				North Bound (NB)				TOTAL
	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	Total	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	Total	
1	0	0	0	**0**	1	0	0	**1**	**1**
2	58	54	60	**172**	71	80	61	**212**	**384**
3	25	19	20	**64**	24	23	19	**66**	**130**
4	0	2	0	**2**	0	0	0	**0**	**2**
5	7	9	6	**22**	0	2	1	**3**	**25**
6	6	10	4	**20**	4	10	9	**23**	**43**
7	0	0	3	**3**	0	0	2	**2**	**5**
8	0	1	1	**2**	0	1	0	**1**	**3**
9	28	26	20	**74**	25	34	31	**90**	**164**
10	1	2	1	**4**	2	1	3	**6**	**10**
11	1	1	1	**3**	0	1	1	**2**	**5**
12	1	0	0	**1**	1	1	1	**3**	**4**
13	1	1	0	**2**	0	1	0	**1**	**3**
Total	128	125	116	**369**	128	154	128	**410**	**779**

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Table B2: Summary of 6 hour traffic count in field for STH 11

FHWA Vehicle Class	West Bound (WB)				East Bound (EB)				TOTAL
	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	
1	0	0	0	**0**	0	0	0	**0**	**0**
2	99	97	90	**286**	117	91	127	**335**	**621**
3	95	95	57	**247**	51	75	65	**191**	**438**
4	3	2	1	**6**	1	2	0	**3**	**9**
5	4	10	14	**28**	6	14	10	**30**	**58**
6	10	16	2	**28**	13	8	6	**27**	**55**
7	2	0	2	**4**	3	2	1	**6**	**10**
8	0	0	0	**0**	1	1	1	**3**	**3**
9	9	8	6	**23**	5	5	6	**16**	**39**
10	0	0	6	**6**	0	1	0	**1**	**7**
11	0	0	0	**0**	0	0	0	**0**	**0**
12	0	0	0	**0**	0	0	0	**0**	**0**
13	0	0	1	**1**	0	0	0	**0**	**1**
Total	222	228	179	**629**	197	199	216	**612**	**1241**

Table B3: Summary of 6 hour traffic count in field for STH 23

FHWA Vehicle Class	West Bound (WB)				East Bound (EB)				TOTAL
	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	
1	0	0	0	**0**	0	0	0	**0**	**0**
2	156	185	168	**509**	179	205	212	**596**	**1105**
3	60	45	55	**160**	59	54	68	**181**	**341**
4	0	0	0	**0**	0	1	3	**4**	**4**
5	24	20	20	**64**	10	15	12	**37**	**101**
6	4	4	9	**17**	5	6	3	**14**	**31**
7	2	2	0	**4**	3	5	1	**9**	**13**
8	3	0	0	**3**	2	1	1	**4**	**7**
9	55	43	46	**144**	57	43	57	**157**	**301**
10	1	1	1	**3**	0	1	1	**2**	**5**
11	0	0	1	**1**	2	1	0	**3**	**4**
12	0	1	0	**1**	0	0	0	**0**	**1**
13	0	0	0	**0**	0	0	1	**1**	**1**
Total	305	301	300	**906**	317	332	359	**1008**	**1914**

Table B4: Summary of 6 hour traffic count in field for STH 26

FHWA Vehicle Class	South Bound (SB)				North Bound (NB)				TOTAL
	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	8:00 to 10:00	10:00 to 12:00	12:00 to 14:00	**Total**	
1	0	0	1	**1**	0	1	0	**1**	**2**
2	245	225	290	**760**	251	283	256	**790**	**1550**
3	58	50	47	**155**	65	52	83	**200**	**355**
4	1	0	1	**2**	2	3	2	**7**	**9**
5	22	20	20	**62**	23	17	25	**65**	**127**
6	6	4	3	**13**	3	9	6	**18**	**31**
7	0	0	0	**0**	1	3	3	**7**	**7**
8	1	0	1	**2**	2	1	0	**3**	**5**
9	92	125	100	**317**	100	127	93	**320**	**637**
10	3	0	1	**4**	2	0	2	**4**	**8**
11	0	0	0	**0**	1	0	0	**1**	**1**
12	0	0	0	**0**	0	0	0	**0**	**0**
13	0	0	0	**0**	0	0	1	**1**	**1**
Total	428	424	464	**1316**	450	496	471	**1417**	**2733**

APPENDIX C: AASHTOWare MEPDG OUTPUT REPORT

EXAMPLE COVER PAGE

Wis 140 (Normal + Permit Traffic)

File Name: C:\Users\VLatifi\Desktop\AASHTOWare Thesis Analysis\WI-140\Wis 140 (Normal + Permit Traffic).dgpx

Design Inputs

Design Life:	20 years	Base construction:	May, 1996	Climate Data Sources (Lat/Lon)	43.141, -89.345
Design Type:	Flexible Pavement	Pavement construction:	June, 1996		
		Traffic opening:	September, 1996		

Design Structure

Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	2.0
Flexible	Default asphalt concrete	2.0
NonStabilized	Crushed stone	4.5
Subgrade	A-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	11.6
Air voids (%)	7.0

Traffic

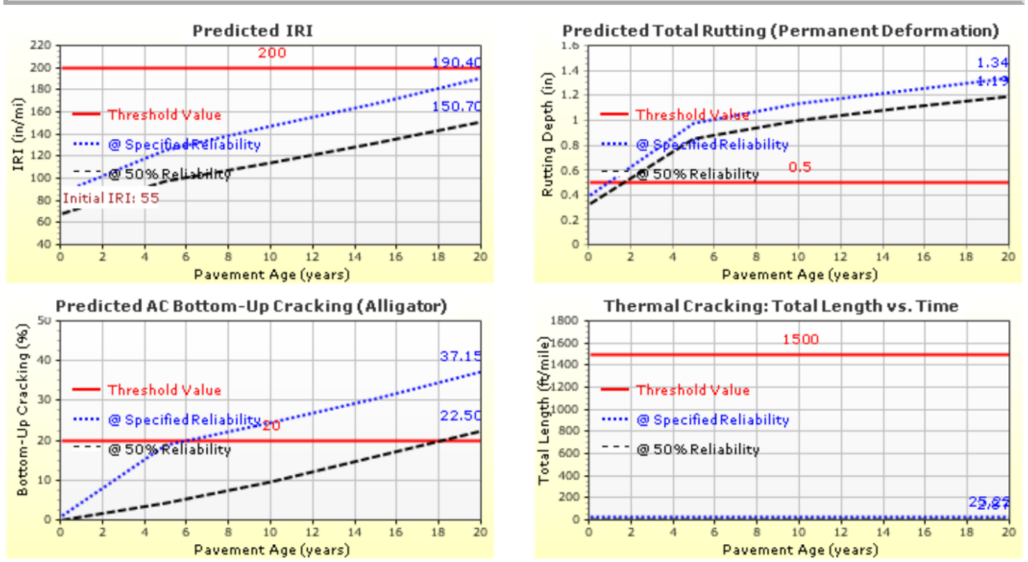
Age (year)	Heavy Trucks (cumulative)
1996 (initial)	644
2006 (10 years)	1,349,500
2016 (20 years)	3,163,120

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	200.00	190.37	85.00	90.12	Pass
Permanent deformation - total pavement (in.)	0.50	1.34	85.00	0.00	Fail
AC bottom-up fatigue cracking (percent)	20.00	37.14	85.00	42.98	Fail
AC thermal cracking (ft/mile)	1500.00	25.22	85.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	10638.04	85.00	0.66	Fail
Permanent deformation - AC only (in.)	0.50	0.34	85.00	99.90	Pass

Distress Charts



Report generated on: 4/23/2014 11:44 AM	Created by: on: 8/1/2013 2:22 PM	Approved by: on: 8/1/2013 2:22 PM	Page 1 of 21

Figure C1: Cover page of output report from AASHTOWare MEPDG for analysis conducted on STH 140 for baseline plus OSOW traffic