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FINAL REPORT FOR ALDOT PROJECT 930-870

WIM-BASED LIVE LOAD FOR ALABAMA BRIDGES

PREPARED BY

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SUBMITTED TO

ALABAMA DEPARTMENT OF TRANSPORTATION
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16. Abstract
The objective of this study is to review the available WIM data for Alabama and assess the degree of damage in highway bridges depending on traffic volume (ADTT) and weight of heavy vehicles. The WIM database for Alabama includes 97 million vehicles. After filtering to eliminate vehicles lighter than 20kips and questionable records, the data was reduced to 57 million. The collected records were provided from 13 WIM stations and they cover a period of 9 years (2006-2014). The statistical parameters are determined for GVW and live load affects such as moment and shear forces. The data can be considered as representative for the state of Alabama. The knowledge of the actual live load is essential for a rational management of highway structures. Overloaded vehicles can cause damage including concrete cracking, potholes, excessive vibration and deflection and even a catastrophic collapse. It has been observed that traffic load is strongly site-specific. There are considerable differences in traffic volume and weight of trucks. The cumulative distribution function (CDF) of the gross vehicle weight (GVW) is considered separately for different locations, years and classes of vehicles. On average, about 10% of all recorded vehicles are heavier than 80 kips. Permit trucks and illegally overloaded vehicles were identified using special filtering criteria. The percentage of permit trucks and illegally overloaded vehicles is less than 0.1% for most locations. The live load effects are calculated using influence lines of moments and shear forces for a broad range of span length. The results are plotted on the probability paper for an easier interpretation of the results. For the considered locations, the percentage of overloaded vehicles is determined to facilitate a site-specific comparison. The present study confirmed that for each WIM location, it is possible to pinpoint which types of vehicles have a significant contribution to bridge damage. A load model is developed for the state of Alabama based the extrapolation of the upper tail of the moment and shear distributions. It is concluded that Weight-in-Motion data is an important source of information about the actual traffic load presented in the region or state.

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ABSTRACT

The objective of this study is to review the available WIM data for Alabama and assess the degree of damage in highway bridges depending on traffic volume (ADTT) and weight of heavy vehicles. The WIM database for Alabama includes 97 million vehicles. After filtering to eliminate vehicles lighter than 20kips and questionable records, the data was reduced to 57 million. The collected records were provided from 13 WIM stations and they cover a period of 9 years (2006-2014). The statistical parameters are determined for GVW and live load affects such as moment and shear forces. The data can be considered as representative for the state of Alabama. The knowledge of the actual live load is essential for a rational management of highway structures. Overloaded vehicles can cause damage including concrete cracking, potholes, excessive vibration and deflection and even a catastrophic collapse. It has been observed that traffic load is strongly site-specific. There are considerable differences in traffic volume and weight of trucks. The cumulative distribution function (CDF) of the gross vehicle weight (GVW) is considered separately for different locations, years and classes of vehicles. On average, about 10% of all recorded vehicles are heavier than 80 kips. Permit trucks and illegally overloaded vehicles were identified using special filtering criteria. The percentage of permit trucks and illegally overloaded vehicles is less than 0.1% for most locations. The live load effects are calculated using influence lines of moments and shear forces for a broad range of span length. The results are plotted on the probability paper for an easier interpretation of the results. For the considered locations, the percentage of overloaded vehicles is determined to facilitate a site-specific comparison. The present study confirmed that for each WIM location, it is possible to pinpoint which types of vehicles have a significant contribution to bridge damage. A load model is developed for the state of Alabama based the extrapolation of the upper tail of the moment and shear distributions. It is concluded that Weight-in-Motion data is an important source of information about the actual traffic load presented in the region or state. Traffic records are also weighty in terms of the frequency and configuration of vehicles and can be widely used for road planning, bridge evaluation, design live load modeling and damage accumulation models.

LIST OF CONTENT

LIST OF TABLES:

LIST OF FIGURES:

1.INTRODUCTION

1.1.Background

Knowledge of the actual loads is needed for efficient bridge maintenance, in particular, evaluation of existing structures, prediction of the remaining life and planning repairs, rehabilitation and/or replacements. The occurrence of illegally overloaded vehicles may call for focusing the law enforcement effort. Most of the state DOT's collect data on traffic loads using the weigh-in-motion (WIM) stations. Alabama WIM data includes more than 100 million records. The objective of this project is to process the available information and develop statistical models for traffic loads in Alabama.

The actual traffic is a mixture of cars, trucks and other special vehicles. Heavy trucks include regular traffic, permit vehicles and illegally overloaded vehicles. All vehicles recorded by WIM stations are categorized using the FHWA vehicle classification scheme depending on whether the vehicle carries passengers or commodities. Non-passenger vehicles are further subdivided depending on the number of axles and number of units, including both power and trailer units. The addition of a light trailer does not change the classification of a vehicle.

There are 13 WIM stations in Alabama. In all of them, except one, the wheel and axle loads are measured using bending plate technique. The other one is referred to as Bridge-WIM station and it uses a bridge as the scale. Bridge girders are instrumented and the system is calibrated. At some WIM stations, the data has been collected since 2006.

Knowledge of the gross vehicle weight (GVW) and axle loads is important from the point of view of law enforcement, in particular, this applied to the identification of illegally overloaded vehicles. However, live load for bridges and roads is the load effect such as moments and shear forces. To assess the effect of the traffic, the vehicles in the WIM database have to be run over the influence lines to determine the maximum moments and shear forces. The influence lines depend on the span length. For short span bridges, the major damage can be attributed to overloaded axles or group of shortly spaced axles rather than vehicles with the maximum GVW.

The design live load specified in AASHTO LRFD Code, HL-93, was developed on the basis of truck load survey in Ontario, Canada in 1977 (NCHRP Report 368) because of lack of reliable truck data in the USA. The available WIM data can serve as a basis for verification of the statistical parameters and validity of HL-93 live load as a representative for the traffic in the United States. In particular, there is a need to compare the Alabama WIM data with other states and verify if HL-93 is representative for Alabama traffic.

1.2.Prior investigation

The WIM system determines wheel and axle loads by measurement changes in the signal received by sensors, such as voltage, strain, and resistance. For the WIM systems embedded in pavements, the accuracy depends on pavement roughness, speed, and vehicle suspension. Other factors including installation, calibration, and maintenance also contribute to the accuracy of measured data. In a Bridge Weigh-in-Motion (BWIM) system, the axle loads are determined from recorded strains, using influence lines and calibration factors.

One of the first WIM systems was developed in 1952 by the United States Bureau of Public Roads (predecessor of FHWA) (*Norman and Hopkins 1952*). It was just a reinforced concrete platform instrumented with resistance wire strain gauges. The vehicle weight was calculated manually with the help of output of an oscilloscope attached to strain gauges. Contemporary WIM systems are very different from the sensors developed in 1952. They can, in addition to axle loads, determine the vehicle type and analyze, process and transmit recorded data (*AASHTO LRFD*, 2014).

In BWIM systems an existing bridge or culvert is used as a scale for weighing the vehicles. It was developed by researchers led by Dr. Fred Moses in 1979 and became widely employed in Australia for instrumenting culverts. In 1990's, an improved and upgraded version of the system was applied in Slovenia, Ireland, and France in 1990's (*COST 323, 2002 , O'Brien; et al. 1999)*. BWIM system is also tried on a selected bridge in Alabama.

Despite the advantages of WIM technologies, a decrease in WIM research was observed since 2000 in comparison to 1999's (*Pigman et al. 2012*). One of the reasons is that the setting of permanent WIM devices, as well as following service, is quite costly. As of 2012 the installation of permanent WIM station for a four-lane highway costs more than $220,000. Therefore, the WIM systems are usually installed on busy state roads or interstate highways. However, a low average daily traffic (ADT) on rural roads does not necessarily mean a low presence of illegally overloaded vehicles.

A properly installed and maintained WIM system has the capacity to produce the traffic data of high quality *(Pigman et al. 2012, Quinley 2010)*. However, the raw data generated by any kind of WIM system has to be validated and processed (*ASTM E1318* 2009). The guidance for quality control, missing data or systematic error identification was developed by Quinley (*2010*).

Weigh-in-motion data is an important source of information about the actual traffic load presented in a particular region or state, including frequency and configuration of vehicles. The detailed records from WIM stations include the exact time and date, lane and direction code, speed, class of vehicle based on FHWA Classification scheme (*MAG Internal Truck Travel Survey and Truck Model Development Study* 2007), individual axle loads and spacing, GVW, speed, etc. (*Traffic Monitoring Guide* 1995). Routine monitoring of the traffic in each lane is also needed for determining the Average Daily Traffic (ADT) and Average Daily Truck Traffic (ADTT) which are necessary for fatigue life and load capacity computation. This data widely used for traffic monitoring and analysis, pavement safety evaluation, bridge structures design, and enforcement.

Use of WIM for evaluation of existing bridges was considered by Moses (*Moses 2001 and Sivakumar 2007*) and it served as a basis for load factors in AASHTO Guide Manual for Condition Evaluation and Load and Resistance Factor Rating *(AASHTO LRFR 2011)*. The changes in the truck traffic volume, weight, and configuration during recent decades were reviewed by Treacy and Brühwiler *(2012)* and Ghosn et al. (*2011)*. A set of protocols and techniques for collection and analysis of the WIM data along with the methods for calibration of the live load factors for LRFD design are presented in the report by Ghosn et al. *(2011*). WIM records collected from 26 sites in 2005-2006 in California, Texas, Florida, Indiana, and Mississippi were considered in this research.

The problem of unrestricted operation of the short trucks with GVW below 80kips was considered by Sivakumar (2007) using much larger WIM database collected from 18 states during 2001-2003. The vehicles meeting Federal Formula B are considered “legal” and posting is not required. However, they often cause stress that exceeds the AASHTO Legal Loads for Posting limitation.

1.3. Objectives of the Project

The main objective of this project is to process and validate the available WIM data for Alabama, develop statistical parameters for gross vehicle weight and live load effects in bridges and identify the vehicles that can be harmful to the roads and bridges.

The research involved the following tasks:

1. Review of the available WIM database collected by ALDOT WIM stations.
2. Processing of the available WIM data to obtain the statistical parameters. The statistical parameters were also determined for various WIM stations and groups of trucks.
3. Development of the statistical parameters for live load effects, i.e. moment and shear.
4. Comparison of the Alabama WIM data with WIM data for other States.
5. Confirmation of the validity of the WIM data for Alabama.
6. Development of recommendations for further WIM needs in Alabama (quantity, quality, locations, equipment, processing).

1.4.WIM Systems

The WIM data was obtained from 13 locations in Alabama. ALDOT operates 12 traditional WIM stations and one SiWIM (or BWIM) station. Currently, ALDOT transforms the traditional WIM stations into Virtual WIM Stations. However, no data from the Virtual WIM Stations was available for this project.

In the traditional WIM station, the wheel loads are measured using a permanent bending plate systems consisting of two scales and inductive loops as shown in Figure 1. Calibration of the weighing system was performed using test trucks according to *ASTM E1318 - 09 - Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods* 2009.

Figure 1: Bending plate systems in WIM location 965 (Shorter, I-85)

The other system is Bridge-WIM, and it uses the bridge as a scale. Strain transducers are attached to structural components to measure strain/stress, and axle loads are calculated using influence lines and calibrated factors as presented in *SiWIM Bridge Weigh-in-Motion Manual: 4th Edition* 2011.

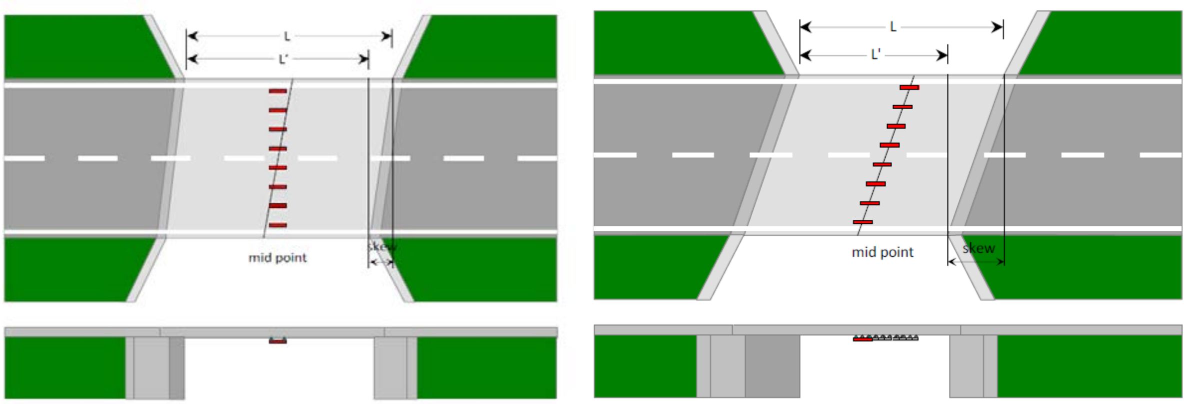


Figure 2: Recommended placement of strain transducers - SiWIM Bridge Weigh-in-Motion Manual, 4th Edition (2011).

The B-WIM system was installed on a bridge carrying US-231. Placement of strain transducers on the bottom surface of the main longitudinal members and axle detectors are shown in Figure 2. The accuracy of B-WIM is verified by following a procedure that is in accordance with the European WIM Specifications – COST 323, 1999. The calibration was performed using test trucks, with known axle loads and spacing.   According to *SiWIM Bridge Weigh-in-Motion Manual: 4th Edition* Class A(5), the accuracy depends on the roughness of the wearing surface. For a smooth surface, approximately 95 % of recorded vehicles are expected to have the GVW within ±5 % of the actual value, a single axle load of ±15 % and a group of axles within ±12 %. However, the results can be considerably less accurate for a very rough wearing surface.

Vehicle classification is primarily based on axial spacing for both WIM systems. For the traditional WIM stations, it follows the Scheme F modified in the *Traffic Monitoring Guide* 1995. The main principle is a comparison of the measured axial spacing with the corresponding values that are assigned to certain vehicle classes. A similar approach is used for SiWIM system records. Finally, vehicle class is verified based on expected GVW and reclassified if needed.

There are several other factors that can influence the accuracy of measurements, such as pavement roughness, resulting in bouncing axle movement or dynamic loads. However, the dynamic portion of load can be estimated and filtered out. Temperature effect can be considered as negligible due to a relative absence of freeze-and-thaw cycles in Alabama.

Most of the WIM systems can record over 15,000 trucks a day and collect about 30 days of continuous raw data. Traffic Volume Trends (TVT) system is used to process the continuous traffic volume data and produces a monthly Traffic Volume Trends report in the FHWA’s Traffic Monitoring Guide Card format(*Traffic Monitoring Guide* 1995). The WIM database obtained by combining TVT monthly reports was analyzed in this project.

2 WIM DATA PROCESSING

2.1.Data Characteristics

WIM data was collected from 13 locations around the State (Figure 3). Initially, WIM database covered the time period from 2009 till 2014. Further on, it was completed with data recorded at the same WIM stations during 2006-2008. Previously, these records were used in project “Development of Alabama Traffic Factors for Use in Mechanistic-Empirical Pavement Design” (2015). A summary of all the available records is presented in for each location identified with a station code, name and year. The following information from each particular site was also specified: time of record, direction of travel code, gross vehicle weight (GVW), vehicle type, axle spacing, axle loads, and also vehicle speed. Special MATLAB routines were developed to convert the data into the required format.

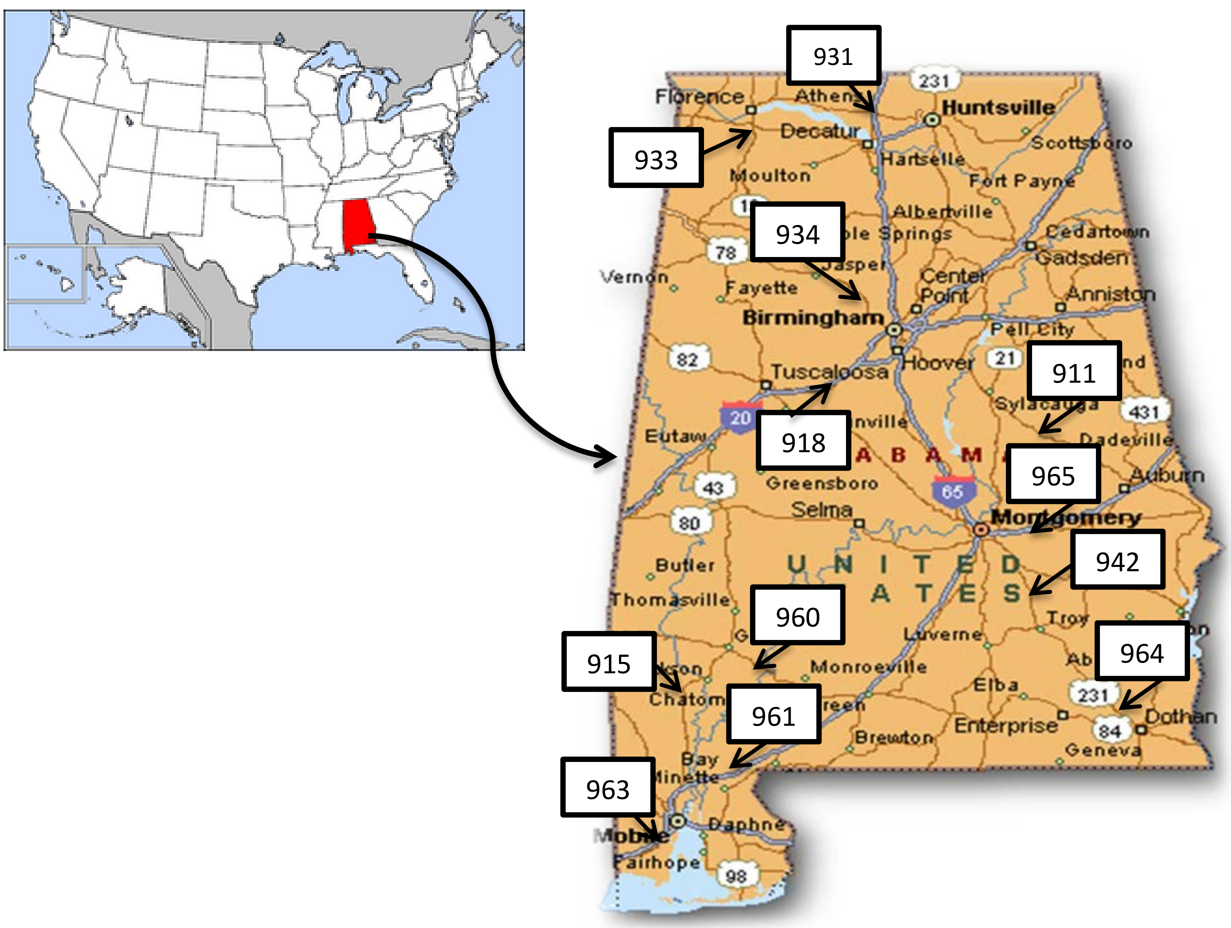


Figure 3: Locations of WIM data stations in Alabama

2.2.WIM Data Collection

Initial processing of available database was based on ensuring proper format and quality of records. Specially developed MATLAB (*MATLAB* 2014) routines were used to convert original records in TMGC format to MATLAB tables suitable for further analysis. The years and months covered are marked in Tables 1, 2 and 3. The names of WIM locations were indicated based on coordinates and then verified with ALDOT (Tables 4 and 5).

It was observed that some data points were recorded incorrectly. WIM data from location 918 (Bucksville) which was corrupted for years 2009-2014, was received later undamaged for years 2006-2008 and processed (Tables 1 and 2). For most of the locations, records were taken from January 2006 until January 2008. Locations 931 (Athens, I-65) for 2006, 933 (Muscle Shoals, AL157-US72) for the year 2007 and 964 (Ozark, US-231) for the year 2007 constitute the only exceptions in records:

- 931 (Athens, I-65) – 2006 – WIM data from April 2006 until January 2007 are missed;
- 933 (Muscle Shoals, AL157-US72) – 2007 – WIM data from July 2007 until December 2007 are missed;
- 964 (Ozark, US-231) – 2007 - WIM data from July 2007 until December 2007 are missed.

Table 1: Summary of received WIM data for years 2006÷2008

Station code	2006												2007												2008											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
911	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
915	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
918	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
931	x	x	x										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
933	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x
934	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
942	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
960	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
961	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
963	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
964	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x
965	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
US231																																				

x – month, when records were taken

Table 2: Summary of received WIM data for years 2009÷2011

Station code	2009												2010												2011											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
911																																				
915																		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
918																																				
931	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
933	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
934																																				
942																																				
960																																				
961																																				
963																																				
964	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
965																																				

x – month when records were taken

Table 3: Summary of received WIM data for years 2012÷2014

Station code	2012												2013												2014											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
911					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x					
915	x	x											x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x					
918	x	x	x	x	x	x	x	x	x	x	x	x														x										
931													x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x					
933													x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x					
934													x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x					
942	x	x	x										x	x	x	x	x	x	x	x	x			x			x	x	x	x	x					
960	x	x		x	x	x							x	x	x	x	x	x	x	x	x			x			x	x	x	x	x					
961													x	x	x	x	x		x	x	x			x		x	x		x	x	x					
963	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x			x	x	x	x	x	x	x						
964													x	x	x	x	x	x	x	x	x			x			x	x	x	x	x					
965	x	x	x	x	x	x	x	x																x	x	x	x	x	x	x	x					
US231											x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							

– change in station in 911 to 915; – 734,277 vehicles eliminated during reading of the file due to errors ;

– data is corrupted; – empty file;

– change in the station in 931 to 915 ;

x – month when records were taken

Table 4: Number of vehicles in the WIM database for years 2006÷2008

Station code	Name	Location	2006	2007	2008	Total
911	**Alex City**	**US280 Coosa Co.**	633,635	853,805	651,465	**2,138,905**
915	**Sunflower**	**US43 Washington Co.**	570,609	614,303	672,752	**1,857,664**
918	**Bucksville**	**I20 Tuscaloosa Co.**	4,014,171	3,600,565	3,977,030	**11,591,766**
931	**Athens**	**I65 Limestone Co.**	236,000	2,439,726	2,139,310	**4,815,036**
933	**Muscle Shoals**	**AL157 US72 Colbert Co.**	1,545,979	902,298	1,381,968	**3,830,245**
934	**Sumiton**	**US78 Walker Co.**	2,084,129	2,132,577	678,764	**4,895,470**
942	**Pine Level**	**US231 Montgomery Co.**	1,426,193	1,468,054	724,325	**3,618,572**
960	**Whatley**	**US84 Clark Co.**	696,390	703,349	517,375	**1,917,114**
961	**Mobile**	**I65 Mobile Co.**	2,128,877	2,016,154	2,428,785	**6,573,816**
963	**Grand Bay**	**I10 Mobile Co.**	4,476,261	3,400,749	3,508,336	**11,385,346**
964	**Ozark**	**US231 Dothan Co.**	701,783	354,362	1,009,975	**2,066,120**
965	**Shorter**	**I85**	2,842,778	2,794,637	2,491,993	**8,129,408**
	US 231					**-**
		TOTAL				**62,819,462**

Table 5: Number of vehicles in the WIM database for years 2009÷2014

Station code	Name	Location	2009	2010	2011	2012	2013	2014	Total
911	**Alex City**	**US280 Coosa Co.**	-	-	-	-	353,633	538,995	**3,031,533**
915	**Sunflower**	**US43 Washington Co.**	-	345,597	615,175	75,275	290,776	266,977	**1,593,800**
918	**Bucksville**	**I20 Tuscaloosa Co.**	-	-	-	-	-	-	**-**
931	**Athens**	**I65 Limestone Co.**	2,384,627	2,709,822	2,694,092	-	-	1,380,679	**9,169,220**
933	**Muscle Shoals**	**AL157 US72 Colbert Co.**	1,350,769	1,548,100	1,597,679	-	630,507	385,424	**5,512,479**
934	**Sumiton**	**US78 Walker Co.**	-	-	-	-	210,097	211,150	**421,247**
942	**Pine Level**	**US231 Montgomery Co.**	-	-	-	-	691,034	463,710	**1,154,744**
960	**Whatley**	**US84 Clark Co.**	-	-	-	-	328,867	214,014	**542,881**
961	**Mobile**	**I65 Mobile Co.**	-	-	-	-	1,332,267	976,753	**2,309,020**
963	**Grand Bay**	**I10 Mobile Co.**	-	-	-	-	2,981,883	2,298,009	**5,279,892**
964	**Ozark**	**US231 Dothan Co.**	988,972	1,242,340	1,178,145	-	600,608	486,204	**4,496,269**
965	**Shorter**	**I85**	-	-	-	-	106,269	1,536,511	**1,642,780**
	US 231		-	-	-	197,954	1,263,733	588,673	**2,050,360**
		TOTAL							**37,204,225**

2.3.WIM Data Filtering

Further analysis of complete database showed a number of records that are incorrect or out of interest in this research. There are certain reasons to consider some records as questionable: one axle vehicle, unreasonably high or zero axle weight, the total weight of axles is significantly different than GVW, etc. Light weight vehicles, such as cars or motorcycles, do no cause a real damaging effect on road and bridges. Thus, they should be taken out of consideration. The overall filtering algorithm developed based on the project *Bridges for Service Life Beyond 100 Years: Service Limit State Design* (2015) is shown in Figure 4.

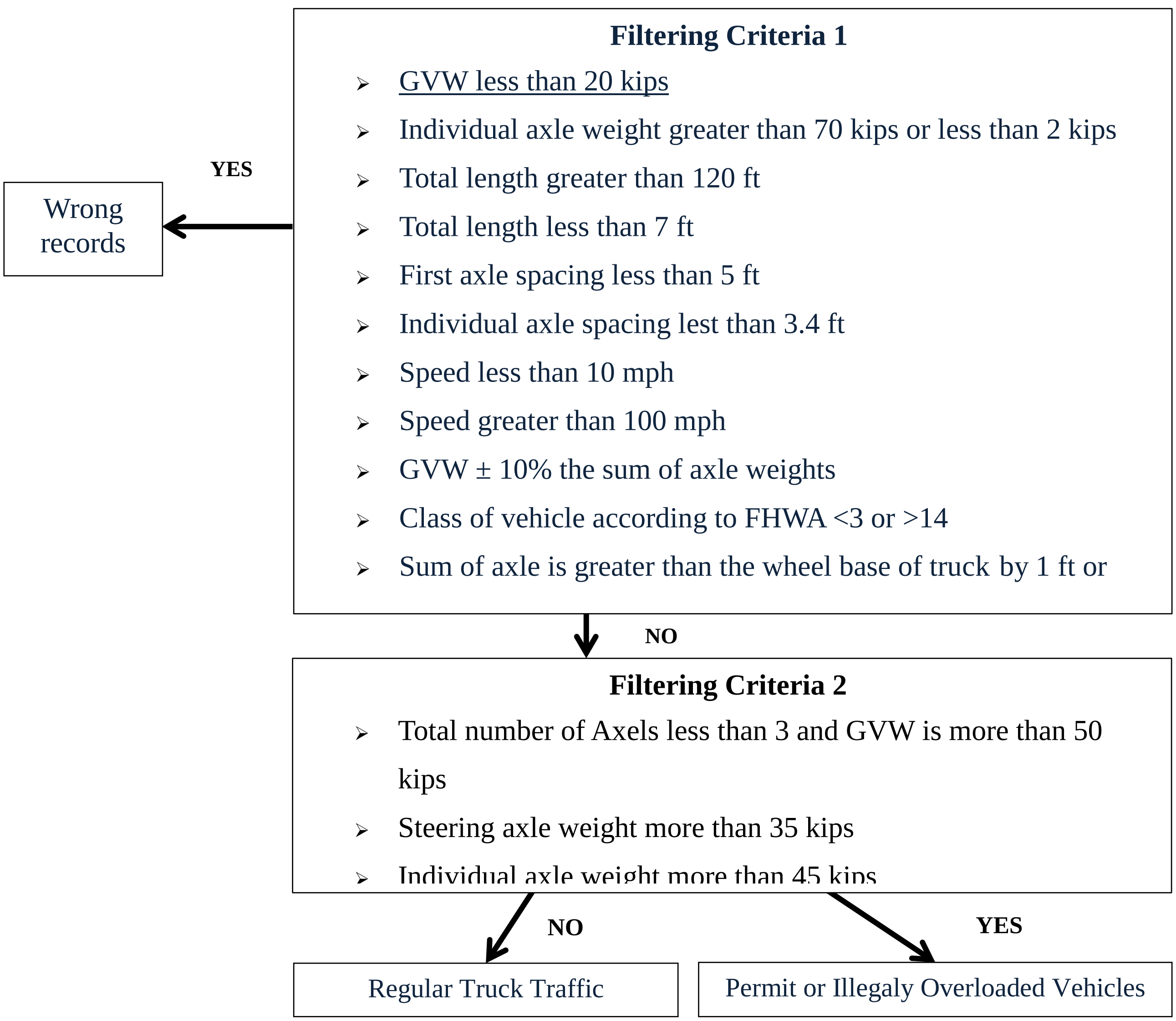


Figure 4: Flowchart of the filtering algorithm

The first set of filtering procedure involves attempts to eliminate most kinds of errors and number of vehicles with low GVW. Light weight vehicles constitute a substantial portion of the database. Thus, after discussion with ALDOT, it was proposed to apply the threshold for minimum GVW at 20 kips as a cutoff to reduce the calculation efforts by not considering light traffic. The vehicles removed by the first set of filtering criteria are summarized in Table 6 (2006-2008) and Table 7 (2009-2014).

The second set of filtering criteria was applied to select vehicles which belong to the regular truck traffic database and represent the Average Daily Truck Traffic (ADTT) volume. The remaining trucks were classified as permit or illegally overloaded. Vehicles of this category are usually exceptionally heavy and have an unusual configuration, such as cranes, industrial or agricultural equipment. Although the percentage of overloaded trucks is quite low, they represent the critical/maximum live load that occurs in Alabama. Thus, they were not removed but considered separately. A summary of vehicles removed with the set of filtering criteria II is shown in Table 8 (2006-2008) and Table 9 (2009-2014). Finally, data remained after filtering along with WIM station information is summarized in Table 10 and Table 11.

The first set of filtering led to the decrease of WIM database in about a half – from 97 to 64 million of records. Then, additional 236,143 of a permit or illegally overloaded vehicles were eliminated. Consequently, the regular traffic database ended up consisting of about 57 million of records.

Table 6: Number of vehicles removed after applying filtering criteria I (2006÷2008)

Station code	**Name**	**Location**	**2006**	**2007**	**2008**	**Total**
911	**Alex City**	US280 Coosa Co.	343,746	494,354	321,899	**1,159,999**
915	**Sunflower**	US43 Washington Co.	294,739	293,973	366,345	**955,057**
918	**Bucksville**	I20 Tuscaloosa Co.	724,238	666,989	746,237	**2,137,464**
931	**Athens**	I65 Limestone Co.	89,269	604,144	596,495	**1,289,908**
933	**Muscle Shoals**	AL157 US72 Colbert Co.	659,889	402,512	544,050	**1,606,451**
934	**Sumiton**	US78 Walker Co.	631,966	710,579	391,416	**1,733,961**
942	**Pine Level**	US231 Montgomery Co.	448,538	542,137	216,083	**1,206,758**
960	**Whatley**	US84 Clark Co.	335,182	359,624	201,351	**896,157**
961	**Mobile**	I65 Mobile Co.	701,450	312,051	1,170,093	**2,183,594**
963	**Grand Bay**	I10 Mobile Co.	2,139,645	1,696,646	1,826,174	**5,662,465**
964	**Ozark**	US231 Dothan Co.	272,116	153,644	415,905	**841,665**
965	**Shorter**	I85	951,555	98,7664	847,432	**2,786,651**
	US 231					**-**
		TOTAL				**39,884,893**

Table 7: Number of vehicles removed after applying filtering criteria I (2009÷2014)

Station code	Name	Location	2009	2010	2011	2012	2013	2014	Total
911	Alex City	US280 Coosa Co.	-	-	-	-	228,881	207,849	1,414,723
915	Sunflower	US43 Washington Co.	-	132,753	254,395	33,244	182,757	163,316	1,668,558
918	Bucksville	I20 Tuscaloosa Co.	-	-	-	-	-	-	9,454,026
931	Athens	I65 Limestone Co.	1,504,020	1,615,696	1,551,436	-	-	937,245	9,133,511
933	Muscle Shoals	AL157 US72 Colbert Co.	757,286	815,636	609,927	-	407,645	247,560	5,061,730
934	Sumiton	US78 Walker Co.	-	-	-	-	100,471	100,058	3,361,605
942	Pine Level	US231 Montgomery Co.	-	-	-	-	518,677	350,063	3,249,384
960	Whatley	US84 Clark Co.	-	-	-	-	249,729	166,130	1,435,591
961	Mobile	I65 Mobile Co.	-	-	-	-	778,213	434,096	5,171,572
963	Grand Bay	I10 Mobile Co.	-	-	-	-	512,083	341,269	6,574,376
964	Ozark	US231 Dothan Co.	532,470	669,615	613,820	-	398,868	328,511	3,767,670
965	Shorter	I85	-	-	-	-	75,402	1,150,834	6,562,102
	US 231		-	-	-	41,153	280,680	130,743	452,576
		TOTAL							17,328,081

Table 8: Number of vehicles removed after applying filtering criteria II (2006÷2008)

Station code	Name	Location	2006	2007	2008	Total
911	Alex City	US280 Coosa Co.	1,469	563	7	2,039
915	Sunflower	US43 Washington Co.	379	65	70	514
918	Bucksville	I20 Tuscaloosa Co.	113	85	78	276
931	Athens	I65 Limestone Co.	14	0	0	14
933	Muscle Shoals	AL157 US72 Colbert Co.	117	1	0	118
934	Sumiton	US78 Walker Co.	29	383	21	433
942	Pine Level	US231 Montgomery Co.	444	7,762	22,964	31,170
960	Whatley	US84 Clark Co.	1,217	4	4	1,225
961	Mobile	I65 Mobile Co.	148	2,740	25,959	28,847
963	Grand Bay	I10 Mobile Co.	32	1,239	586	1,857
964	Ozark	US231 Dothan Co.	33	35	1	69
965	Shorter	I85	160	1310	5,421	6,891
	US 231					-
		TOTAL				73,453

Table 9: Number of vehicles removed after applying filtering criteria II (2009÷2014)

Station code	Name	Location	2009	2010	2011	2012	2013	2014	Total
911	Alex City	US280 Coosa Co.	-	-	-	-	139	494	633
915	Sunflower	US43 Washington Co.	-	-	-	-	-	-	-
918	Bucksville	I20 Tuscaloosa Co.	-	-	-	-	-	-	-
931	Athens	I65 Limestone Co.	-	174	13	-	-	7,686	7,873
933	Muscle Shoals	AL157 US72 Colbert Co.	2	72	3,290	-	98	684	4,146
934	Sumiton	US78 Walker Co.	-	-	-	-	-	-	-
942	Pine Level	US231 Montgomery Co.	-	-	-	-	2	-	2
960	Whatley	US84 Clark Co.	-	-	-	-	-	-	-
961	Mobile	I65 Mobile Co.	-	-	-	-	188	520	708
963	Grand Bay	I10 Mobile Co.	-	-	-	-	117,046	59,727	176,773
964	Ozark	US231 Dothan Co.	943	1	9	-	69	15	1,037
965	Shorter	I85	-	-	-	-	-	9	9
	US 231		-	-	-	97	551	141	789
		TOTAL							191,970

Table 10: Number of vehicles in the ALDOT WIM database left after filtering procedure (2006-2008)

Station code	Name	Location	2006	2007	2008	Total
911	Alex City	US280 Coosa Co.	288,420	360,014	329,559	977,993
915	Sunflower	US43 Washington Co.	275,491	320,265	306,337	902,093
918	Bucksville	I20 Tuscaloosa Co.	3,289,820	2,933,491	3,230,715	9,454,026
931	Athens	I65 Limestone Co.	146,717	1,835,582	1,542,815	3,525,114
933	Muscle Shoals	AL157 US72 Colbert Co.	885,973	499,785	837,918	2,223,676
934	Sumiton	US78 Walker Co.	1,452,134	1,421,615	287,327	3,161,076
942	Pine Level	US231 Montgomery Co.	977,211	918,155	485,278	2,380,644
960	Whatley	US84 Clark Co.	359,991	343,721	316,020	1,019,732
961	Mobile	I65 Mobile Co.	1,427,279	1,299,251	1,232,733	3,959,263
963	Grand Bay	I10 Mobile Co.	2,336,584	1,702,864	1,681,576	5,721,024
964	Ozark	US231 Dothan Co.	429,634	200,683	594,069	1,224,386
965	Shorter	I85	1,891,063	1,805,663	1,639,140	5,335,866
	US 231					-
		TOTAL				39,884,893

Table 11: Number of vehicles in the ALDOT WIM database left after filtering procedure (2006-2008)

Station code	Name	Location	2009	2010	2011	2012	2013	2014	Total
911	**Alex City**	**US280 Coosa Co.**	-	-	-	-	228,881	207,849	**1,203,195**
915	**Sunflower**	**US43 Washington Co.**	-	132,753	254,395	33,244	182,757	163,316	**766,465**
918	**Bucksville**	**I20 Tuscaloosa Co.**	-	-	-	-	-	-	**-**
931	**Athens**	**I65 Limestone Co.**	1,504,020	1,615,696	1,551,436	-	-	937,245	**5,608,397**
933	**Muscle Shoals**	**AL157 US72 Colbert Co.**	757,286	815,636	609,927	-	407,645	247,560	**2,838,054**
934	**Sumiton**	**US78 Walker Co.**	-	-	-	-	100,471	100,058	**200,529**
942	**Pine Level**	**US231 Montgomery Co.**	-	-	-	-	518,677	350,063	**868,740**
960	**Whatley**	**US84 Clark Co.**	-	-	-	-	249,729	166,130	**415,859**
961	**Mobile**	**I65 Mobile Co.**	-	-	-	-	778,213	434,096	**1,212,309**
963	**Grand Bay**	**I10 Mobile Co.**	-	-	-	-	512,083	341,269	**853,352**
964	**Ozark**	**US231 Dothan Co.**	532,470	669,615	613,820	-	398,868	328,511	**2,543,284**
965	**Shorter**	**I85**	-	-	-	-	75,402	1,150,834	**1,226,236**
	US 231		-	-	-	41,153	280,680	130,743	**452,576**
		TOTAL							**18,188,996**

2.4.WIM Data for the US

WIM database for Alabama collected during 2006-2014 was compared to WIM data from 32 stations over the US. Two sources were used to obtain the WIM data: NCHRP Project 12-76 (Nowak 1999, Sivakumar 2007) and FHWA files. This data were used for *Bridges for Service Life Beyond 100 Years: Service Limit State Design* performed in 2013. The available data cover 32 sites for years 2005-2009. The locations of WIM stations are shown in Figure 5. The years and months covered are marked in Table 12 and NCHRP data is for multilane cases, lane with maximum ADTT is listed Table 13.

Originally WIM database from NCHRP and FHWA consisted of more than 65 million vehicles. Later on, about 10 million records were filtered out because of errors in reading. The WIM database from New York (about 8 million) was removed because of a considerable number of extremely heavy vehicles which may significantly affect statistical parameters of Live Load for the US. A part of WIM database from Indiana (about 13 million) was removed as well because of different format of the recorded data. Thus, the remaining database consists of 34 million of vehicles. This database was used for comparison with WIM data obtained from ALDOT.

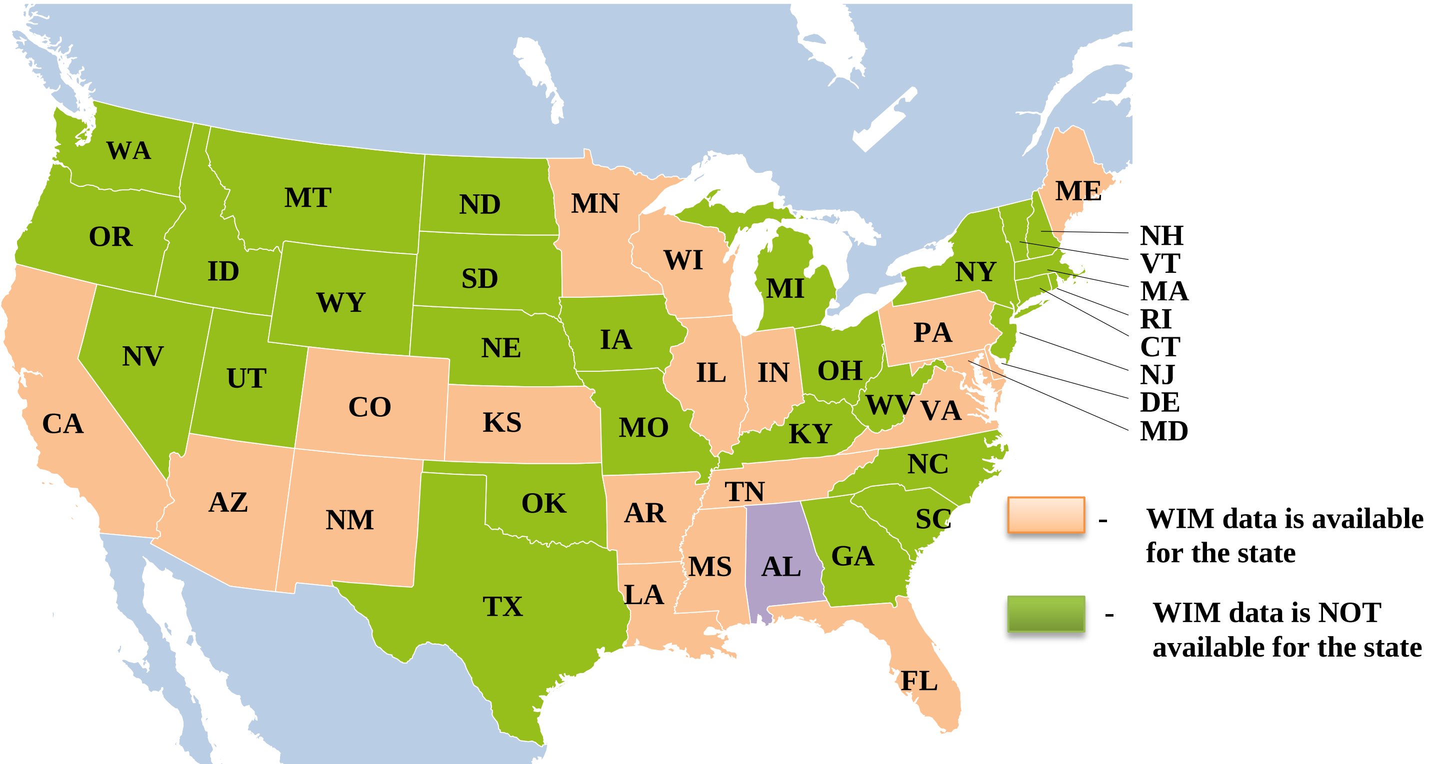


Figure 5: Locations of WIM data stations in the United States

Table 12: Summary of received WIM data for the United States for years 2005÷2006

#	State	# of records	ADTT	2005												2006											
				1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	MS	5,914,950	254-2,967*													x	x	x	x	x	x	x	x	x	x	x	x
2	CA	13,458,818	2,018-8,366*																x	x	x	x	x	x	x	x	x
3	FL	4,143,162	606-2,558*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
4	AR	1,675,349	97-3,919																								
5	AZ	1,466,033	4590																								
6	CO	343,603	941																								
7	DE	201,677	553																								
8	IL	854,075	2340																								
9	IN	185,267	508																								
10	LA	477,922	1309																								
11	MD	328,778	235																								
12	ME	183,576	503																								
13	MN	55,572	450																								
14	NM	725,382	321-1,667																								
15	PA	1,495,741	4098																								
16	TN	1,622,320	4445																								
17	VA	259,190	710																								
18	WI	226,943	622																								

* NCHRP data is for multilane cases, lane with maximum ADTT is listed

Table 13: Summary of received WIM data for the United States for years 2007÷2008

#	State	# of records	ADTT	2007												2008											
				1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	MS	5,914,950	254-2,967*																								
2	CA	13,458,818	2,018-8,366*	x	x	x																					
3	FL	4,143,162	606-2,558*																								
4	AR	1,675,349	97-3,919													x	x	x	x	x	x	x	x	x	x	x	x
5	AZ	1,466,033	4590													x	x	x	x	x	x	x	x	x	x	x	x
6	CO	343,603	941													x	x	x	x	x	x	x	x	x	x	x	x
7	DE	201,677	553													x	x	x	x	x	x	x	x	x	x	x	x
8	IL	854,075	2340													x	x	x	x	x	x	x	x	x	x	x	x
9	IN	185,267	508													x	x	x	x	x	x	x	x	x	x	x	x
10	LA	477,922	1309													x	x	x	x	x	x	x	x	x	x	x	x
11	MD	328,778	235													x	x	x	x	x	x	x	x	x	x	x	x
12	ME	183,576	503													x	x	x	x	x	x	x	x	x	x	x	x
13	MN	55,572	450													x	x	x	x	x	x	x	x	x	x	x	x
14	NM	725,382	321-1,667													x	x	x	x	x	x	x	x	x	x	x	x
15	PA	1,495,741	4098													x	x	x	x	x	x	x	x	x	x	x	x
16	TN	1,622,320	4445													x	x	x	x	x	x	x	x	x	x	x	x
17	VA	259,190	710													x	x	x	x	x	x	x	x	x	x	x	x
18	WI	226,943	622													x	x	x	x	x	x	x	x	x	x	x	x

* NCHRP data is for multilane cases, lane with maximum ADTT is listed

3 GROSS VEHICLE WEIGHT

3.1. Statistical Analysis of the Data

The obtained WIM data includes millions of vehicles. The objective of the project is to determine how heavy are vehicles on Alabama roads? This involves presenting the data and interpreting it in a user-friendly format. Therefore, the statistical data is presented in the normal probability paper. The construction and use of the normal probability paper are described in textbooks (e.g. Benjamin 1970, Nowak and Collins 2012). It will be summarized in this report.

A traditional form of presenting the statistical data is a histogram. For example, the gross vehicle weight (GVW) for US231 measured so far in 2014 is shown in Figure 6. The corresponding cumulative distribution function (CDF) is shown in Figure 7. The most important are the values of on the right end of the graphs in Figures 6 and 7 and they are very difficult to see, as they are close to zero in Figure 6 and close to 1 in Figure 7.

Normal probability paper is a special scale for the presentation of the cumulative distribution function. It is built up based on the standard normal non-decreasing CDF (s-shape function). The CDF of GVW in Figure 7, plotted on the normal probability paper is shown in Figure 8. The horizontal axis remains the same as in Figure 7. However, for each value of GVW, the corresponding value on the vertical axis represents the probability that this value of GVW will not be exceeded. For example, the probability that GVW is less than 80k is 0.98, and less than 100k is 0.999. This interpretation is practically very difficult or even impossible when using a traditional plot (Figures 6 and 7).

Furthermore, the shape of CDF on the normal probability paper can help in the determination of the type of distribution. If the CDF is represented by a straight line, the variable can be considered as normal.

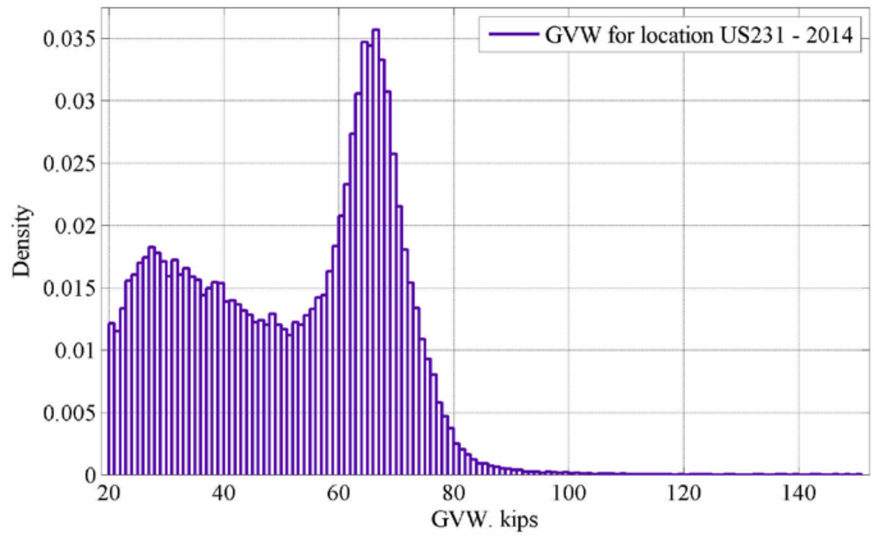


Figure 6: Histogram of GVW for US231, the year 2014 (kips)

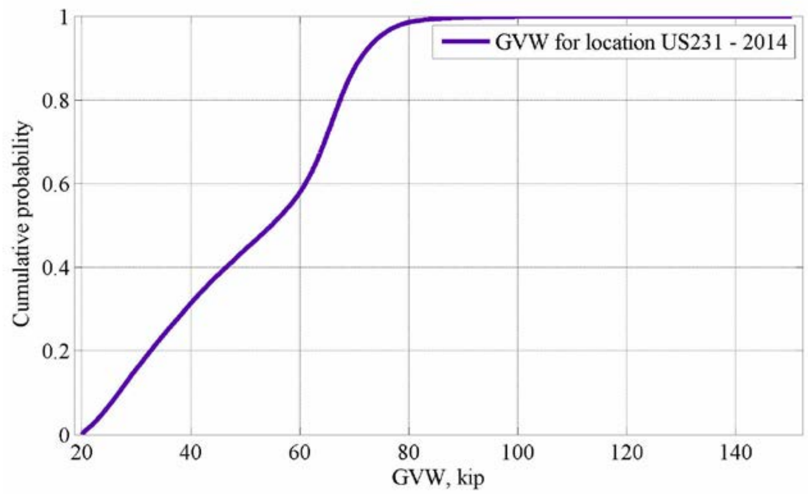


Figure 7: CDF of GVW for US231, the year 2014, (kips)

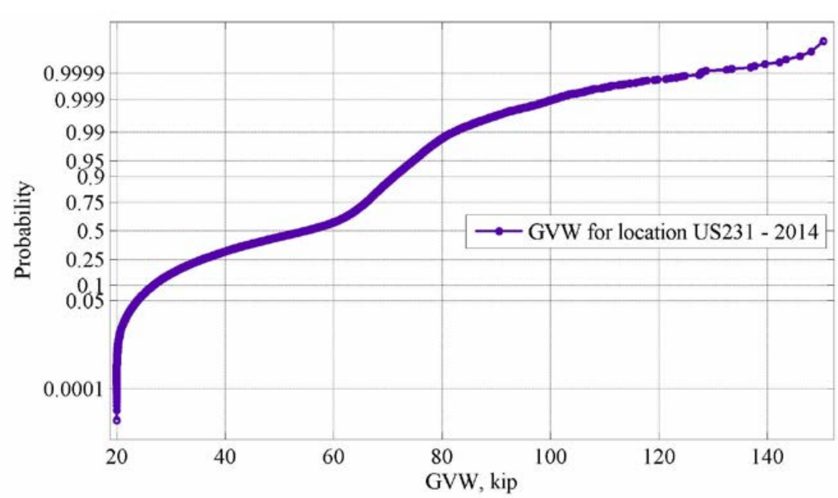


Figure 8: CDF of GVW for US231, year 2014, plotted on the probability paper (kips)

3.2.Annual Data Analysis

The gross vehicle weight was considered for each location and year. Cumulative distribution functions of each truck weight were plotted on the normal probability paper. In Figure 9 the data is plotted for years 2006-2007 respectively and twelve locations. Similarly, CDF's of GVW for years 2008-2009 are plotted in Figure 10. In Figures 11, 12 and 13 for 2010-2014 the data is plotted for all records available (Tables 4 and 5). The distribution of GVW annual data for each location is represented by CDF curve. The CDF's for each year, but for data from all available locations is plotted in Figure 14a and CDF's for each year for each location over all period of taking records are plotted in Figure 14b. The CDF's of the mean and maximum GVW for all available are plotted in Figure 15.

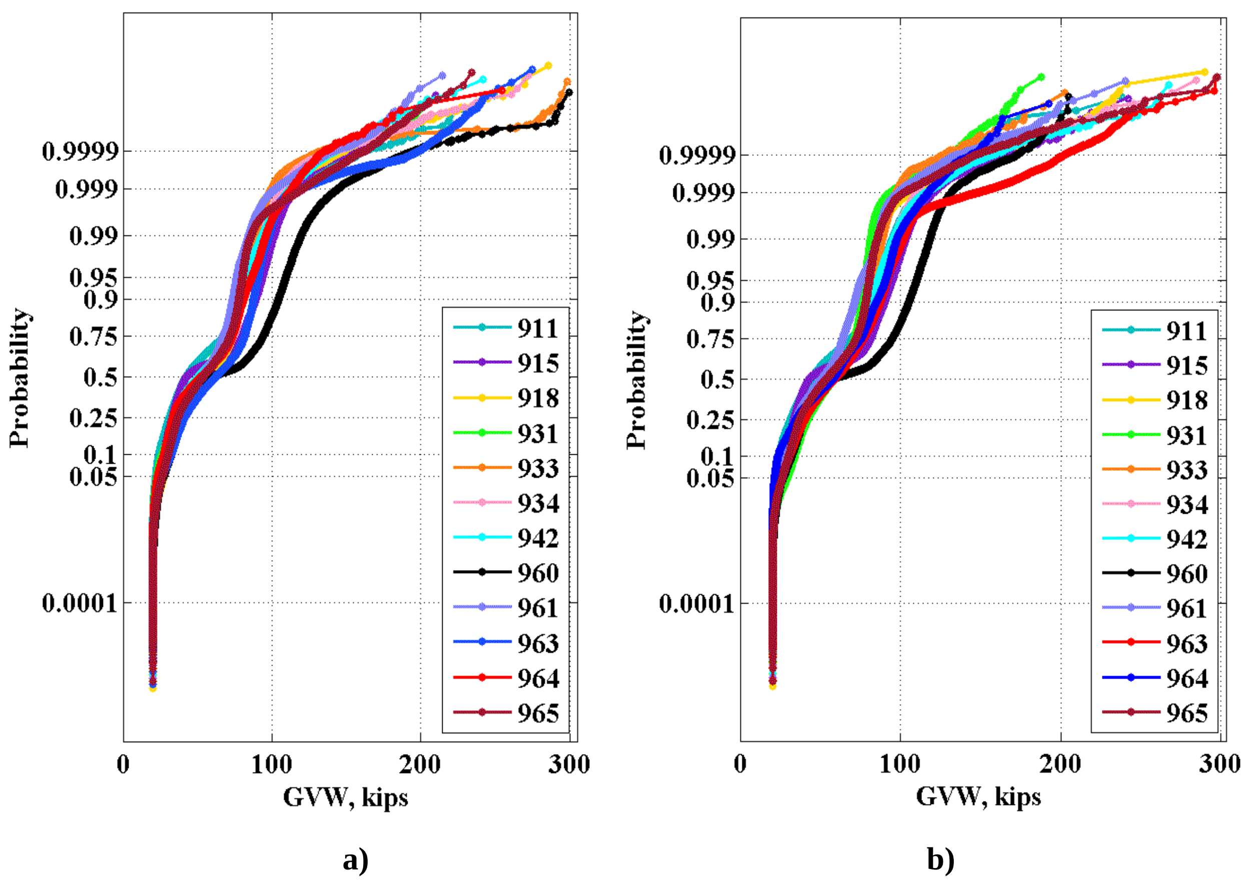
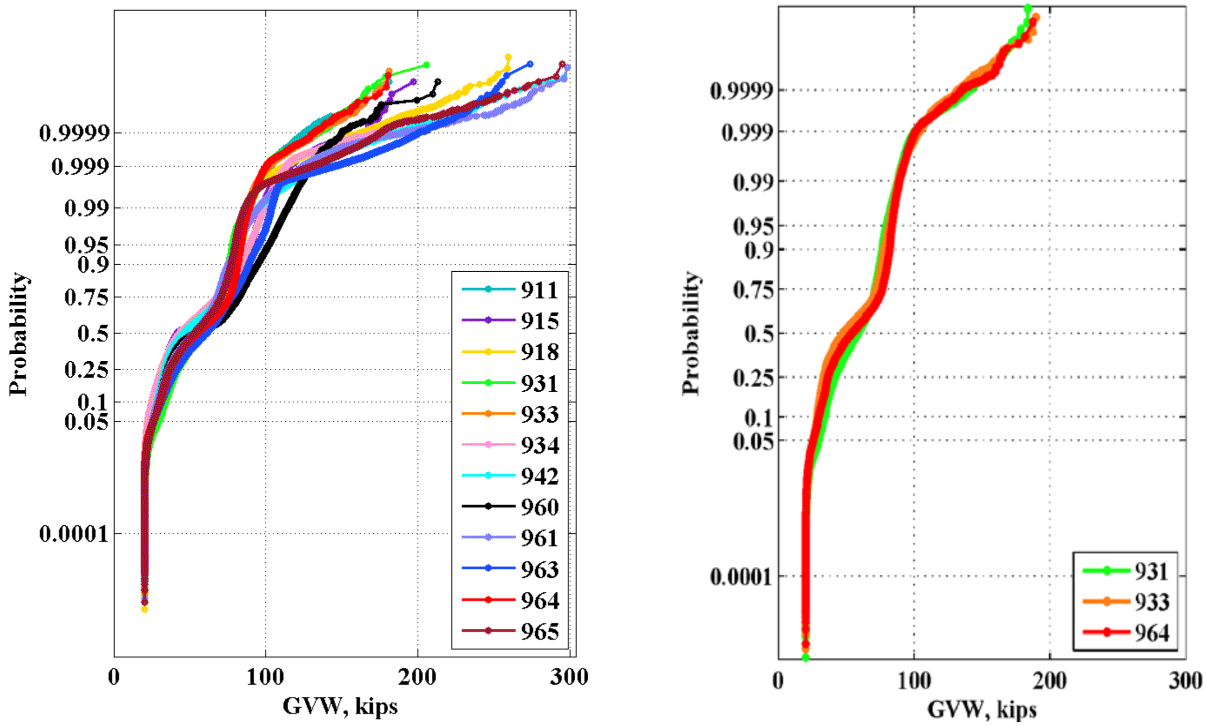
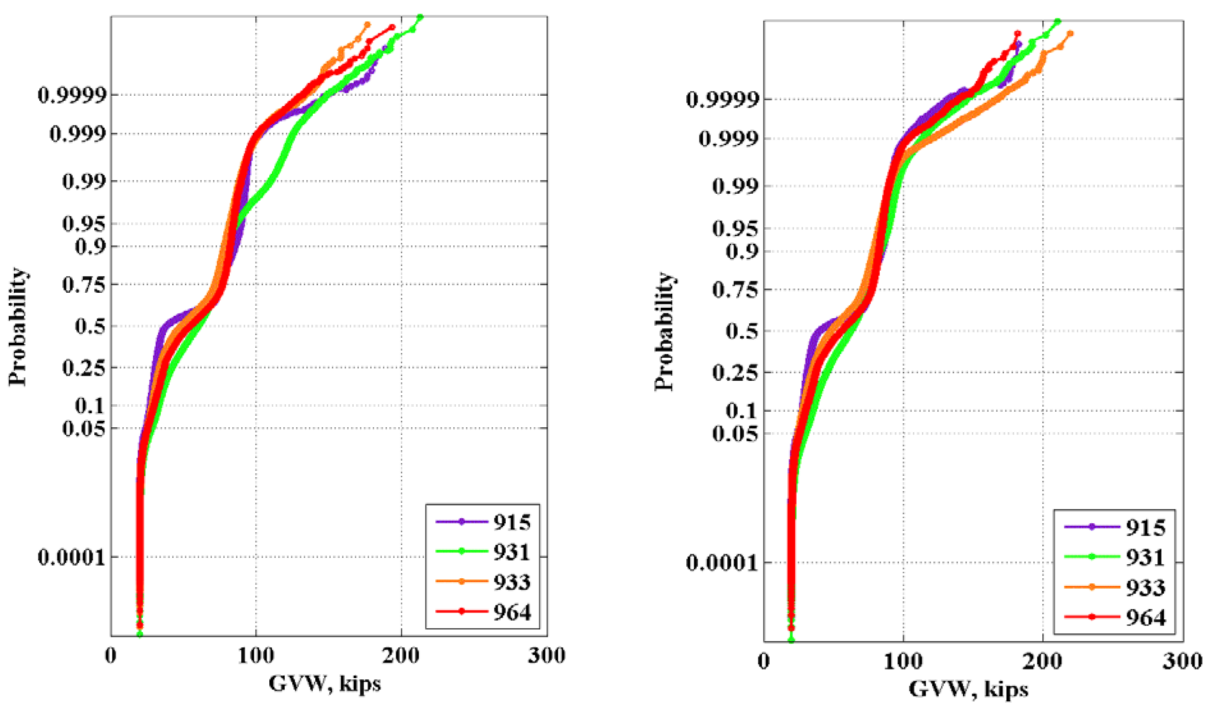


Figure 9: CDF plot for ALDOT WIM database for 2006(a) and 2007(b) for all available locations



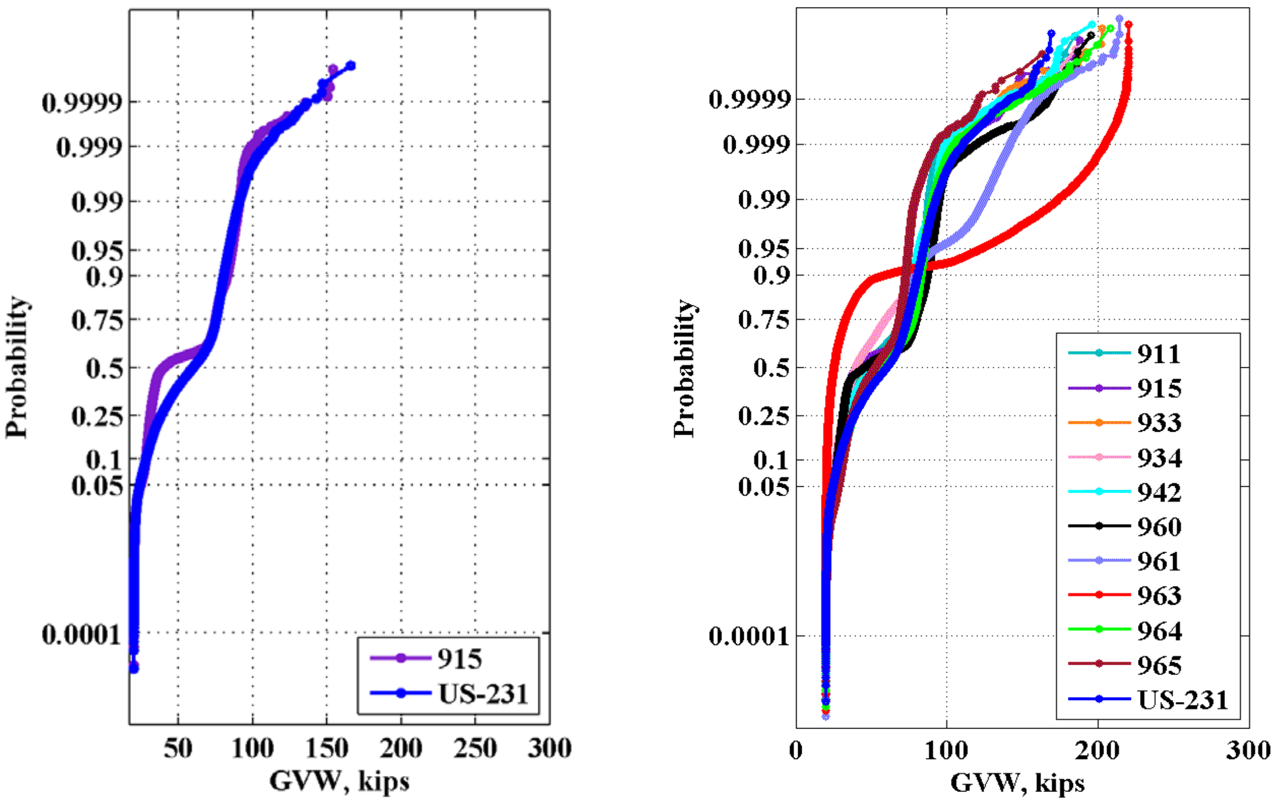
a) b)

Figure 10: CDF plot for ALDOT WIM database for 2008(a) and 2009(b) for all available locations.



a) b)

Figure 11: CDF plot for ALDOT WIM database for 2010(a) and 2011(b) for all available locations.



a) b)

Figure 12: CDF plot for ALDOT WIM database for 2012(a) and 2013(b) for all available locations.

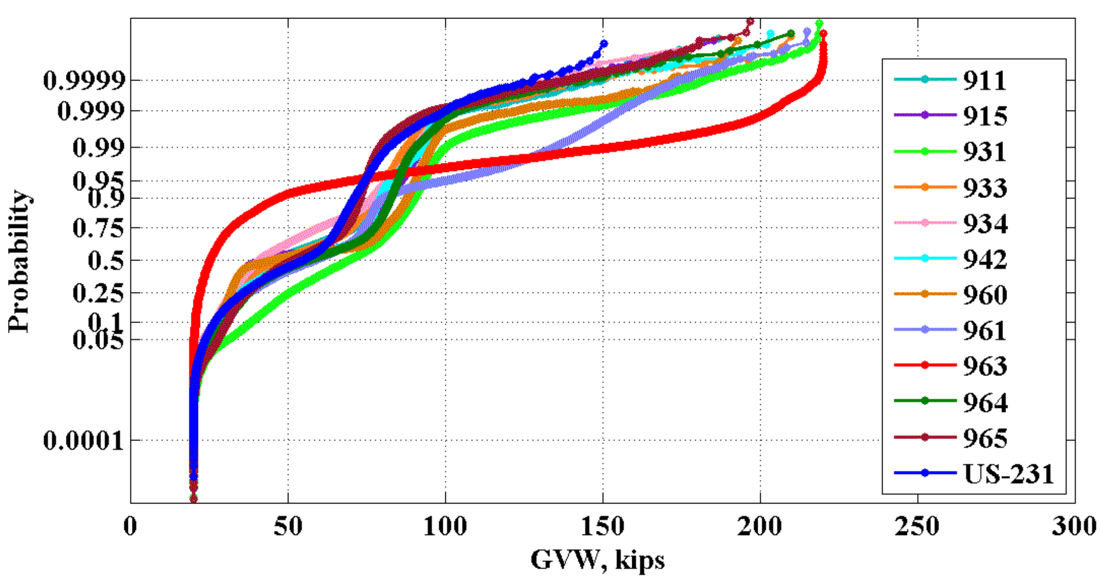
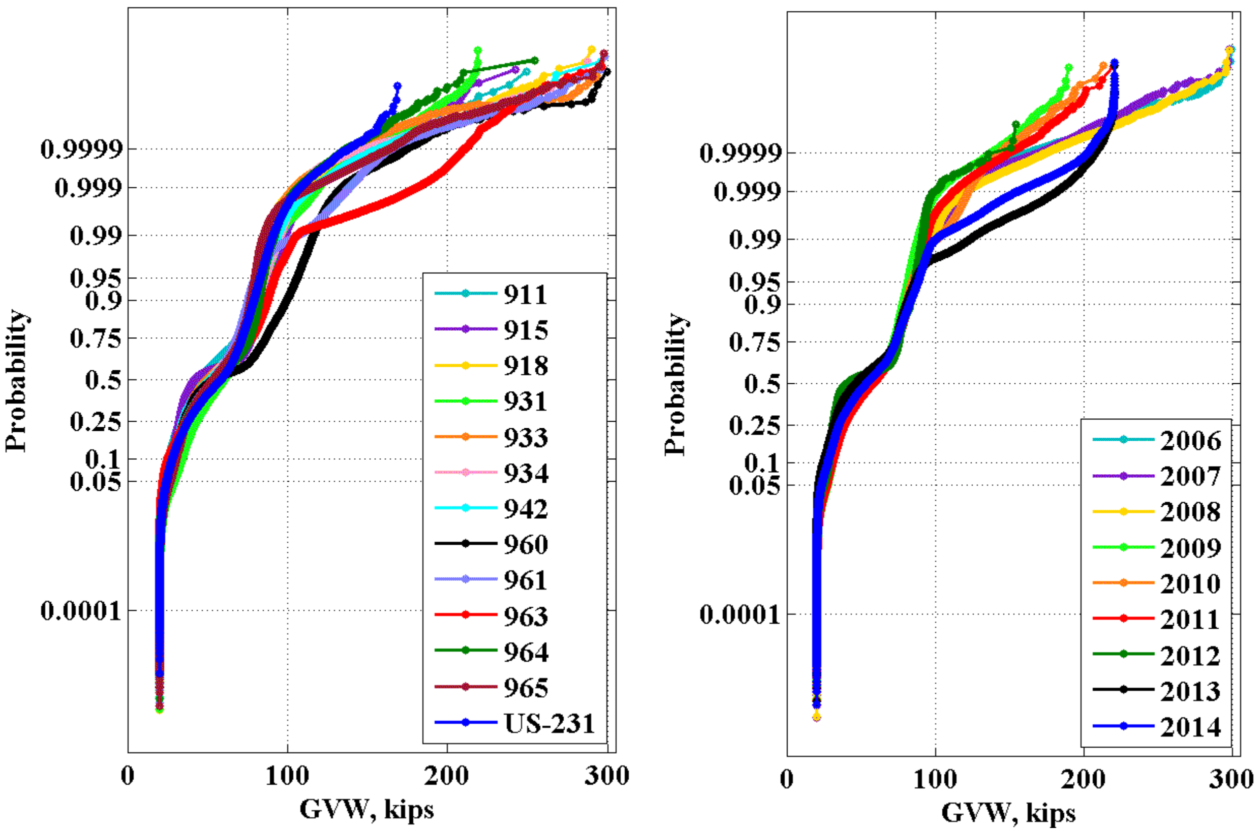


Figure 13: CDF plot for ALDOT WIM database for 2014 for all available locations.



a) **b)**

Figure 14: CDF plot for ALDOT WIM database for all available locations (a) and years (b).

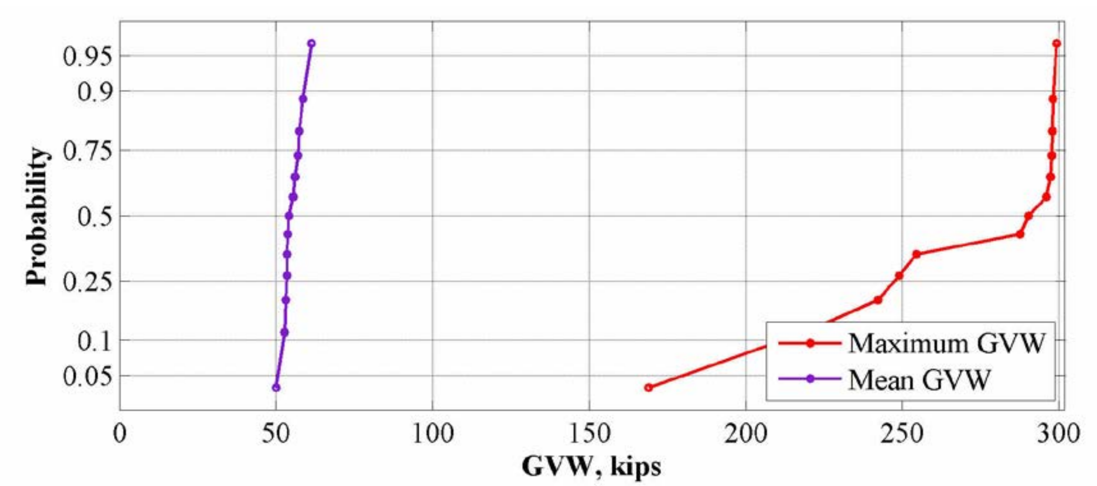


Figure 15: CDF's of mean and maximum GVW for all locations

The analysis of the plotted data indicates that the shape of the distribution is similar for almost all considered locations in Alabama, except locations 960(Whatley US-84), 963(Grand Bay, I-10) (Figure 14). Obviously, the overall shapes of CDF's are not straight except the upper tails representing 1% maximum. Thus, the distributions are not normal. Verity of vehicle types, different range of loading and length of the vehicle frame created such irregularity. All CDF's have a vertical part which is 20kips cut off according to the filtering criteria. From 60 to 95 % of all trucks are lighter than 80 kips, about 15% are between 80kips and 150kips, and less than 1% are above 150kips. GVW of analyzed traffic tended to decrease since the year 2008 from 300 kips to 220kips. The heaviest truck with GVW about 300k was recorded in location 960 (Whatley, US-84). However, the mean values remained the same with the old WIM database (2006-2008) from 30-60 kids. The configuration of the heaviest vehicle (Class 13 of FHWA Vehicle Classification Scheme) is shown in Figure 16.

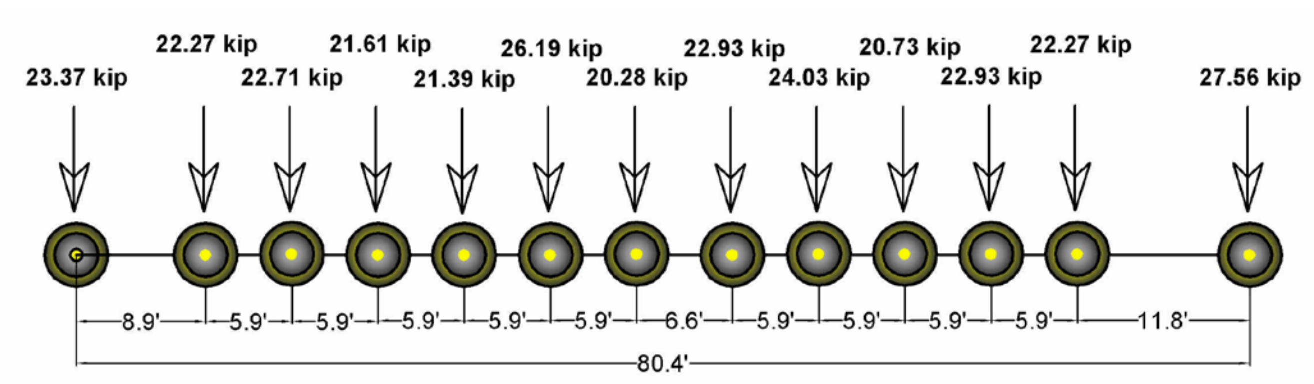


Figure 16: The heaviest vehicle in "Regular Traffic" category WIM database for Alabama (vehicle class 13, GVW-298kips)

3.3.Maximum Daily/Weekly/Monthly Data

For each day in the considered database, the maximum GVW was recorded. The time of passing each WIM location was recorded quite accurately, including year, month, day, hour, minute, second and millisecond (US 231 – B-WIM systems). Thus, the distribution maximum expected GVW per each month was found. The maximum weekly GVW and load effects were calculated using available daily and monthly data and specially developed MATLAB code. All extreme daily/weekly/monthly distributions are presented as cumulative distribution functions using probability scale.

The resulting CDF's of the maximum daily, weekly and monthly GVW are plotted in Figure 17-Figure 24 for the period from 2006 to 2014 (records for 2012 are not available). All these plots are for one location 933 (Muscle Shoals – AL157-US72) which was considered as a typical one. The shapes of CDF's for all WIM database remain similar for years 2006-2014. For other locations, the results are saved, and they will be included in Appendix A.

CDF's the maximum daily GVW for all years are plotted in Figure 25a. CDF's the maximum weekly GVW for all years are plotted in Figure 25b.

The mean values of GVW vary from 110 to 180kip. The daily maximum values varied from 160 kips in 2008-2010 to 300 kips in 2006. The mean values for the maximum weekly GVW's vary from 130 to 160 kips for the same period. From the Figure 25, it is clear that GVW for location 933 (Muscle Shoals – AL157-US72) was higher in 2011.

It is clear, that the GVW of 300kips was recorded only in the year 2006. From Figure 9a, there is a number of vehicles with GVW around 300kips were recorded during 2006. However, CDF's of maximum GVW (Figure 17) shows that these heavy vehicles were recorded in one day – 04.06.2006.

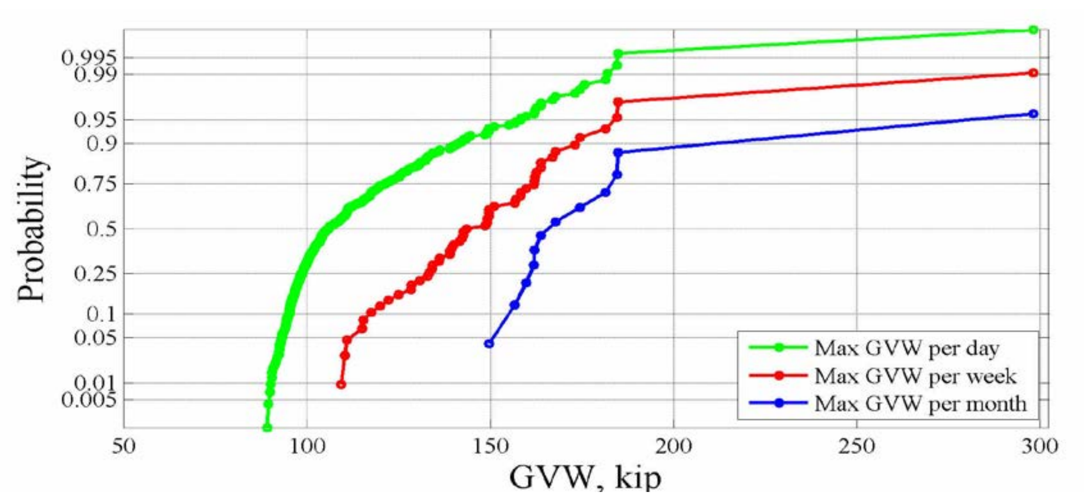


Figure 17: Maximum values of GVW for the location 933 – 2006

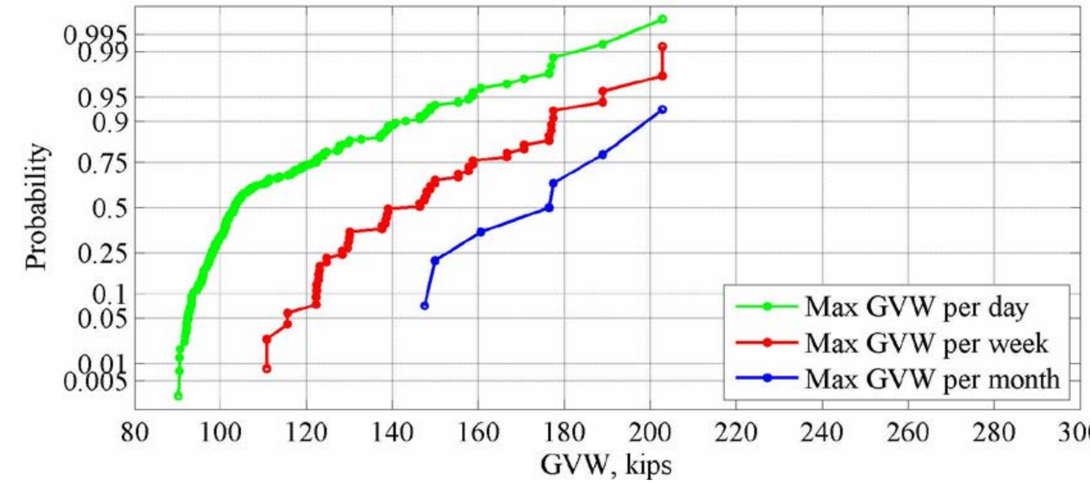


Figure 18: Maximum values of GVW for the location 933 – 2007

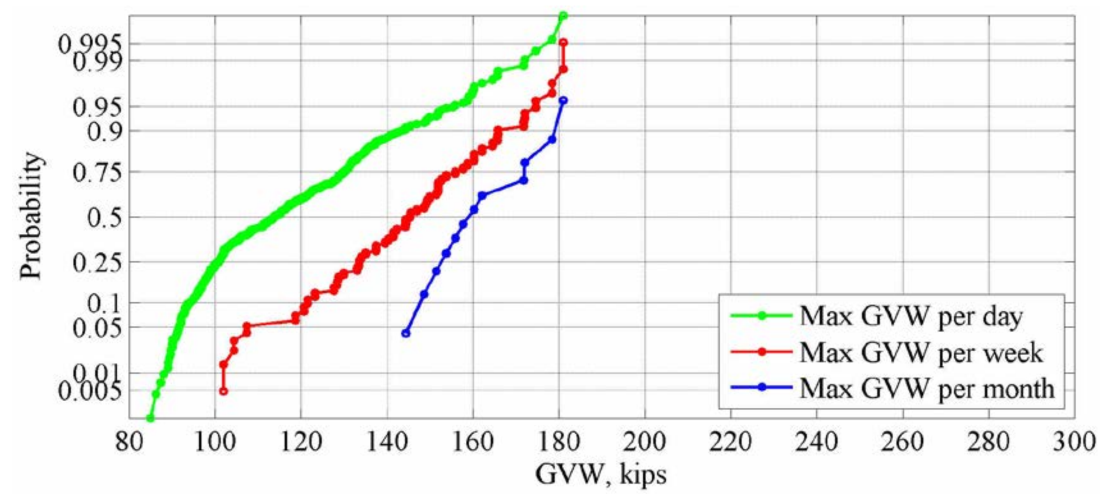


Figure 19: Maximum values of GVW for the location 933 – 2008

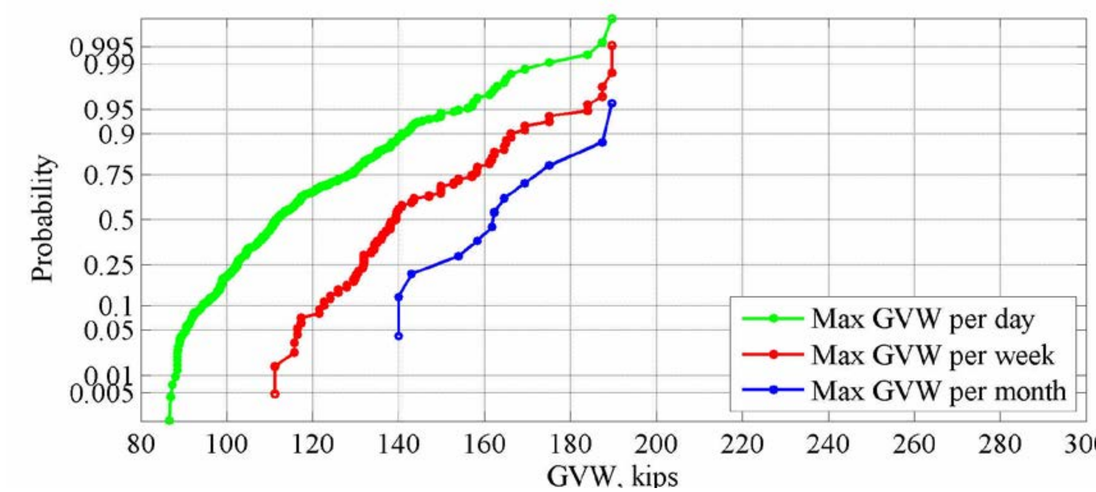


Figure 20: Maximum values of GVW for the location 933 – 2009

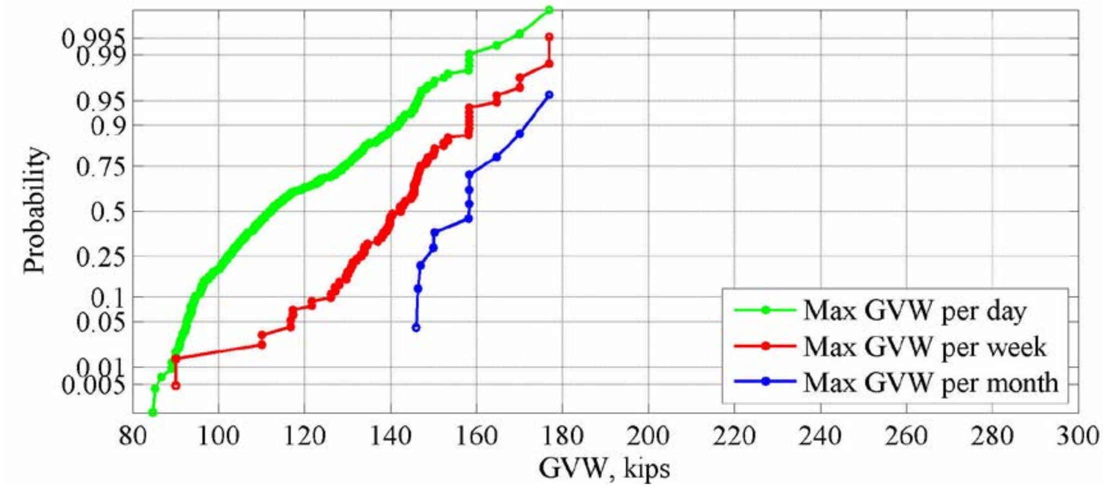


Figure 21: Maximum values of GVW for the location 933 – 2010

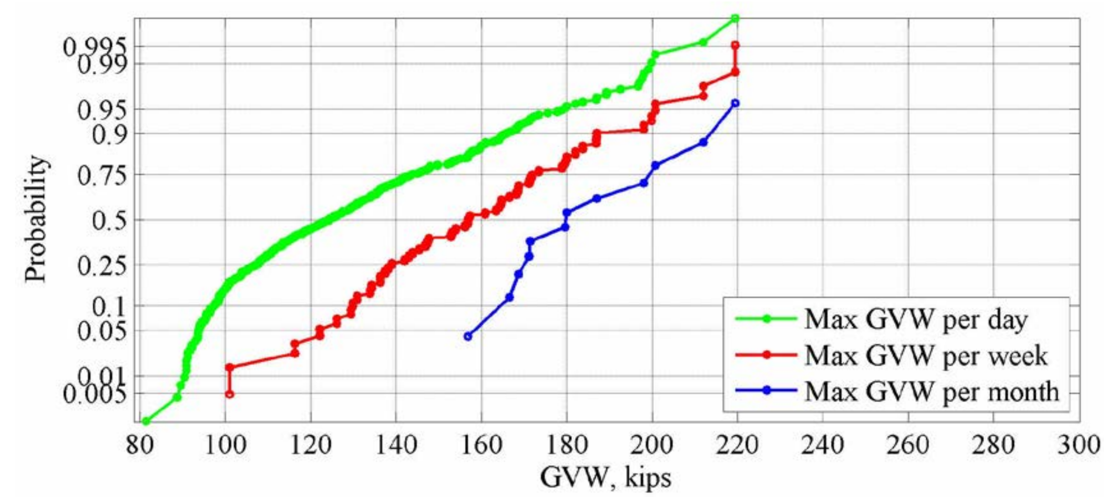


Figure 22: Maximum values of GVW for the location 933 – 2011

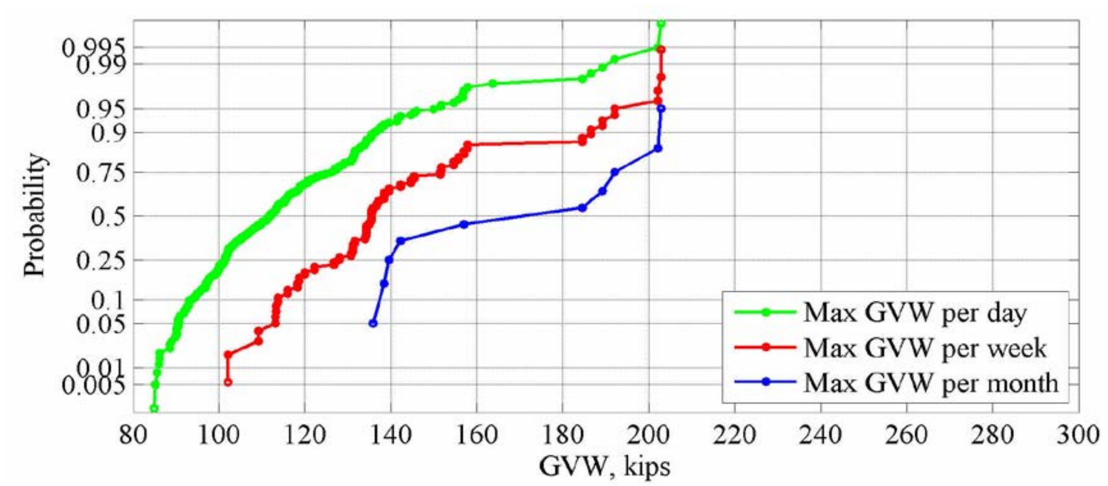


Figure 23: Maximum values of GVW for the location 933 – 2013

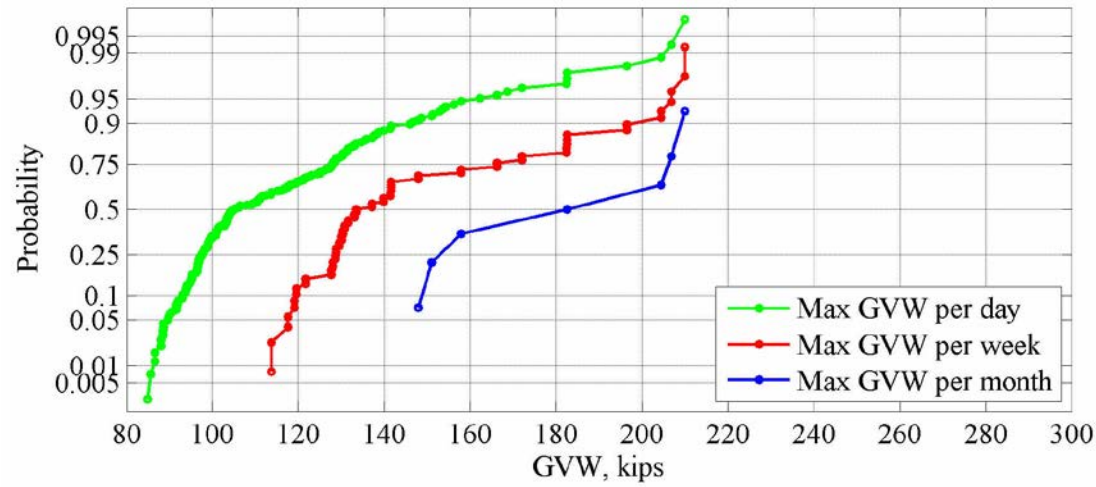
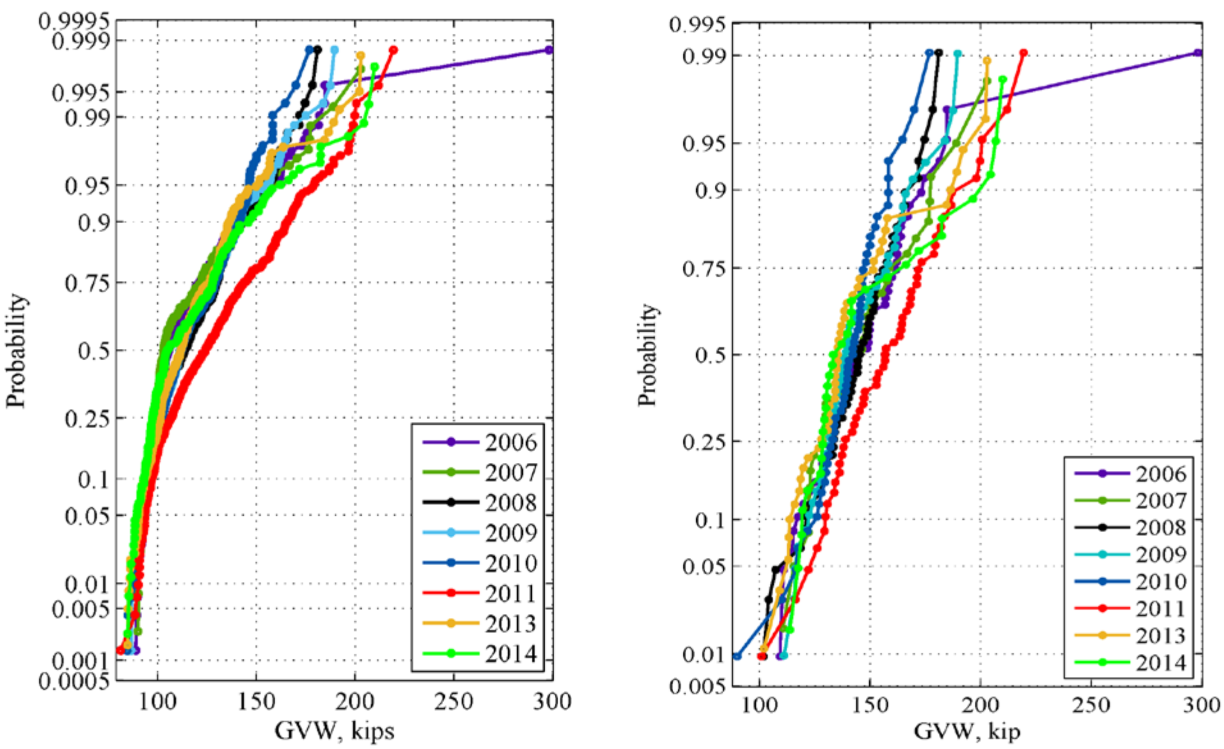


Figure 24: Maximum values of GVW for the location 933 – 2014



a) **b)**

Figure 25: Maximum daily a) and week b) values of GVW for the location 933 – (2006-2014)

3.4.Vehicle Class Analysis

For each location, the distribution of GVW strongly depends on traffic mix, in particular, the dominating vehicle types. Therefore, the CDF's were considered separately for different vehicle classes as specified by the FHWA - *MAG Internal Truck Travel Survey and Truck Model Development Study* 2007– Figure 26. In the considered database the GVW data selected dependently on vehicle class. The traffic mix composition was reviewed for each location and summarized in Table 14 and shown in Figure 27 and Appendix B. It can be concluded, that 9th vehicle class (five-axle, single trailer truck) (Table 14, Figure 27) is the most common for the available locations in Alabama WIM database (Appendix B).

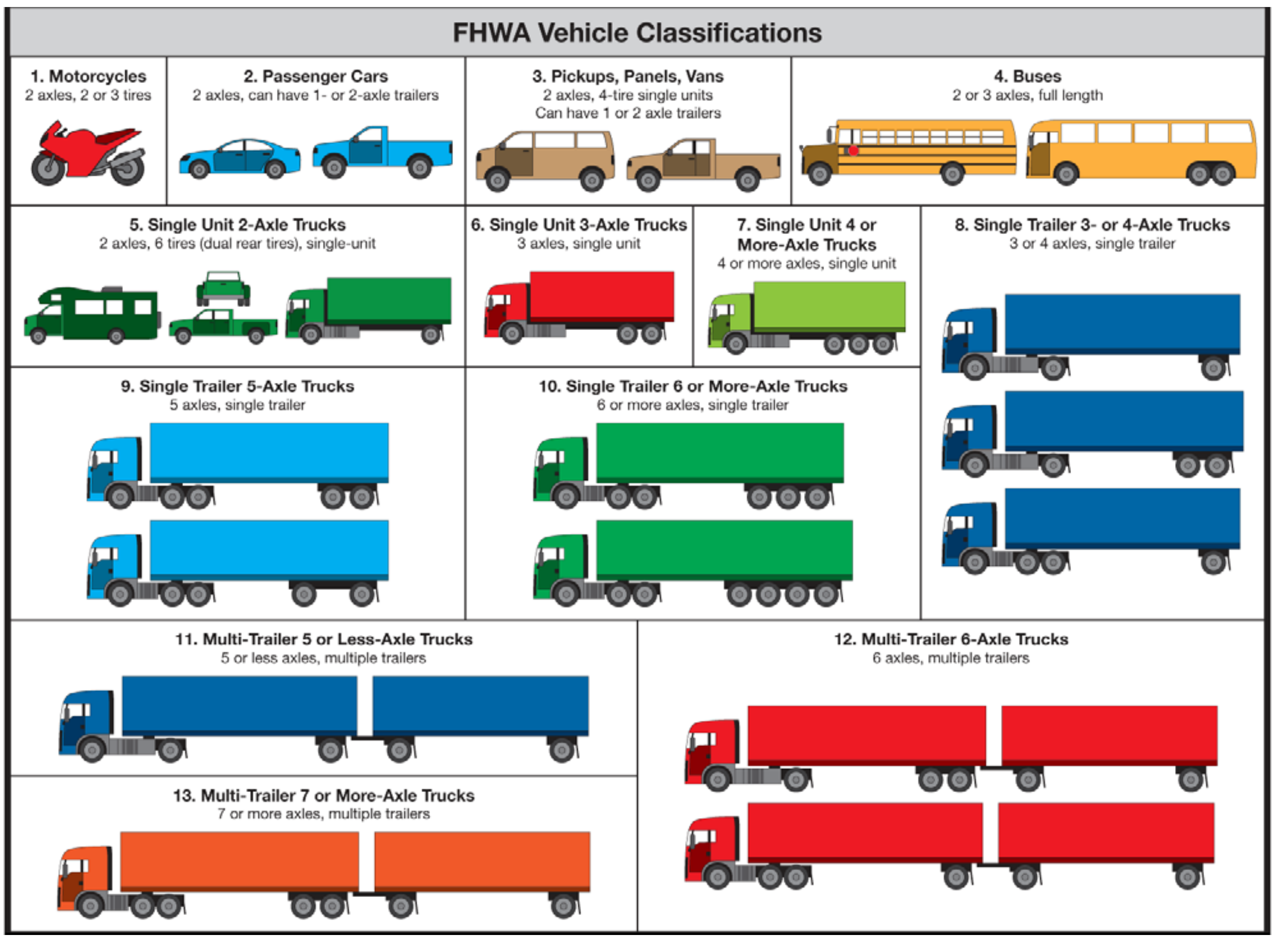


Figure 26: FHWA Vehicle Classification Scheme

Table 14: Percentage of vehicles in each class for WIM locations for Alabama

	All WIM data for Alabama									
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
4	1.27	1.33	1.39	2.69	2.79	2.91	2.30	1.95	2.08	2.46
5	3.65	3.95	3.20	1.53	2.73	1.69	2.45	2.64	2.32	2.20
6	4.11	4.47	3.68	2.31	2.65	2.88	7.16	5.55	4.27	3.59
7	0.32	0.37	0.33	0.51	0.58	0.61	0.82	0.66	0.56	0.58
8	4.51	4.63	4.45	3.93	3.81	4.08	5.75	4.16	3.66	3.91
9	81.27	80.08	81.51	84.90	83.20	83.39	76.37	80.22	82.53	82.80
10	0.97	1.11	1.50	1.49	1.76	2.02	4.40	1.76	1.28	1.65
11	2.57	2.67	2.64	2.53	2.29	2.16	0.01	1.89	2.00	2.15
12	1.18	1.21	1.14	0.01	0.09	0.12	0.62	0.99	1.11	0.51
13	0.15	0.17	0.16	0.10	0.10	0.14	0.11	0.19	0.19	0.15

The maximum value of GVW for class 9 (location 933 and year 2014) is about 200 kips. About 10% of all truck traffic of class 9 have GVW larger than 80 kips (49,127 trucks), and about 1% have GVW exceeding 100 kips (4,913 trucks). This corresponds to 8 % and 0.8 % of a total number of vehicles for all locations.

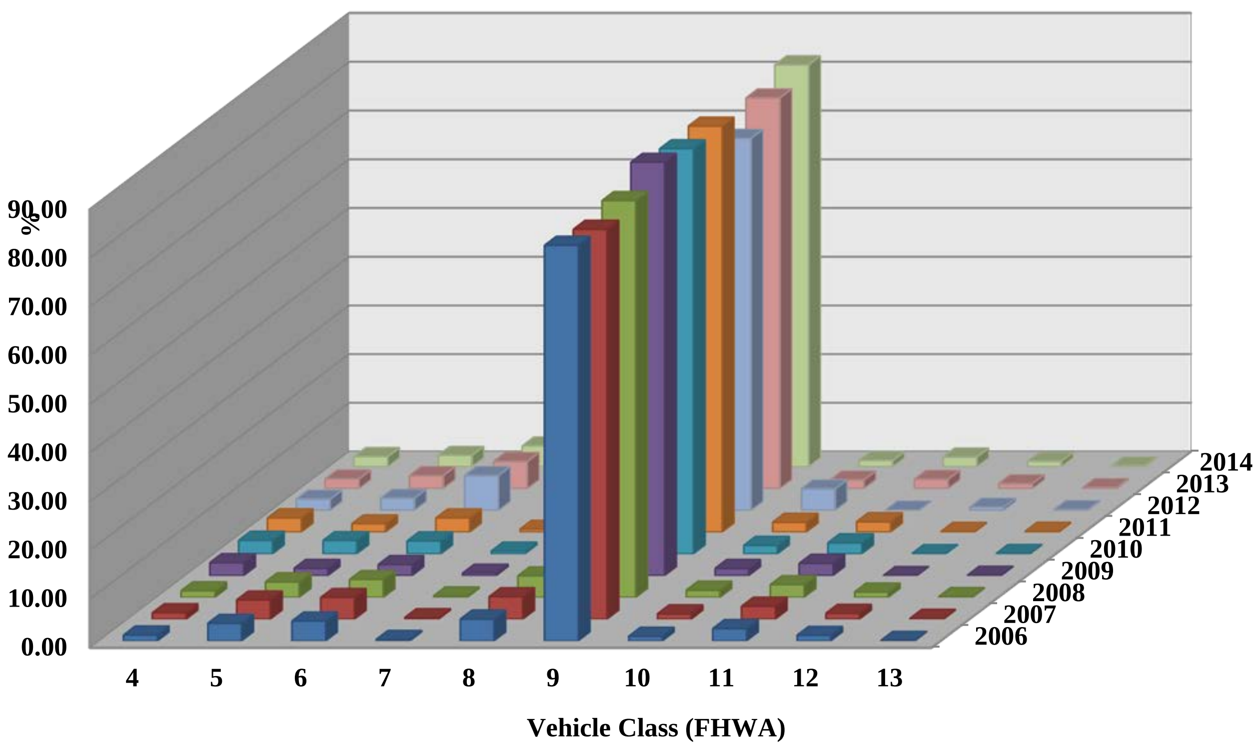


Figure 27: Percentage of each vehicle class for Alabama

However, class 9 is not the dominating type for all of the other locations, for example for location 963 and years 2013 and 2014. At this location, class 5 (five-axle, six-tire, single unit truck) is the most common vehicle with about 40% (434,867 trucks) out of the total number of 134,556 in 2013 and 65% in 2014.

The distribution of GVW strongly depends on axle truck configuration which is specified by the FHWA system of vehicle classification. CDF's of GVW distribution for each considered vehicle class were compared with the load effects for different span length. To make an example, the older (2006-2008) data for the typical location 933 was selected. The cumulative distribution functions of GVW and vehicle classes 4-13 are plotted in Figure 28 for 2006, Figure 29 for 2007 and Figure 30 for 2008. For other locations, the results are included in Appendix B.

According to the Figures 28, 29 and 30, the heaviest vehicles moving in this location mostly belong to class 13(multi-trailer, 7 or more-axle trucks). The mean value for the GVW varies from 20 to 80 kips (class 10) for years 2006 and 2008. The maximum values for most of the vehicle classes vary from 100 to 150 kips and about 300 kips for class 13. According to Figure 17, the heaviest vehicles of class 13(Figure 28) were recorded during one day.

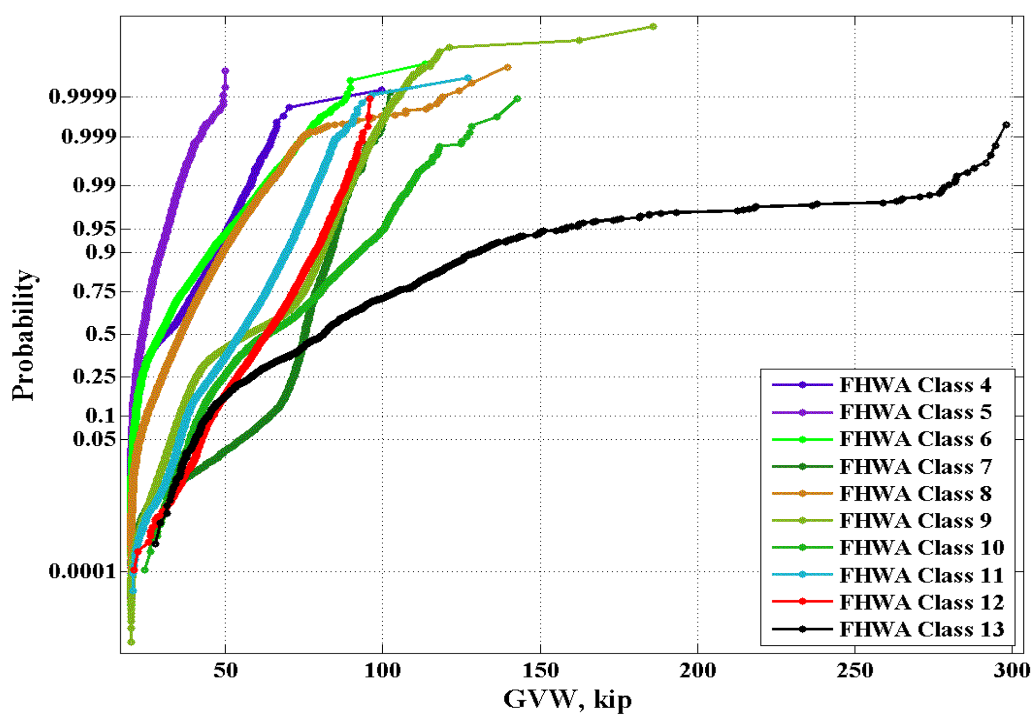


Figure 28: CDF's of GVW for vehicle classes 4-13 for 933 (Muscle Shoals) – 2006

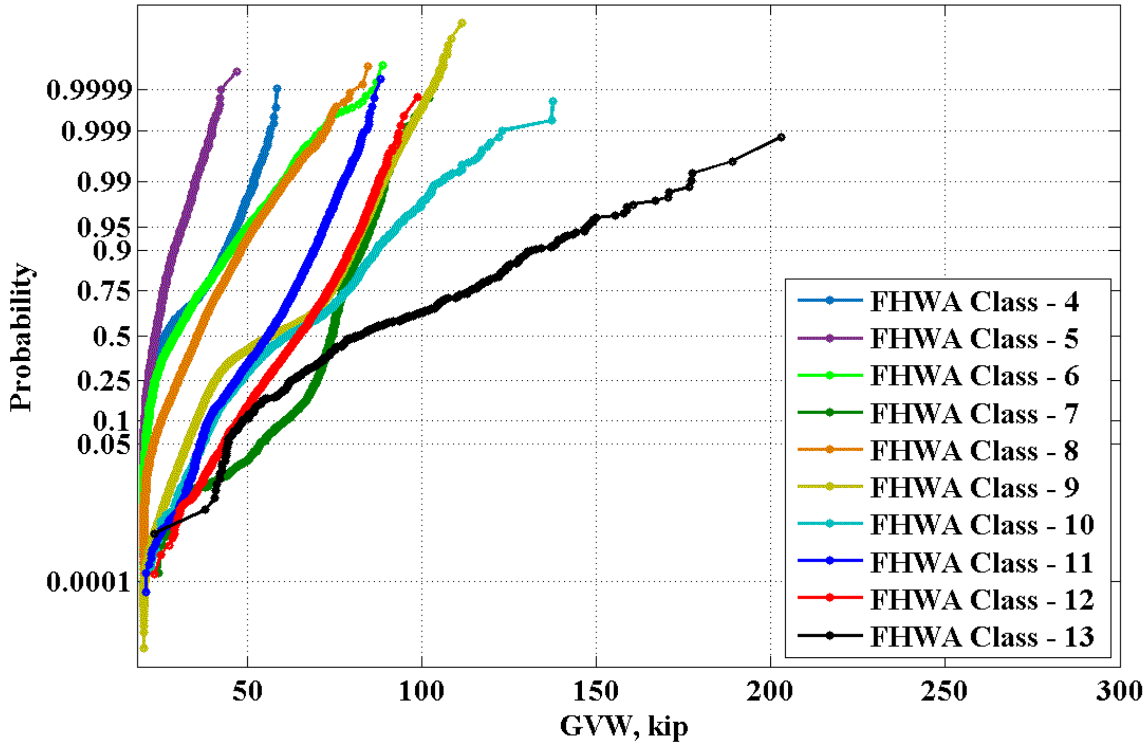


Figure 29: CDF's of GVW for vehicle classes 4-13 for 933 (Muscle Shoals) – 2007

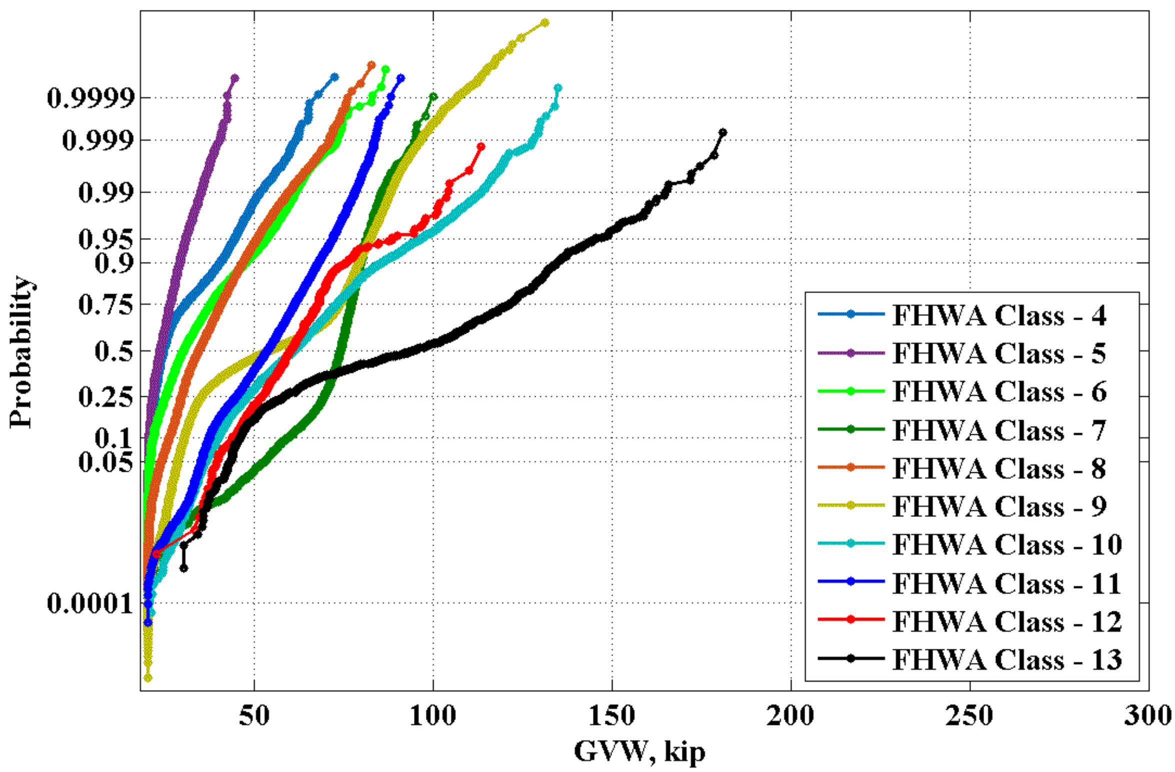


Figure 30: CDF's of GVW for vehicle classes 4-13 for 933 (Muscle Shoals) – 2008

Additionally, the CDF's for GVW distribution of the governing class 9 (Figure 27, Table 15) for the location 933 were plotted in Figure 31.

Table 15: Percentage of each class of vehicle presence (933 Muscle Shoals)

	933 (Muscle Shoals)							
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2013**	**2014**
4	0.91	1.02	2.09	2.20	2.27	2.65	1.32	1.44
5	3.17	2.97	1.94	2.29	2.15	2.59	3.65	2.93
6	5.11	4.60	3.26	3.49	4.21	4.72	4.95	4.94
7	0.77	0.61	0.64	0.84	1.17	1.17	0.72	0.72
8	4.14	4.11	4.20	4.61	4.04	4.75	5.27	4.28
9	83.54	83.54	83.54	83.54	83.35	80.55	81.20	82.81
10	0.52	0.51	1.05	1.09	1.07	1.31	0.61	0.58
11	1.97	1.82	1.88	1.85	1.65	1.97	1.71	1.91
12	0.51	0.64	0.04	0.01	0.00	0.10	0.51	0.32
13	0.11	0.07	0.09	0.08	0.09	0.20	0.07	0.07

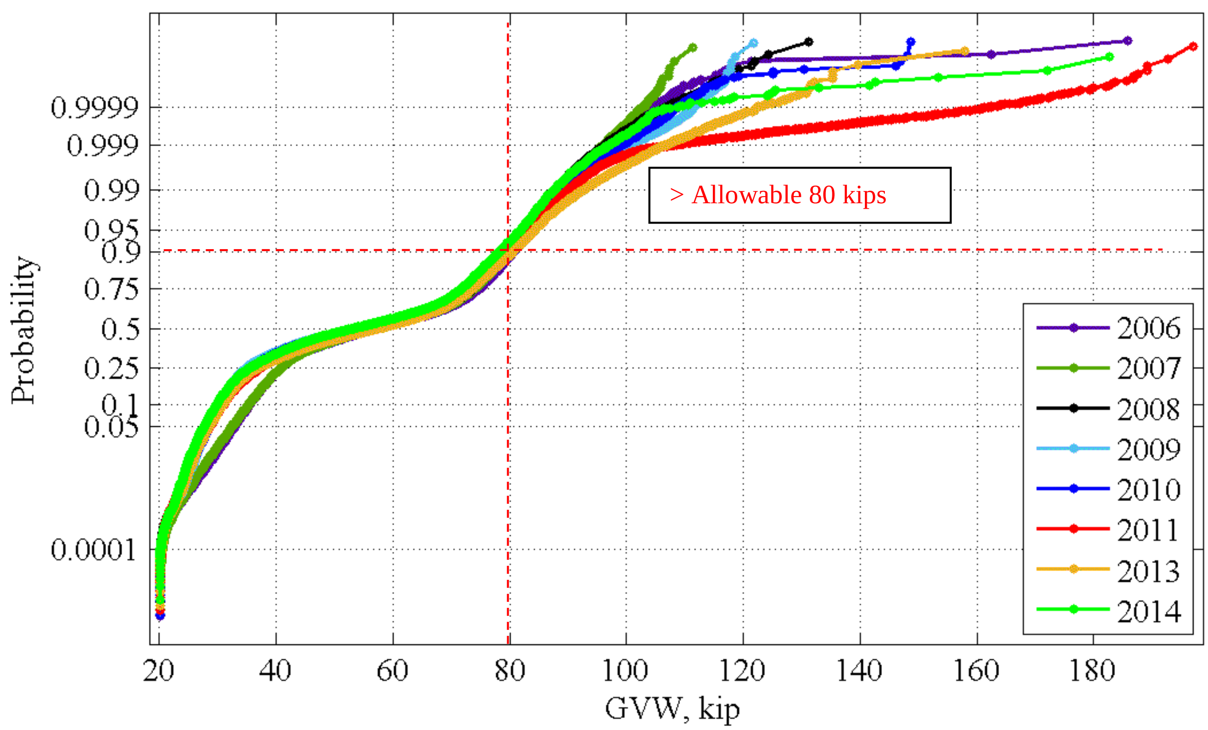


Figure 31: Distribution of 9th (governing) class of vehicle presence (933, Muscle Shoals – AL157-US72) 2006-2014

3.5.Statistical Parameters for Permit Data (GVW)

The objective of this research is to analyze all available WIM database for Alabama. Thus, vehicles previously filtered out as permit or illegally overloaded were then considered separately. These trucks were previously eliminated by the following criteria:

- Total number of axles less than 3 and GVW is more than 50 kips;
- Steering axle weight more than 35kips;
- Individual axle weight more than 45kips;

A summary of vehicles removed by the filtering criteria listed above is shown in Tables 16 (2006-2008) and 17 (2009-2014). Annual percentage of this category of trucks varies from 0 to 0.5 for most locations. However, in some locations, the number of overloaded vehicles is 2-4% (942, 961 in 2008) and 17-22% (963 in 2013-2014).

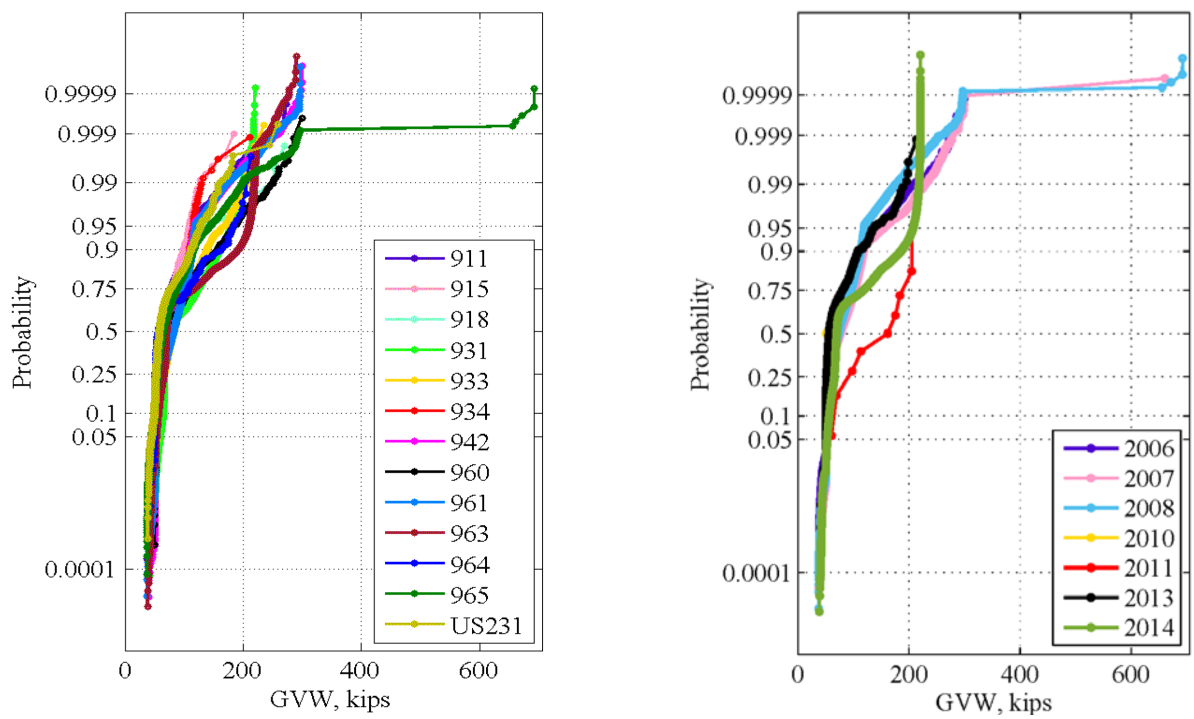
Table 16: Number of vehicles removed after applying filtering criteria II (2006÷2008)

Station code	Name	Location	2006	2007	2008	Total
911	**Alex City**	**US280 Coosa Co.**	1,469	563	7	**2,039**
915	**Sunflower**	**US43 Washington Co.**	379	65	70	**514**
918	**Bucksville**	**I20 Tuscaloosa Co.**	113	85	78	**276**
931	**Athens**	**I65 Limestone Co.**	14	-	-	**14**
933	**Muscle Shoals**	**AL157 US72 Colbert Co.**	117	1	-	**118**
934	**Sumiton**	**US78 Walker Co.**	29	383	21	**433**
942	**Pine Level**	**US231 Montgomery Co.**	444	7,762	22,964	**31,170**
960	**Whatley**	**US84 Clark Co.**	1,217	4	4	**1,225**
961	**Mobile**	**I65 Mobile Co.**	148	2,740	25,959	**28,847**
963	**Grand Bay**	**I10 Mobile Co.**	32	1,239	586	**1,857**
964	**Ozark**	**US231 Dothan Co.**	33	35	1	**69**
965	**Shorter**	**I85**	160	1310	5,421	**6,891**
	US 231					**-**
		TOTAL				**73,453**

Table 17: Number of vehicles removed after applying filtering criteria II (2009÷2014)

Station code	Name	Location	2009	2010	2011	2012	2013	2014	Total
911	**Alex City**	**US280 Coosa Co.**	-	-	-	-	139	494	**633**
915	**Sunflower**	**US43 Washington Co.**	-	-	-	-	-	-	**-**
918	**Bucksville**	**I20 Tuscaloosa Co.**	-	-	-	-	-	-	**-**
931	**Athens**	**I65 Limestone Co.**	-	174	13	-	-	7,686	**7,873**
933	**Muscle Shoals**	**AL157 US72 Colbert Co.**	2	72	3,290	-	98	684	**4,146**
934	**Sumiton**	**US78 Walker Co.**	-	-	-	-	-	-	**-**
942	**Pine Level**	**US231 Montgomery Co.**	-	-	-	-	2	-	**2**
960	**Whatley**	**US84 Clark Co.**	-	-	-	-	-	-	**-**
961	**Mobile**	**I65 Mobile Co.**	-	-	-	-	188	520	**708**
963	**Grand Bay**	**I10 Mobile Co.**	-	-	-	-	117,046	59,727	**176,773**
964	**Ozark**	**US231 Dothan Co.**	943	1	9	-	69	15	**1,037**
965	**Shorter**	**I85**	-	-	-	-	-	9	**9**
	US 231		-	-	-	97	551	141	**789**
		TOTAL							**191,970**

Similarly to the regular truck traffic data, distribution of gross vehicle weight (GVW) for overloaded vehicles was considered for each location and year. CDF's of GVW are plotted in Figure 32 for all available locations (a) and years 2006-2014 (b) using probability scale.



a) b)

Figure 32: CDF's of GVW of permit or illegally overloaded trucks for available locations (a) and years 2006-2014 (b)

Most of the CDF curves are consistent with regard to the shape. The maximum GVW is 300 kips for most of the locations and years. There is also a vertical segment in CDF's for 2013-2014 that represents a big population of vehicles with GVW about 220 kips and do not exceed this limit. However, the outlying maximum GVW reaches 700 kips in location 965(Shorter, I-85 in 2007-2008). The configuration of the heaviest vehicle (Class 13 of FHWA Vehicle Classification Scheme) is shown in Figure 33. The axle load reaches 54 kips. In general, less than 80% of all trucks are lighter than 80kips, and about 20% are between 80kips and 300kips. Only 5 vehicles are above 300kips.

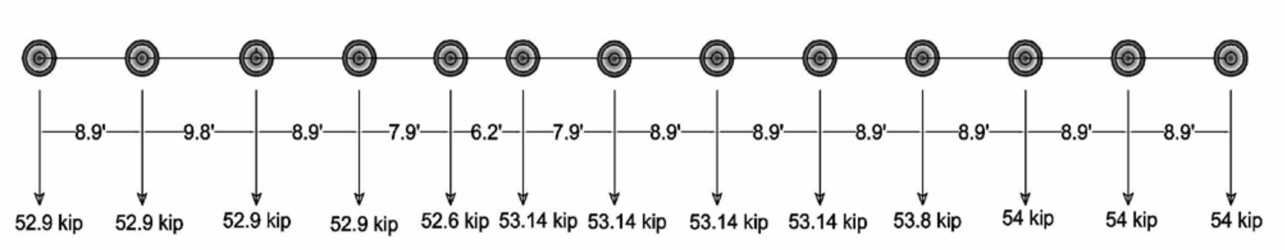


Figure 33: The heaviest vehicle in "Permit and illegally overloaded Traffic" WIM database for Alabama (Vehicle class 13, GVW – 697 kips)

3.6.Outlying Data

The results for location 933 presented in Figures 17-25 can be considered as representative for most other locations. However, the recorded WIM data for two locations 963, 960 and US-231 was different than everything else. These locations require special consideration.

As an example, CDF's of the GVW for location 963(Grand Bay, I-10) demonstrated considerable differences in GVW distribution in the period from 2008 till 2013 (Figure 34). There is a certain number of days with significantly overloaded trucks in recent years 2013-2014. However, the percentage of heavily loaded trucks is relatively small in comparison to the other locations, as it is less than 0.01%. In other words, total number of trucks with GVW larger than 200 kips varies:

- from 57 to 169 trucks per month (3 per day on average) in 2013;
- from 47 to 105 trucks per month (2 per day on average) in 2014;

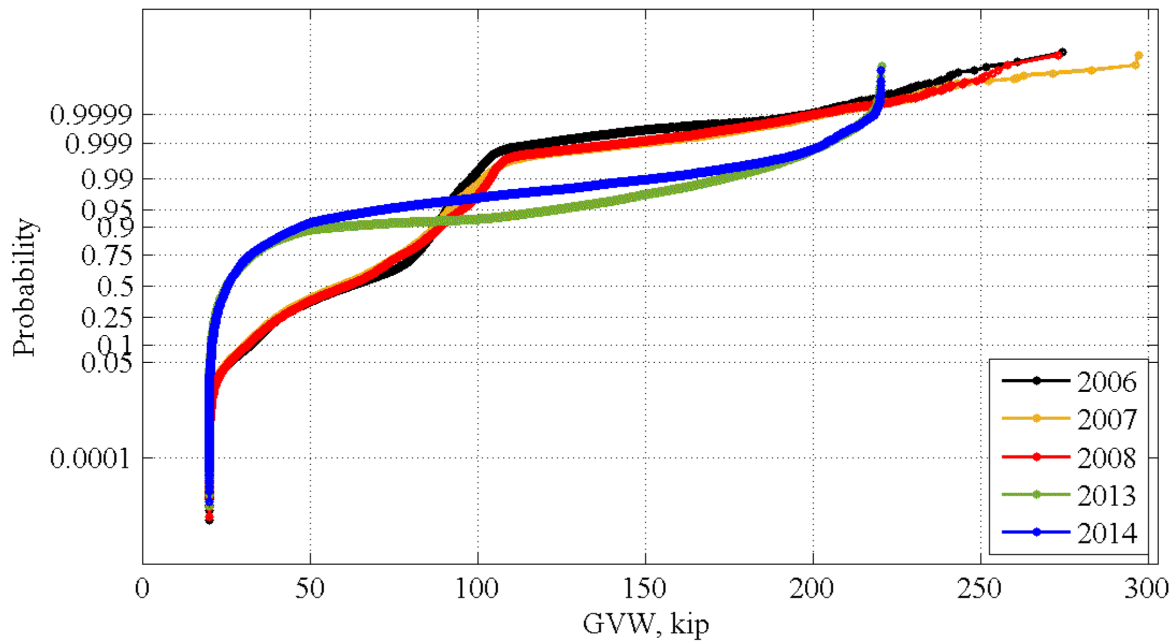


Figure 34: CDF's of GVW for location 963 (2006-2014)

During previous years 2006-2008 the maximum GVW reached 300 kips. The mean value of GVW changed from 80 (2006-2008) to 25 for (2013-2014). The maximum GVW decreased as well, from 280-300kip (2006-2008) to 220 (2013-2014). However, the percentage of overloaded vehicles was smaller during 2006-2008 (Figure 34). Only 0.001% of "regular truck traffic" is heavier than 200 kip. The total number of records also indicate the decrease from about 400.000/month in 2006-2008 to 300.000/month in 2013-2014 which indicates changes in ADTT for this region.

The proportions of some vehicle classes also have changed since 2008 as it is shown in Figure 35. In particular, the percentage of trucks that belong to class 9 (single trailer 5-axle trucks) decreased from 82-83% during 2006-2008 to 3% in 2014. Conversely, the percentage of trucks of class 5 (single unit 2-axle trucks) increased from 4% during 2006-2008 to 67 % in 2013. For other vehicle classes, all changes can be observed from Figure 35 and Table 18.

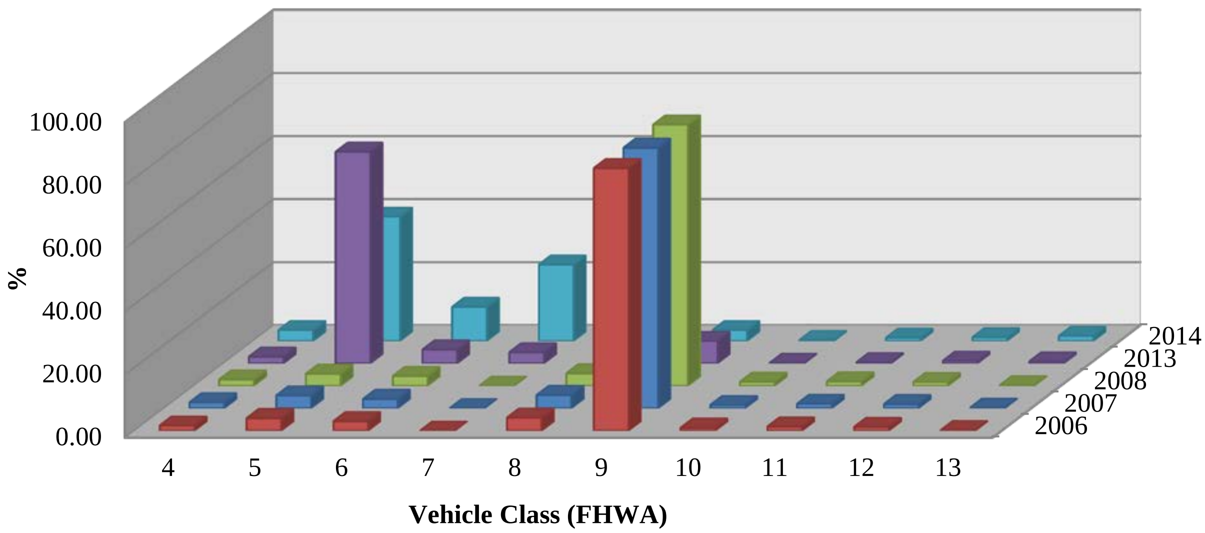


Figure 35: Percentage of each vehicle class for location 963 (I-10, Mobile)

Table 18: Percentage of each class of vehicle presence (I-10, Mobile)

FHWA class	963 (I-10, Mobile)				
	2006	**2007**	**2008**	**2013**	**2014**
4	1.69	1.90	2.01	2.13	3.45
5	4.00	4.09	3.84	67.15	39.43
6	3.02	2.98	3.12	4.40	10.82
7	0.04	0.06	0.06	3.52	24.25
8	4.17	4.23	3.96	12.94	14.52
9	83.33	82.66	82.88	7.13	3.45
10	0.96	1.06	1.30	0.14	0.26
11	1.34	1.45	1.41	0.36	1.04
12	1.25	1.33	1.21	0.86	1.18
13	0.21	0.23	0.22	0.64	1.61

3.7.Summary

This chapter presents the results of statistical analysis of the GVW of “regular truck traffic” in Alabama. Normal probability scale was applied for user-friendly representation of the cumulative distribution function of the data. The major advantage of using it is a possibility to analyze the upper tail of CDF which represents the heaviest vehicles in range. It also allows considering each portion of data with respect to the GVW.

CDF of GVW WIM data was processed for 13 locations in the state. It is assumed that the recorded traffic is representative for the considered state. The following can be concluded:

- Most of the CDF’s of the recorded data are consistent with regard to shape, which allows generating a representative live load distribution pattern for the state. Nevertheless, the differences in truckload magnitude were considered, identified and analyzed;

- Obtained results, however, indicate that there are certain differences in truck loads between locations and years (site-specific differences);

- Processed WIM database for years 2006-2008 demonstrated a significant difference in maximum GVW in comparison with years 2009-2014. The heaviest vehicles were recorded at the following locations: 918, 933, 942, 960, 961 and 963;

- Vehicle class 9 (five-axle, single trailer truck) is the most common for the considered Alabama WIM location. However, class 9 is not the dominating type for all of the other locations, for example for location 963 and years 2013 and 2014. The heaviest vehicles moving in this location mostly belong to class 13 (multi-trailer, 7 or more-axles trucks).

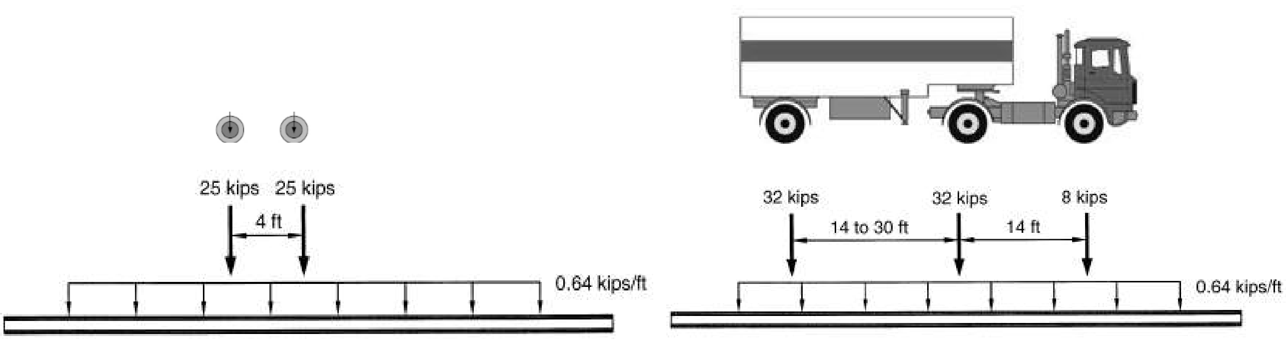
- Considerable change in GVW distribution was observed in years from 2008 till 2013 at location 963.

4 MID-SPAN MOMENTS CAUSED BY WIM TRUCKS

4.1.Statistical parameters for moment ratios – Annual Data

This chapter is focused on the load effects, such as bending moment ratios. Moving vehicles can cause damage to bridge structures leading to a partial damage or even a total loss of the load carrying capacity. Therefore, it is important to identify the types of vehicles that exceed legal load limits and prevent overloaded trucks from entering the bridge. Potential bridge damage can be considered in terms of live load effects, i.e. moments and shears. In the present study, the moments and shear forces were calculated using influence lines.

Statistical parameters for live load effects, i.e. moment and shear forces were calculated using the available WIM database. For each truck, a specially developed code was used to find the maximum value of the bending moment. The trucks from the WIM data were run over influence lines and for each vehicle, the maximum moment was computed. The calculations were performed for simply supported spans of 30, 60, 90, 120 and 200 ft. For an easier interpretation of the results, the obtained moments and shear forces were divided by the corresponding code specified values, i.e. HL-93 live load effects (*AASHTO LRFD*, 2014) – Figure 36. Two cases of HL-93 loading were considered: Design Tandem + Design Lane (Figure 36a); Design Truck + Design Lane (Figure 36b). The load combination which creates the maximum moment for specific span length controlled.



a) **b)**

Figure 36: HL-93 Loading Cases

The CDF’s of the computed non-dimensional ratios for moments and shear forces were plotted on the normal probability paper for each location and year. Examples of annual results are shown in Figures 37-45a for moment ratios and span of 30 ft in Figures 37-45b for moment ratios and span of

200 ft. The mean value for the moment ratio varies from 0.3 to 0.5 for all considered span lengths. However, the maximum value for each moment ratio is 1.0 to 2.5 for most cases. CDF's of moment ratios for all available locations are shown in Figure 46a for 30ft span and Figure 46b for the 200ft span. Similarly, moment ratios with regard to the years of taking records are presented in Figure 47 for 30 and 200ft span respectively.

For each location, the shape of the obtained CDF curves is very similar to that of GVW. It also can be observed, that the mean value of the ratio for both moment and shear force gradually decreases for longer spans in most cases. However, live load parameters such as bending moment ratios are very sensitive with regards to the span length and axial configuration of the vehicle. Thus, in some cases (Locations – 918, 933, 960) the maximum values of moment ratios for long span (200ft) are higher (up to 2.1) than for short spans (30ft). The heaviest vehicles in these locations mostly belong to class 13 (multi-trailer, 7 or more – axle truck) 14 or 15 (undefined by FHWA classification – Figure 26) with uniformly distributed load, while short span moment ratios reflect mostly the effects caused by short vehicles or closely spaced axial loads (such as tandems and tridems).

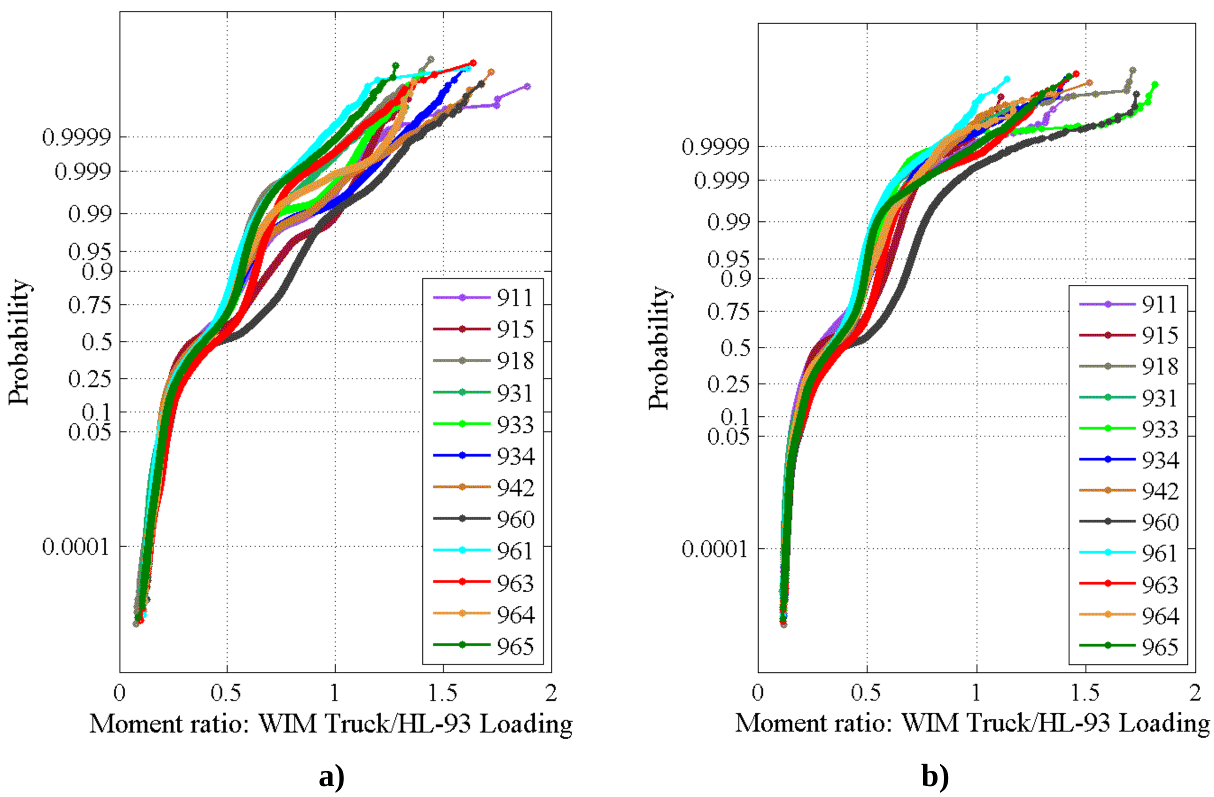
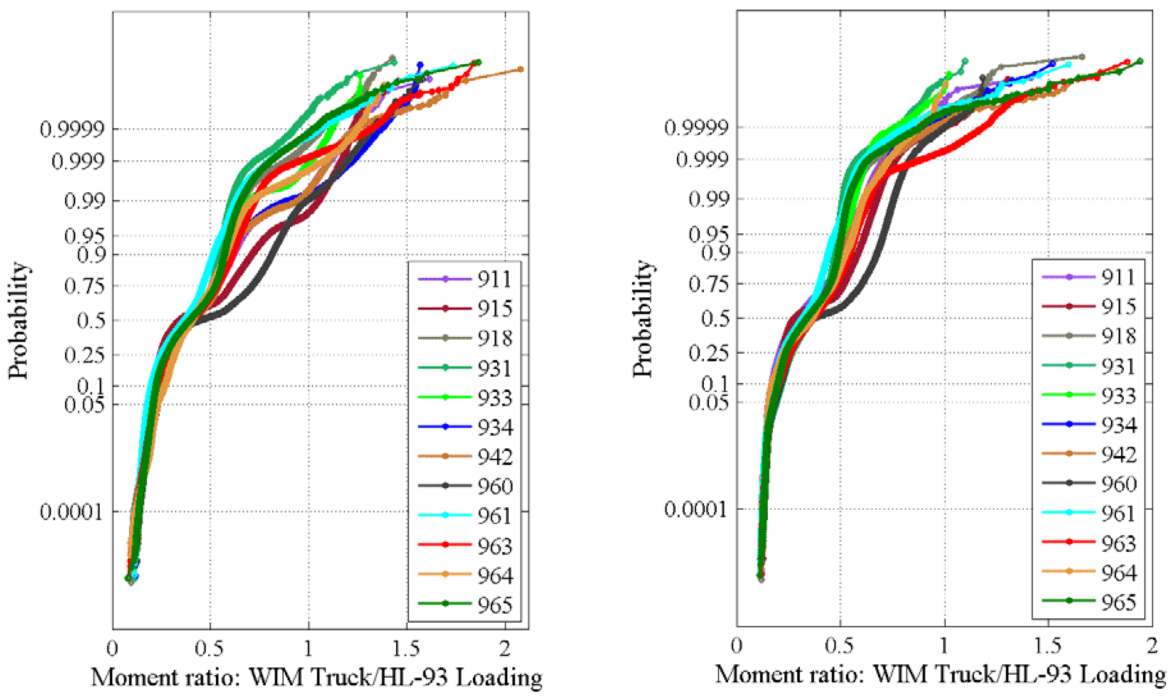
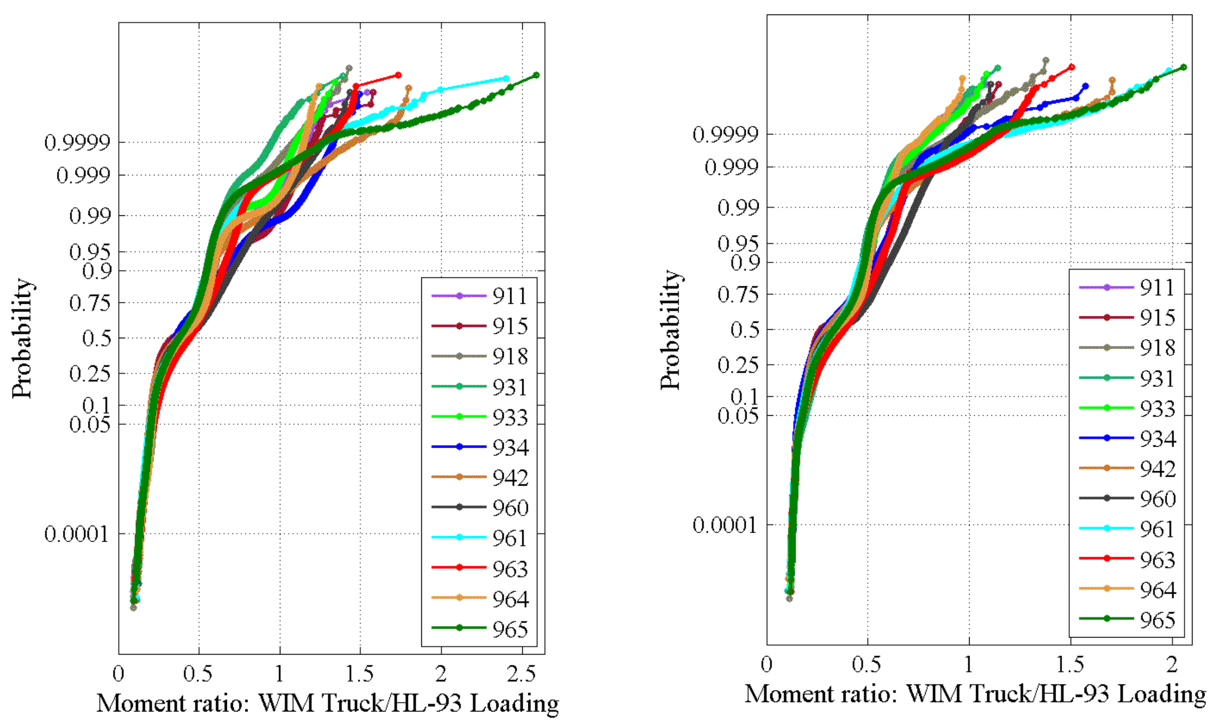


Figure 37: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2006 for all available sites.



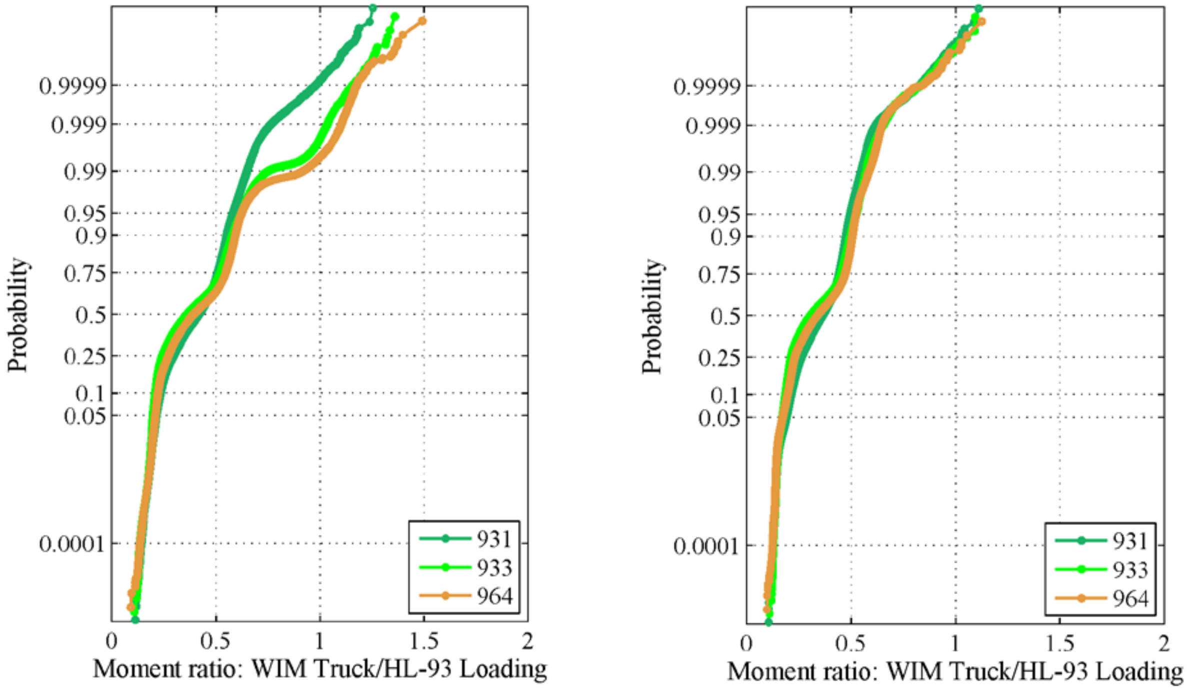
a) **b)**

Figure 38: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2007 for all available sites.



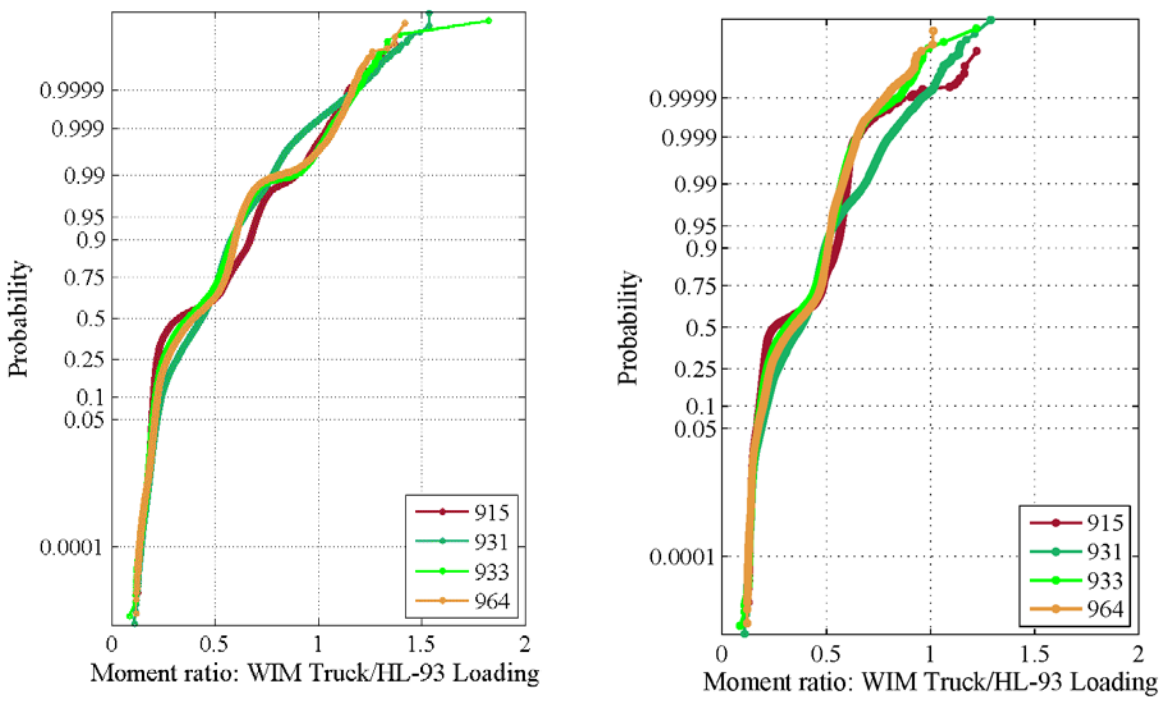
a) **b)**

Figure 39: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2008 for all available sites.



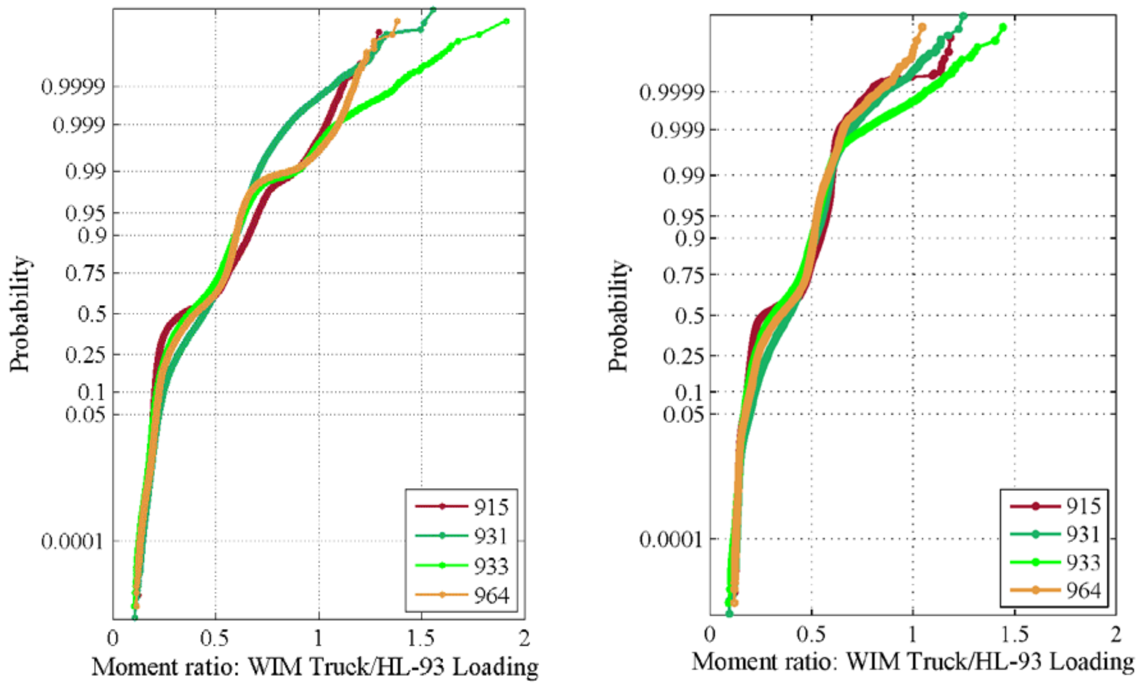
a) **b)**

Figure 40: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2009 for all available sites.



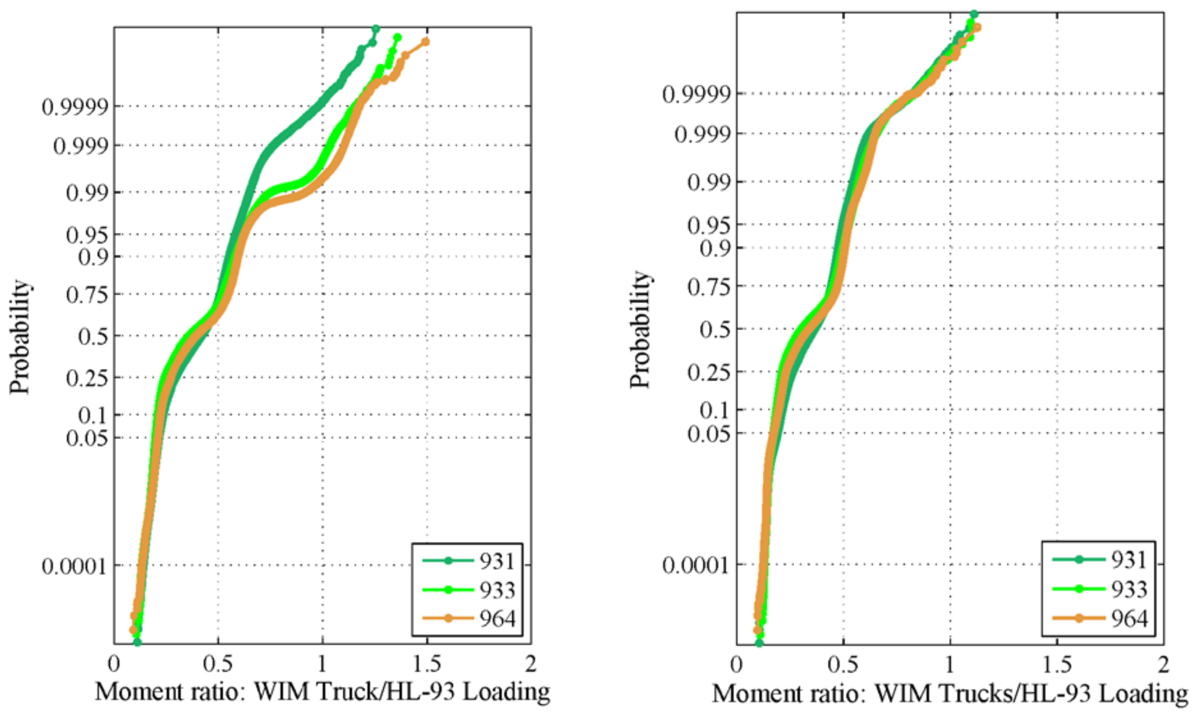
a) **b)**

Figure 41: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2010 for all available sites.



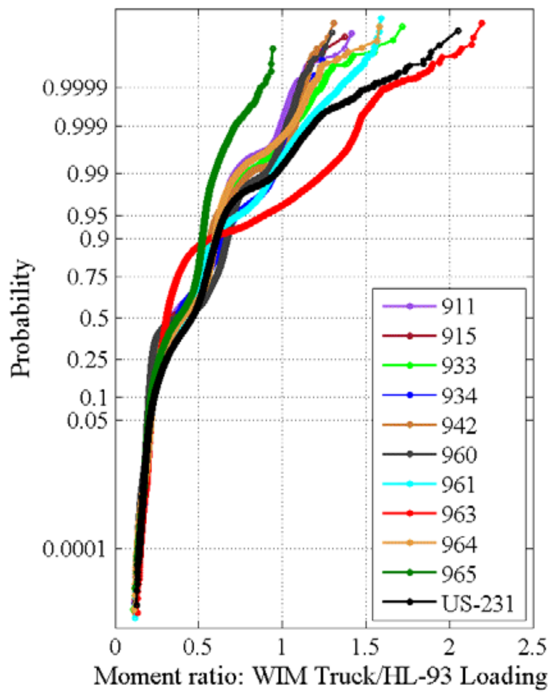
a) b)

Figure 42: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2011 for all available sites.

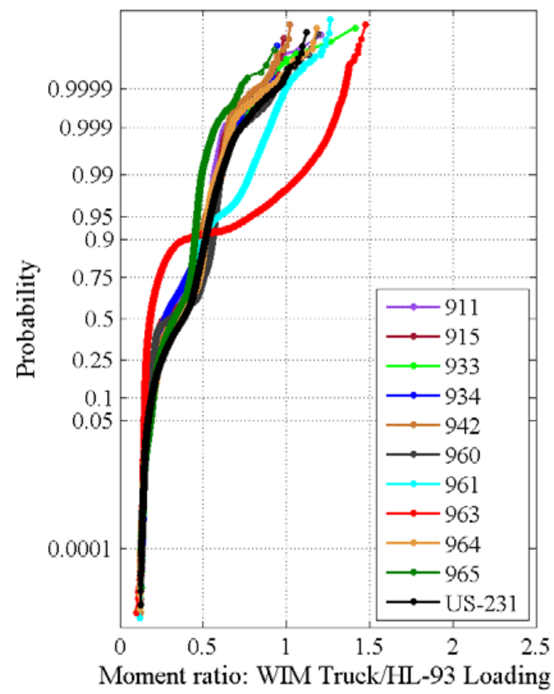


a) b)

Figure 43: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2012 for all available sites.

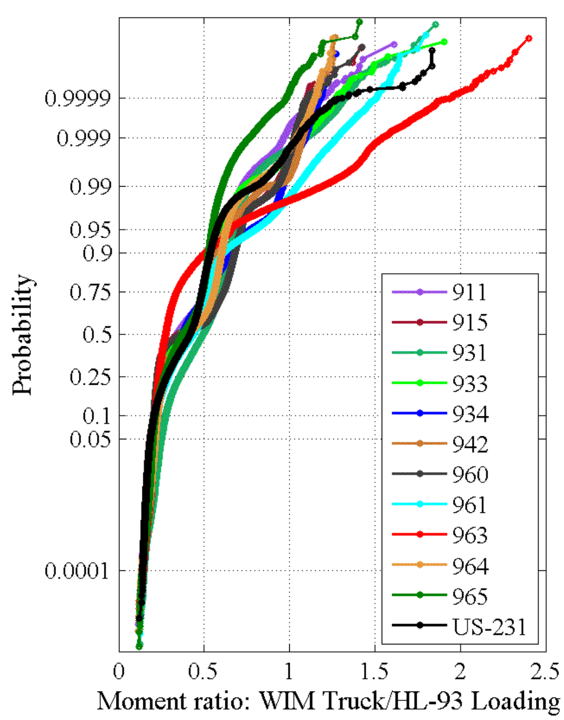


a)

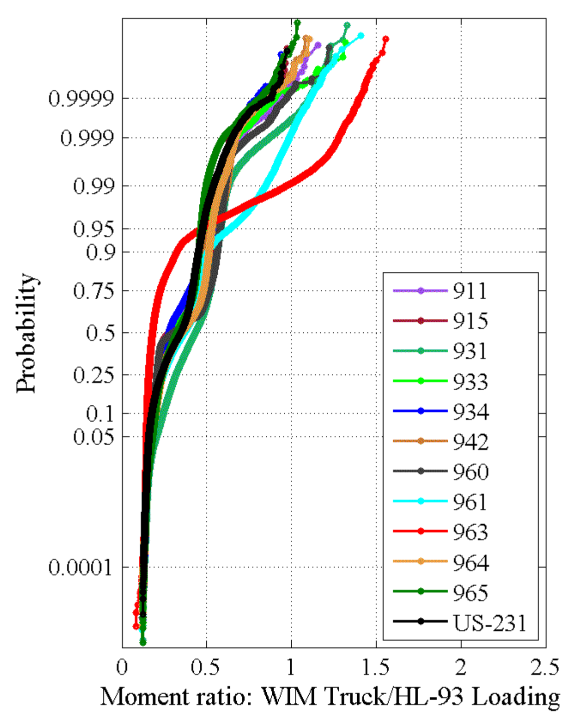


b)

Figure 44: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2013 for all available sites.

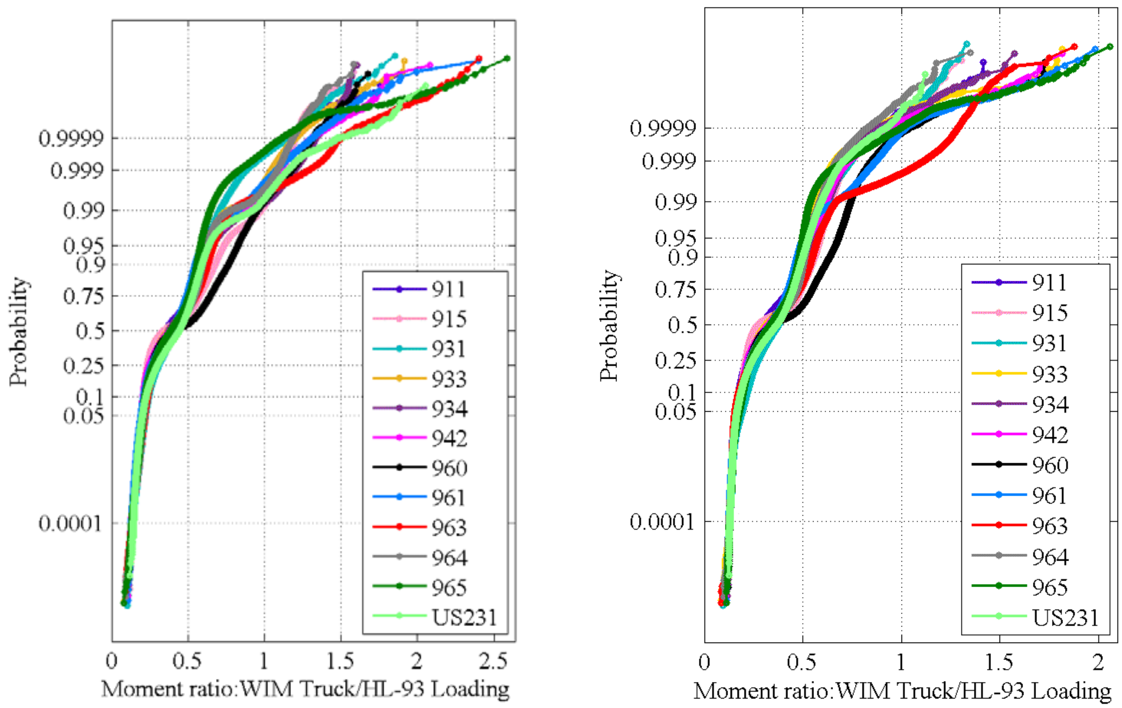


a)



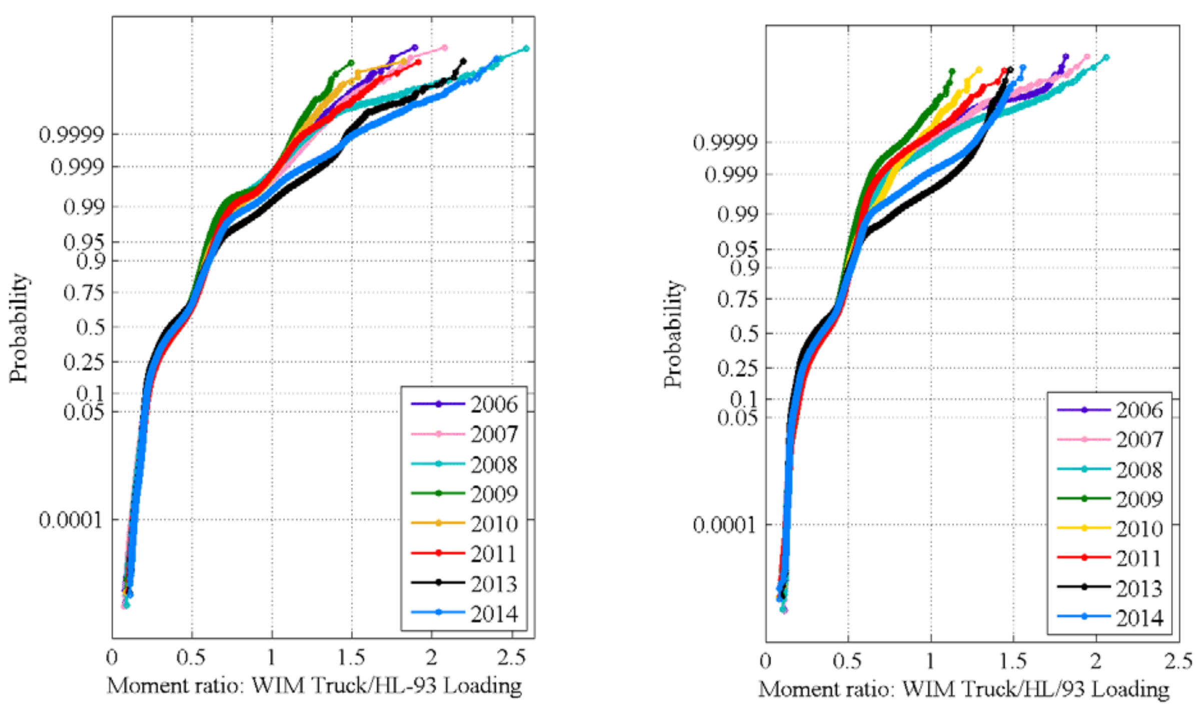
b)

Figure 45: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft span (b) for 2014 for all available sites.



a) **b)**

Figure 46: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft (b) span for all available locations



a) **b)**

Figure 47: CDF plot for ALDOT WIM database moment ratio for 30ft (a) and 200ft (b) span for all period of taking records

4.2. Maximum Daily/Weekly/Monthly Live Load Moments

In the considered database, for each day, the maximum GVW was recorded and the maximum bending moment ratio was calculated. Similarly, the maximum weekly and monthly moment ratios were found for all the considered span lengths. The resulting CDF's of the maximum daily, weekly and monthly bending moment ratio are plotted in Figure 48-Figure 55 a) and Figure 48-Figure 55 b) for 30ft and 200ft respectively. All these plots are shown for a selected location 933 (Muscle Shoals – AL157 US72).

CDF's the maximum daily moment ratio for all years are plotted in Figure 56, a) and b) for 30ft and 200ft span respectively. For other locations, the results are saved, and they will be included in Appendix C.

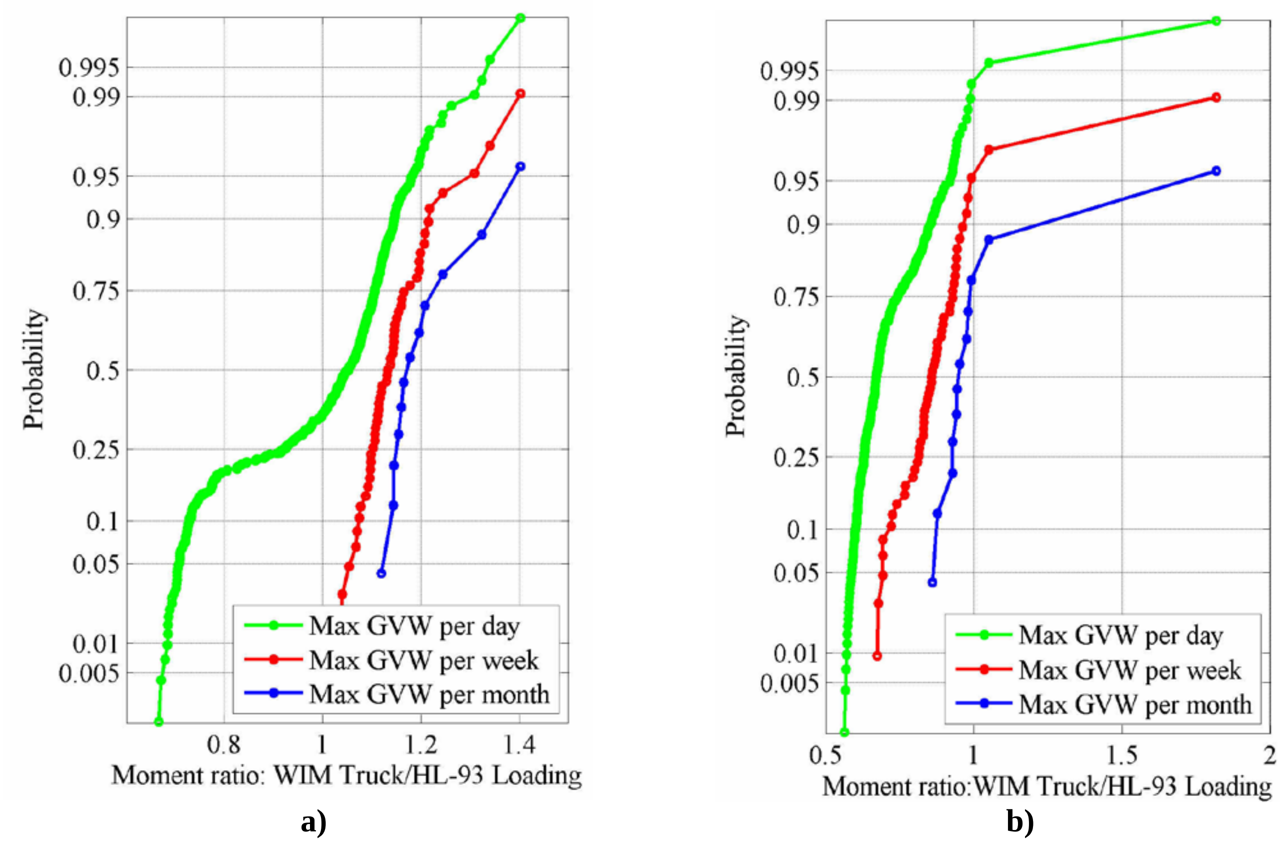
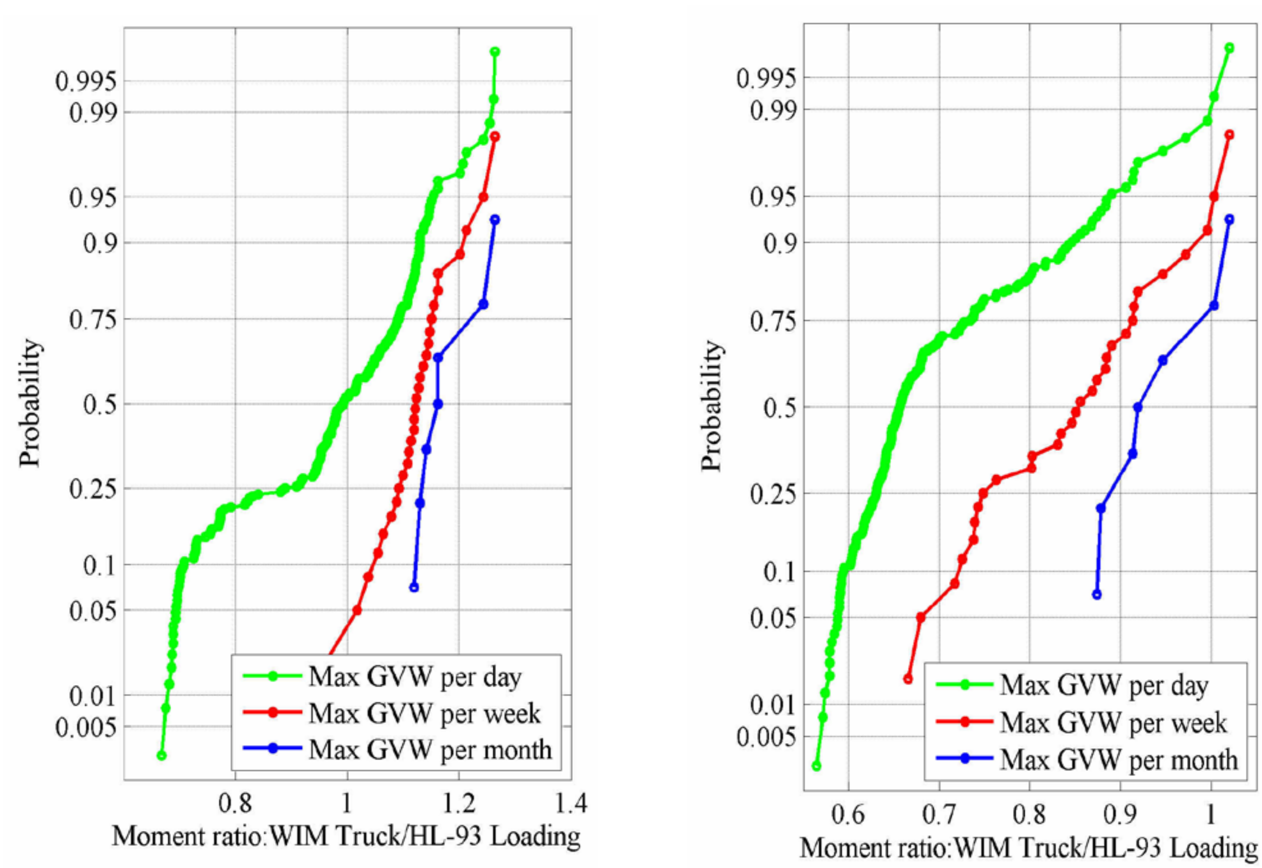


Figure 48: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2006

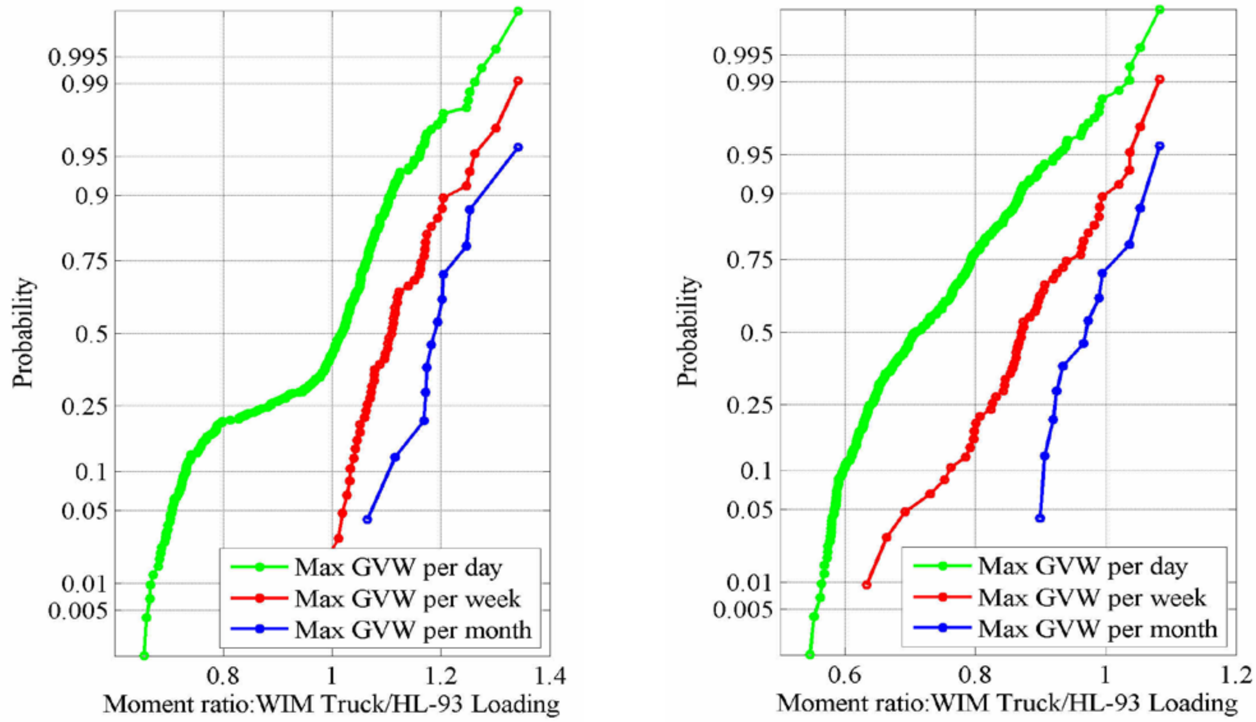
The mean maximum daily values vary from 0.9 to 1.0 for short span moment ratios. The daily maximum values vary from 1.2 in 2008-2010 to 1.9 in 2006. The mean values for the maximum weekly GVW's vary from 130 to 160 kips for the same period.

From the Figure 56, it is clear that GVW for location 933 was higher in 2011. At the same time, the maximum moment ratio for short spans (30ft) tended to increase from 1.3 in 2006-2009 to 1.8 in 2010-2014. Conversely, the maximum moment ratio for longer spans (200ft) decreased from 1.8 in 2006 to 1.2 in 2007-2014. Such difference clearly reflected the changes in traffic mix happened between 2006 and 2014. Similarly to GVW, the moment ratio1.8 for 200ft in 2006 was reached during one day – 04.06.2006.



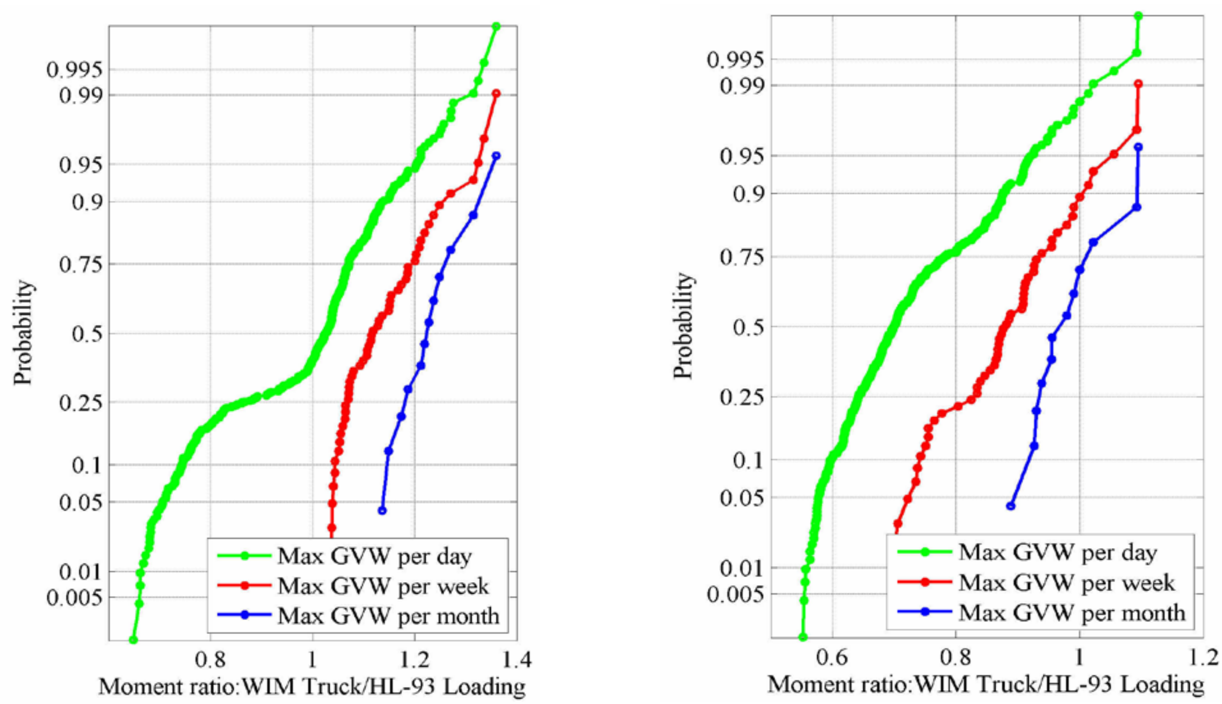
a) **b)**

Figure 49: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2007



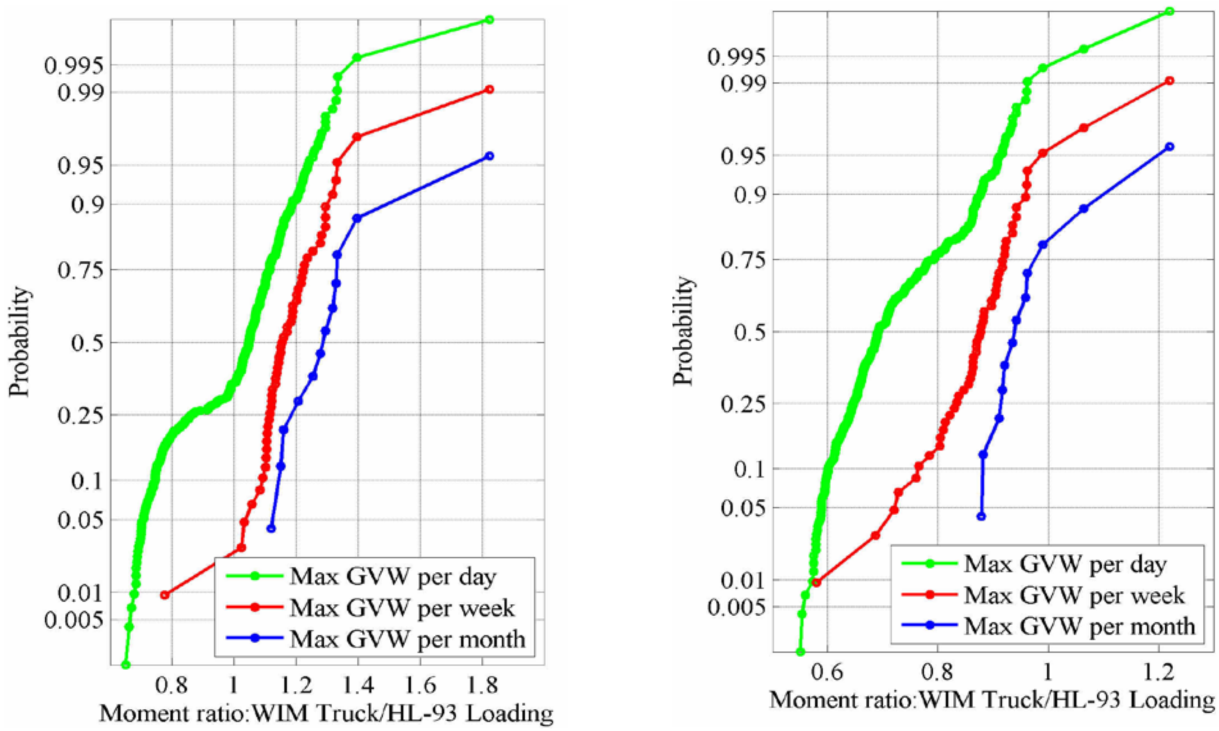
a) **b)**

Figure 50: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2008



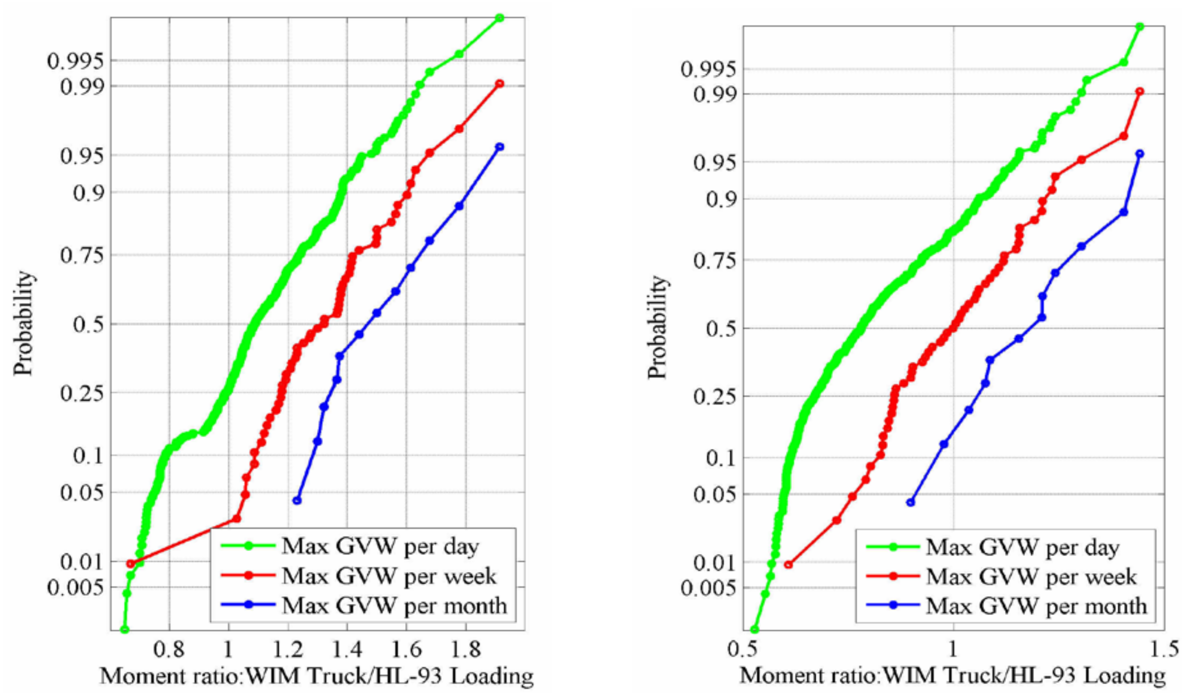
a) **b)**

Figure 51: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2009



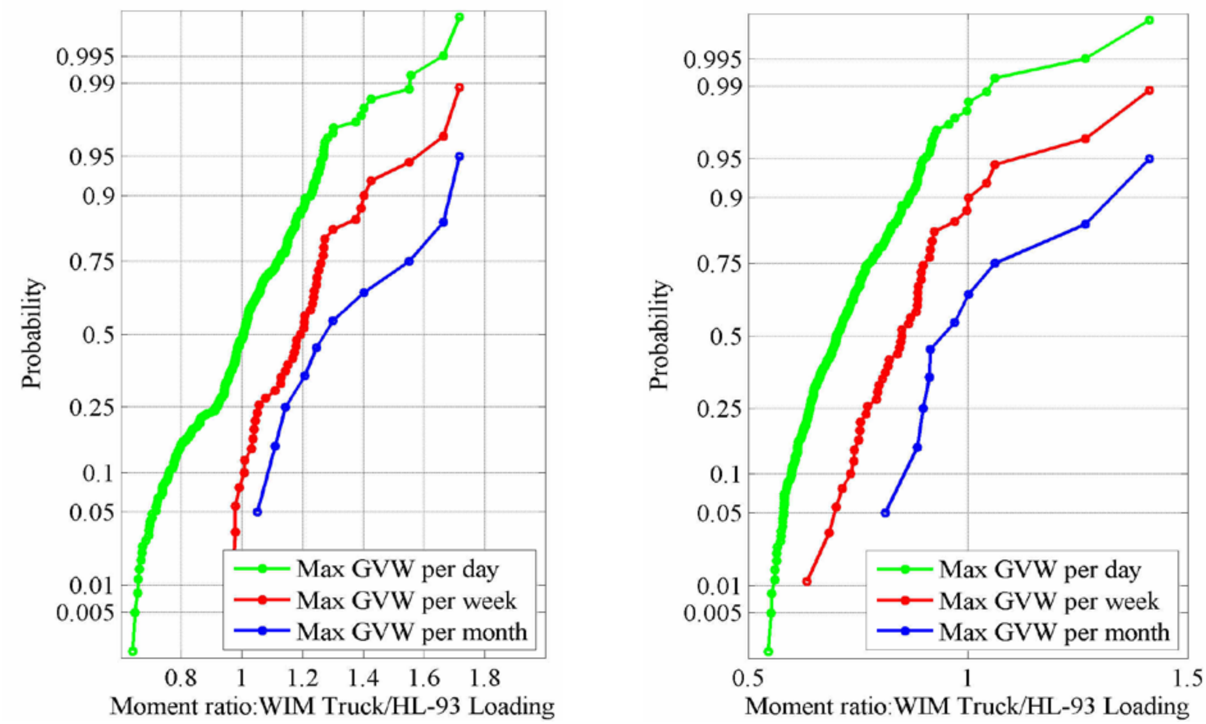
a) **b)**

Figure 52: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2010



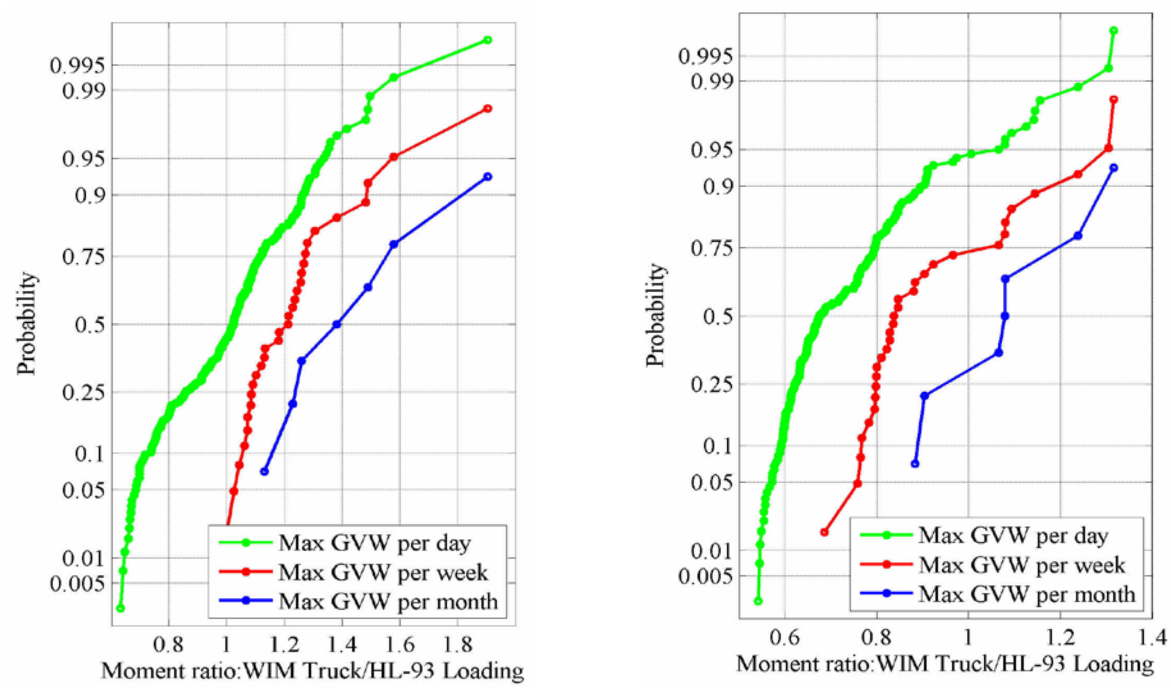
a) **b)**

Figure 53: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2011



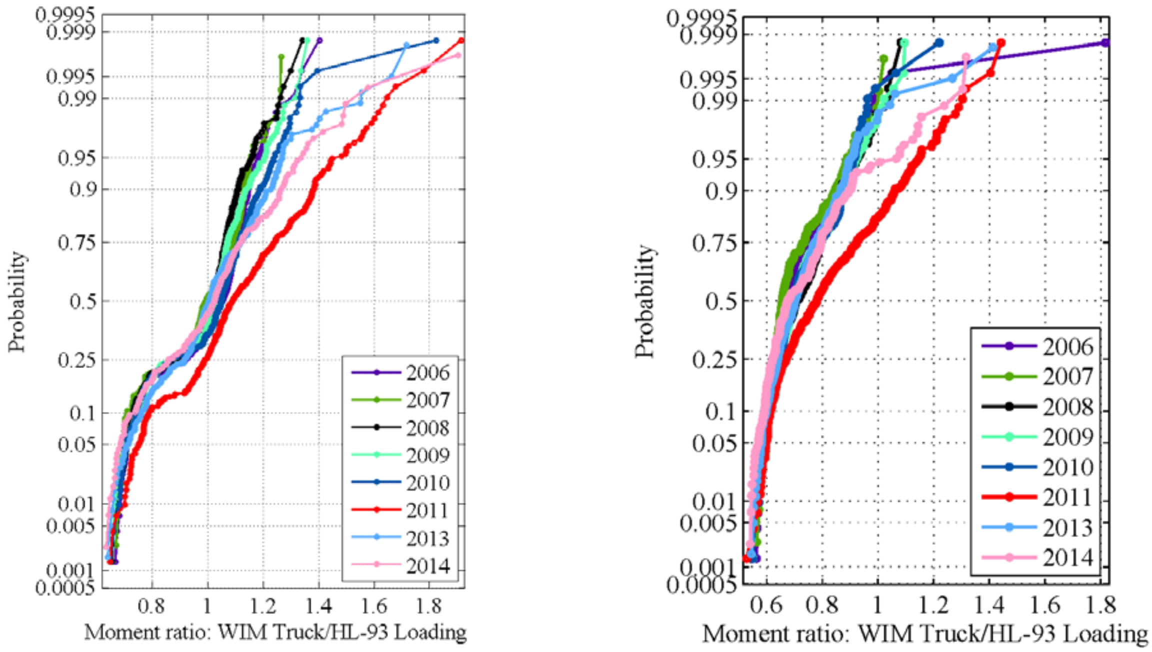
a) **b)**

Figure 54: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2013



a) **b)**

Figure 55: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2014



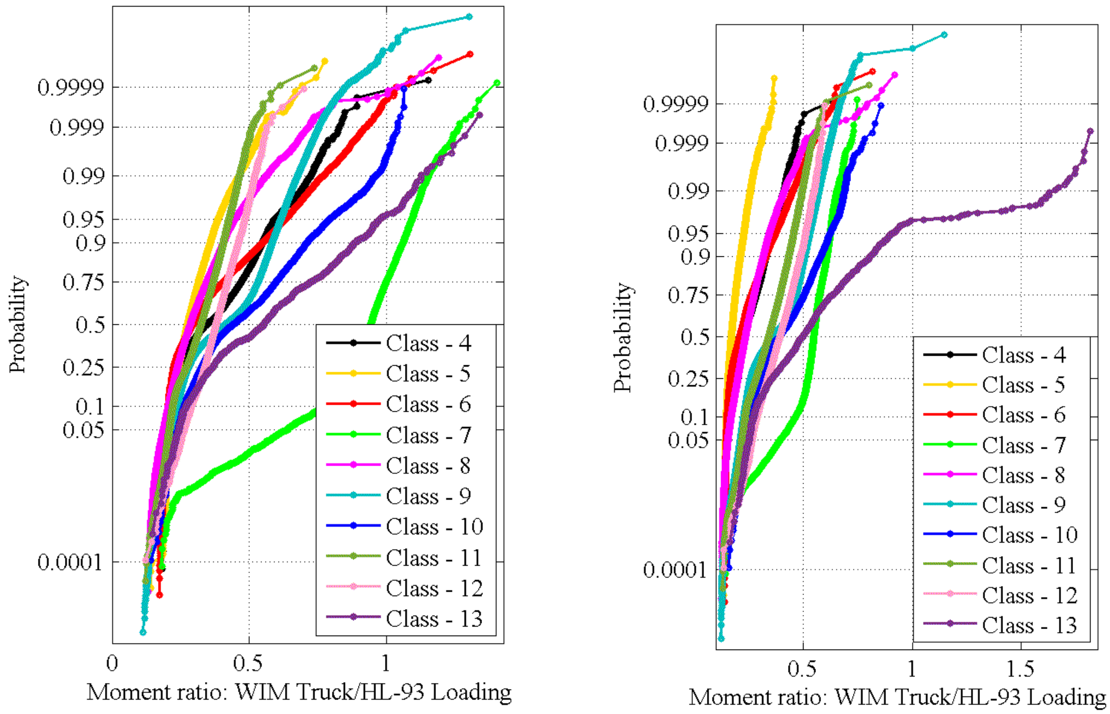
a) **b)**

Figure 56: Maximum values of moment ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2006-2014

4.3. Moments Caused by Different Classes of Vehicles

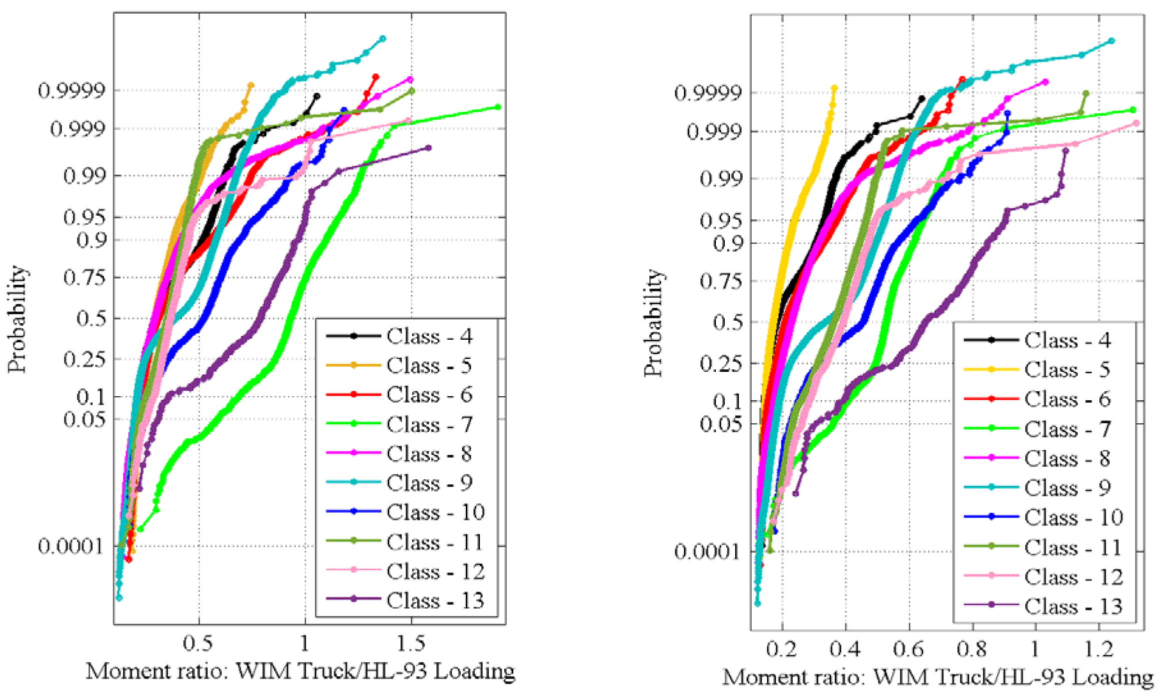
The distribution of load effects such as moment ratios is highly sensitive to the vehicle axial load configurations. These details about each WIM truck are specified by the FHWA system of vehicle classification – *MAG Internal Truck Travel Survey and Truck Model Development Study* (2007). CDF's of moment ratio distribution for each considered vehicle class were plotted for different span length and years. As an example, the data for the typical location 933 was considered. The cumulative distribution functions of moment ratios and vehicle classes 4-13 are plotted in Figure 57 for 2006 and Figure 58 for 2014. The span lengths of 30ft (a) and 60ft (b) were considered for comparison purposes.

According to the Figure 57, the highest short span moments in 2006 were caused by vehicles of class 7 (single-unit, 4 or more–axle truck) – mean value and maximum values are 0.9 and 1.5 respectively. Similarly, the highest moments for 30ft spans in recent 2014 caused by class 7 trucks – mean value and maximum values are 0.9 and 1.8 respectively (Figure 58). Conversely, vehicle class causing the highest moment for longer spans in 2006 (Figure 57b) is 13th – multi-trailer, 6-axle trucks (Figure 26).



a) **b)**

Figure 57: CDF's moment ratios caused by different vehicle classes for 30 ft (a) and 200 ft(b) span length for the location 933 – 2006



a) **b)**

Figure 58: CDF's moment ratios caused by different vehicle classes for 30ft (a) and 200ft (b) span length for the location 933 – 2014

The mean and maximum values are 0.5 and 1.8 respectively. However, the mean value for the moment ratio for a 200ft span in recent 2014 varies from 0.2 to 0.8 for most of the vehicle classes, while the max value is about 1.2 for most vehicle classes.

4.4. Statistical Parameters for Permit Data (Moment Ratio)

Statistical parameters for live load effects, i.e. moment and shear forces were calculated for illegally overloaded or permit vehicles to access the possible degree of damage caused by this category of trucks. For each truck, the maximum bending moment and shear force was calculated for simple spans of 30, 60, 90, 120, 200ft. The resulting moments were divided by the corresponding HL-93 moments (Figure 36). The CDF’s of these non-dimensional ratios are plotted on the normal probability paper. In Figure 59 and Figure 60, the CDF’s of moment ratios are plotted for 30 and 200ft spans, respectively. The data is presented for all available locations (Figure 59a) and years (Figure 59b).

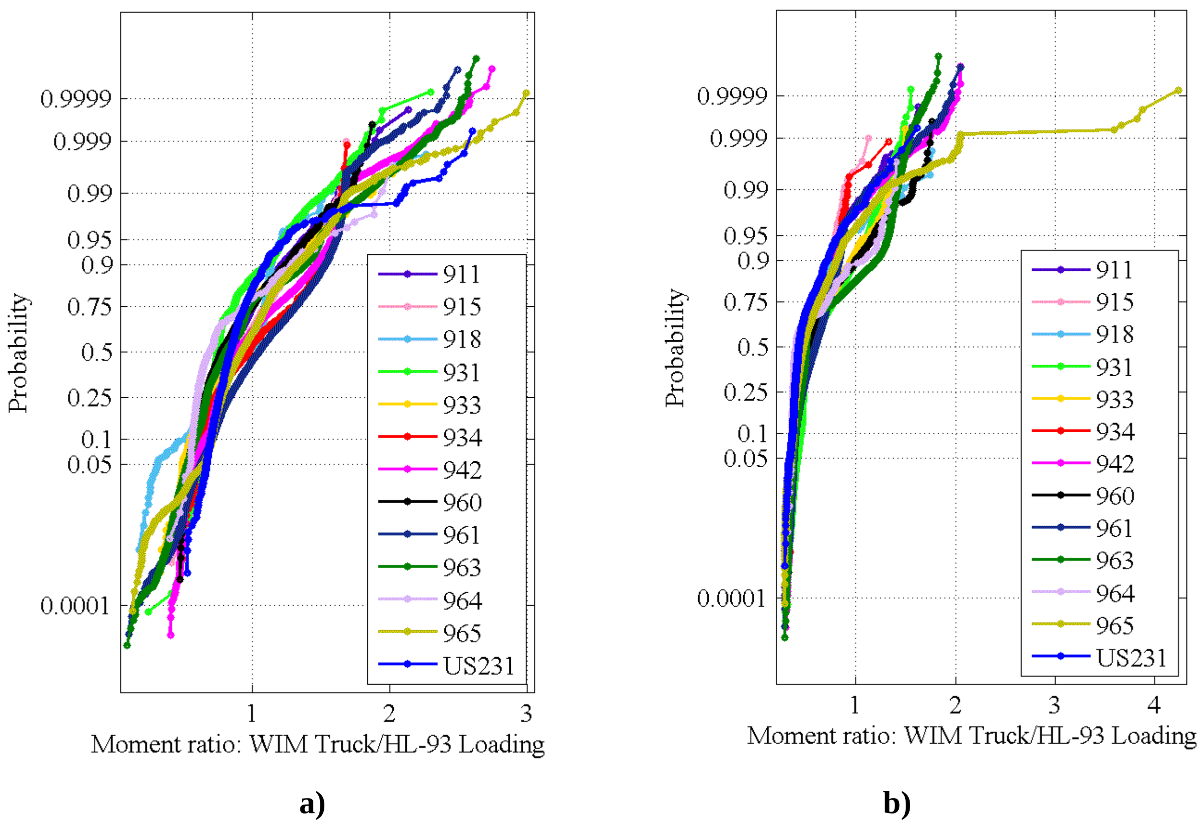
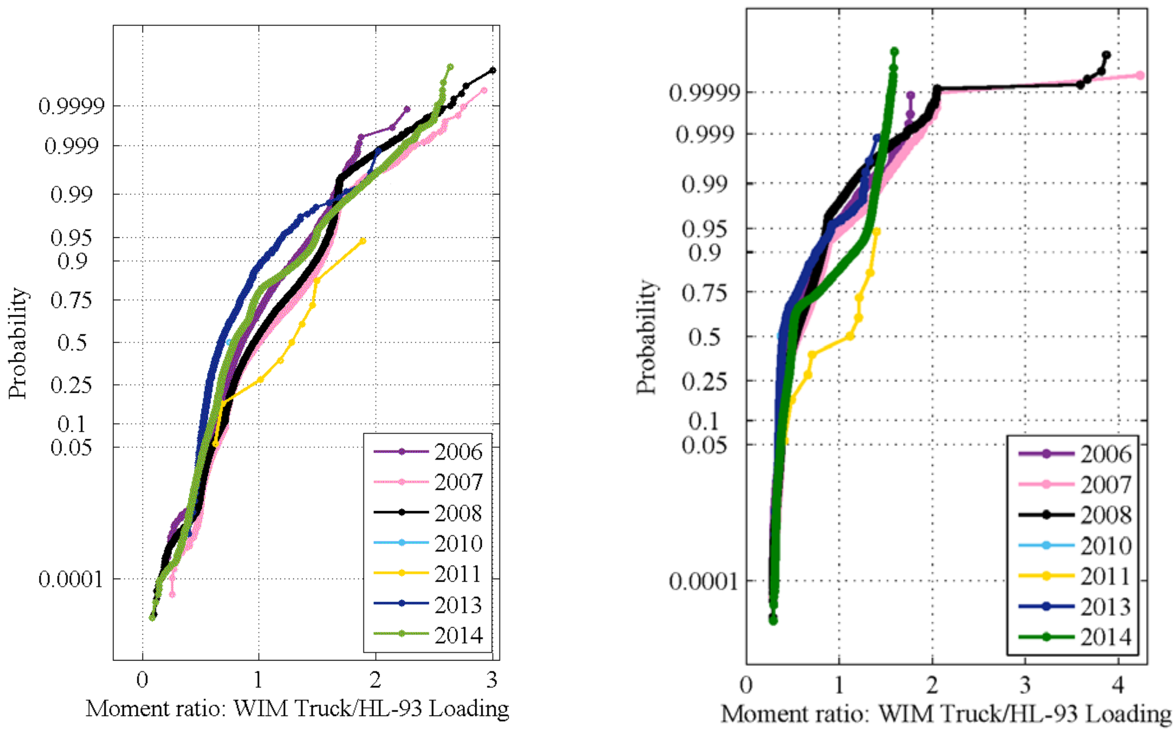


Figure 59: CDF’s moment ratios caused by permit or illegally overloaded trucks for 30ft (a) and 200ft (b) span length for all available locations



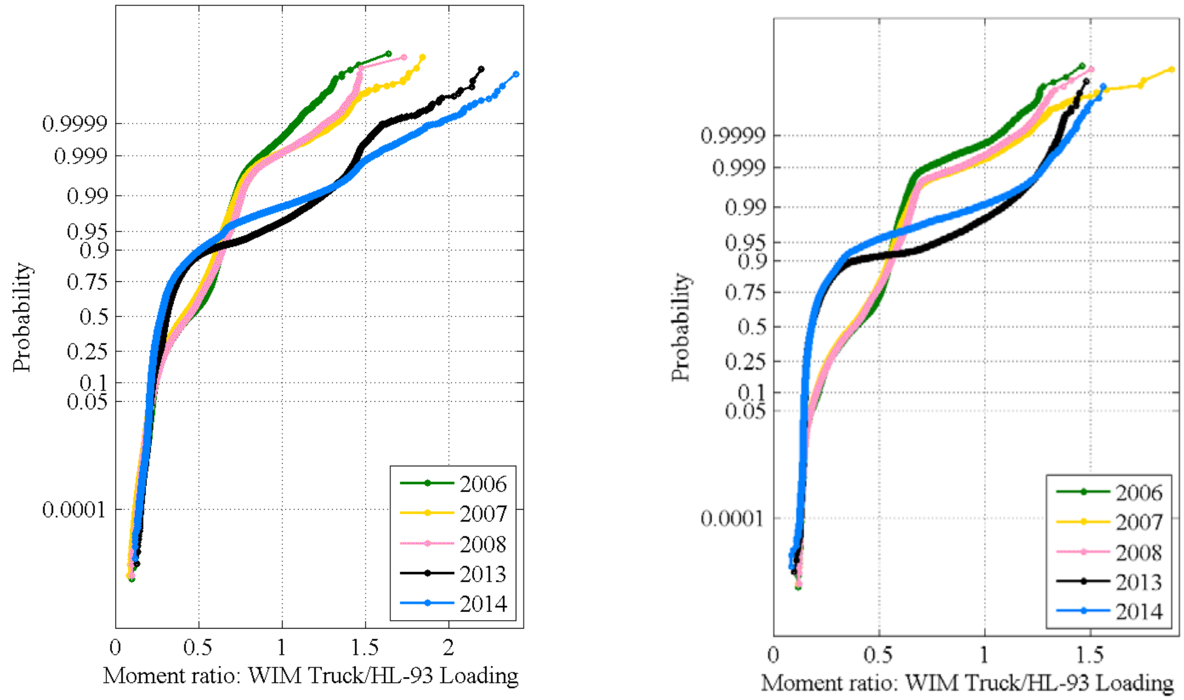
a) **b)**

Figure 60: CDF's moment ratios caused by permit or illegally overloaded trucks for 30ft (a) and 200ft (b) span length for years 2006-2014

Similarly to the regular traffic data, the mean value of moment ratios decreases as the span length increases in most cases from 0.9-1.2 (Figures 59a and 60a) to 0.4-1(Figure 59b and Figure 60b). However, the maximum effect caused by overloaded vehicles to the short span 30ft is lower than for longer span 200ft due to the trucks configuration (axial loads are not applied simultaneously). There is a substantial number of trucks with parameters which are not specified in FHWA scheme. In most cases their base length exceeds 100ft. Thus, these vehicles create a significant but not the maximum load effect for short spans. The maximum moment ratio for 200ft is about 4 (Figure 59b)

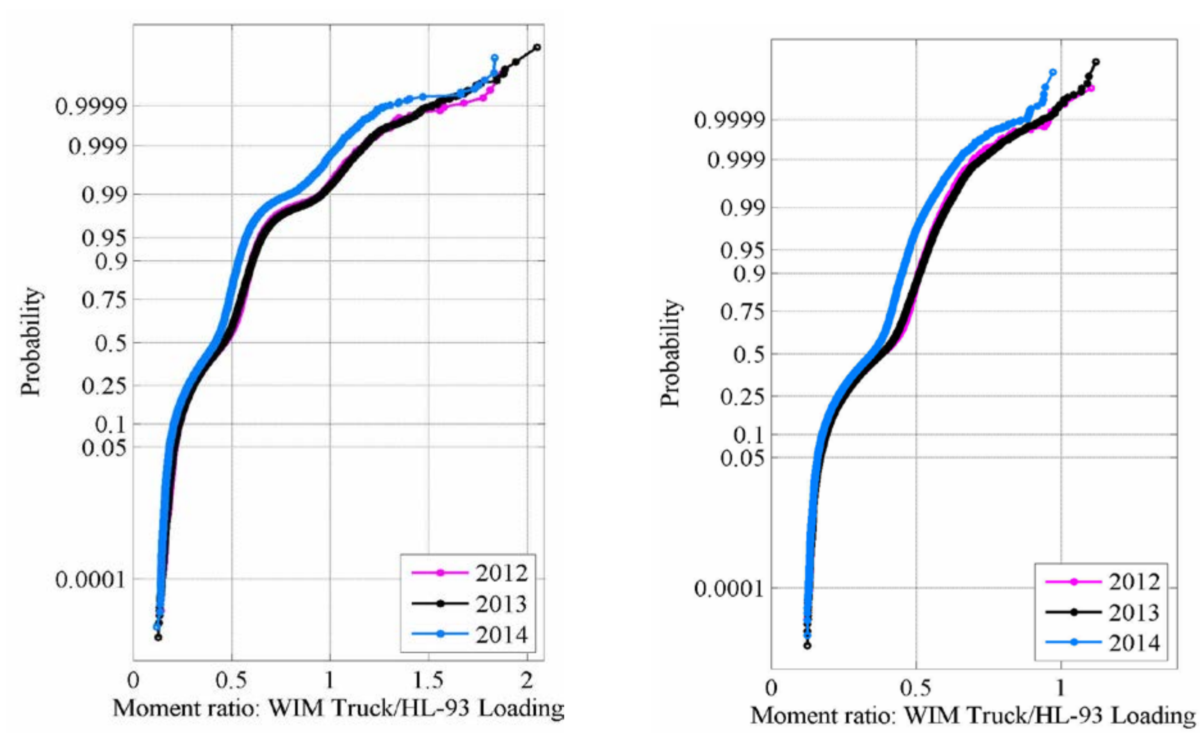
4.5. Outlying Data

Annual and maximum daily/weekly/monthly data for moment ratios were shown for the most typical location which represents the live load distribution for most of the regions in Alabama. Outlying distribution of the load effects for locations 963 and US-231 is considered in this chapter. For short spans (30ft) there is a considerable variation in moment ratios statistics for these locations. CDF's for moment ratios for locations 963 (I10, Mobile) and US-231 are plotted in Figures 61 and 62 respectively.



a) b)

Figure 61: CDF's of moment ratios for 30 ft (a) and 200 ft(b) span length for the location 963 – 2006-2014



a) b)

Figure 62: CDF's of moment ratios for 30 ft (a) and 200 ft(b) span length for the location US231 – 2012-2014

There is a significant difference in CDF's of moment ratios during 2006-2014 for all span lengths. From the Figure 61, it is clear that the changes occurred during 2008-2013 (WIM database for 2009-2012 is not available). The mean value decreased from 0.7 (2006-2008) to 0.3 (2013-2014) while the maximum moment ratios increased from 1.5 (2006-2008) to 2.4 (2013-2014). Moment ratio 2.4 is the maximum value for the whole ALDOT WIM database. Opposite trend with GVW was already discussed for the same location (Figure 34) as well as changes in truck traffic mix.

Live load effects for location US231 are also remarkable because of the substantially high moment ratios (2.1) for short spans (Figure 62, a). Unlike in the case of location 963, the shapes of CDF's are very consistent with regard to the years. Thus, there were no changes in truck traffic during the period of taking records. However, there is a difference in vehicle class proportions in comparison to all the other locations. The traffic mix composition for location US-231 is summarized in Table 19 and presented as a bar chart in Figure 63. Obviously, vehicles class 9(5 axles, single trailer trucks) is substantial but not dominating type for this location, while class 11(5 or less-axles, multiple trailers) is about 50% of the total number of trucks.

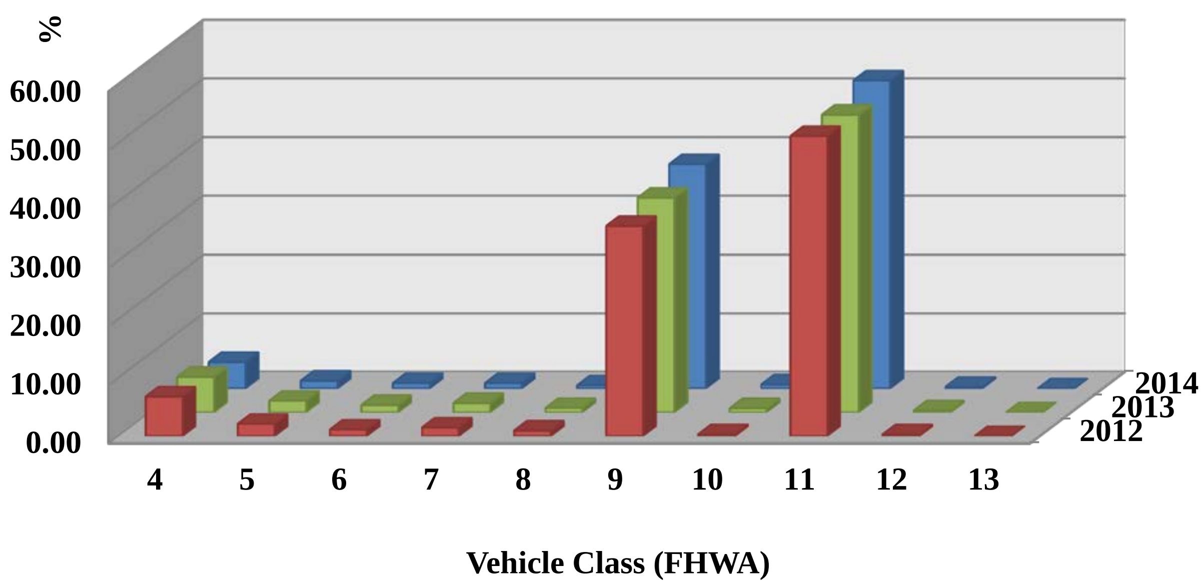


Figure 63: Percentage of each vehicle class for location US-231

Table 19: Percentage of each class of vehicle presence US-231

FHWA classes	US231		
	2012	2013	2014
4	6.76	6.07	4.53
5	2.11	1.97	1.34
6	1.12	1.26	0.93
7	1.47	1.59	0.93
8	0.94	0.76	0.53
9	35.82	36.56	38.23
10	0.32	0.70	0.69
11	51.17	50.74	52.52
12	0.28	0.34	0.30
13	0.00	0.00	0.00

Another example of outlying distribution if of the load effect ratios is WIM site 965 (Shorter, I-85). The shapes of CDF's are mostly consistent over the time for all considered span lengths except the 1% of the upper tails of curves (Figures 37-45). Maximum moment ratios (2.5 for 30ft and 2for 200ft) were found exceptionally high for the whole database. There is no difference in the traffic mix (Appendix B), but in GVW (Figures 9-13). The maximum moment ratios vary 0.7-1.6 for 30ft and 1-2 for 200ft for all period of taking records, except 2008 (Figures 37-47).

4.6.Summary

Live load effects in the form of a non-dimensional ratio of the moment caused by WIM truck divided by tabulated HL-93 value are presented in this chapter. The resultant moment ratios were computed for 30, 60, 90, 120 and 200ft spans and plotted as CDF's on probability paper.   Maximum daily/weekly/monthly values were calculated, plotted and analyzed as it was done for GVW (Chapter 3). The distributions of moments caused by vehicles of different classes were also considered. All results were presented for the most typical location. However, all the locations were analyzed and outlying data discussed in special section.

The following can be concluded:

- Obtained results indicate that there are considerable differences in truckloads between locations (site-specific differences) and years. Mostly it relates to the upper tail of CDF's which represents the maximum values of the moment ratios;

- For short spans (30 ft), there is a considerable variation in maximum bending moment statistics. The largest values of moment ratio and shear force ratio (Truck/HL-93 Loading) were computed for four locations: 961, 963, 965 and US-231;

- Vehicle class 7 (single-unit, 4 or more–axle truck) caused the highest bending moment to short (30ft) spans, while class 13 (multi-trailer, 6-axle trucks) controls for longer spans;

- Class 9 is not the dominating type for location US-231 (2012-2014) but class 11 (5 or less-axles, multiple trailers);

- Similarly to GVW, a considerable change in moment ratios distribution was indicated in the period from 2008 till 2013 at location 963.

5 SHEAR FORCE RATIOS CAUSED BY WIM TRUCKS

5.1.Statistical Parameters for Shear Force Ratios – Annual Data

Live load effects analysis is continued in this chapter. It is focused on studying shear forces caused by the recorded vehicles in Alabama. The approach is similar to the bending moments considered in Chapter 4. Shear forces were calculated by running each recorded WIM truck though influence lines using the same MATLAB routine as for moments. The same span lengths of 30, 60, 90, 120 and 200ft were chosen for computing the shear forces.

Maximum in the envelope shear forces caused by each vehicle was divided by the corresponding tabulated shear forces caused by HL-93 loading (*AASHTO LRFD Bridge Design Specifications, 7th Edition* 2014) – Figure 64. Unlike in the case of bending moment, only one case of HL-93 loading is considered for all span lengths: Design Truck + Design Lane (Figure 64).

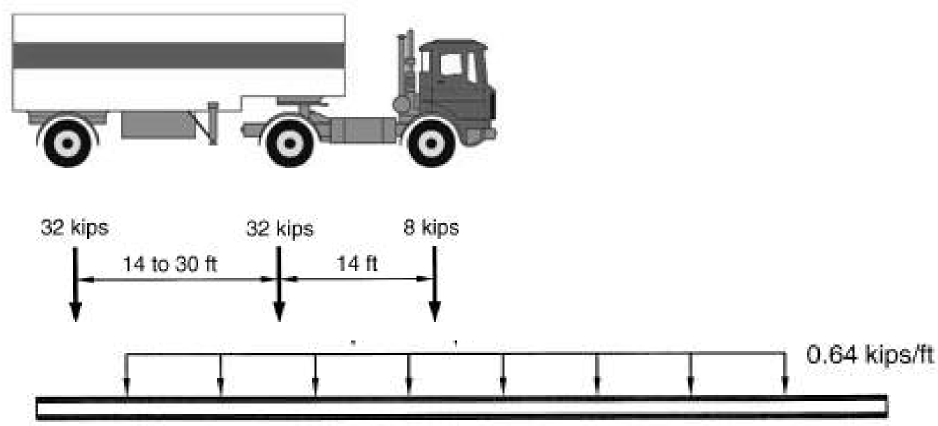
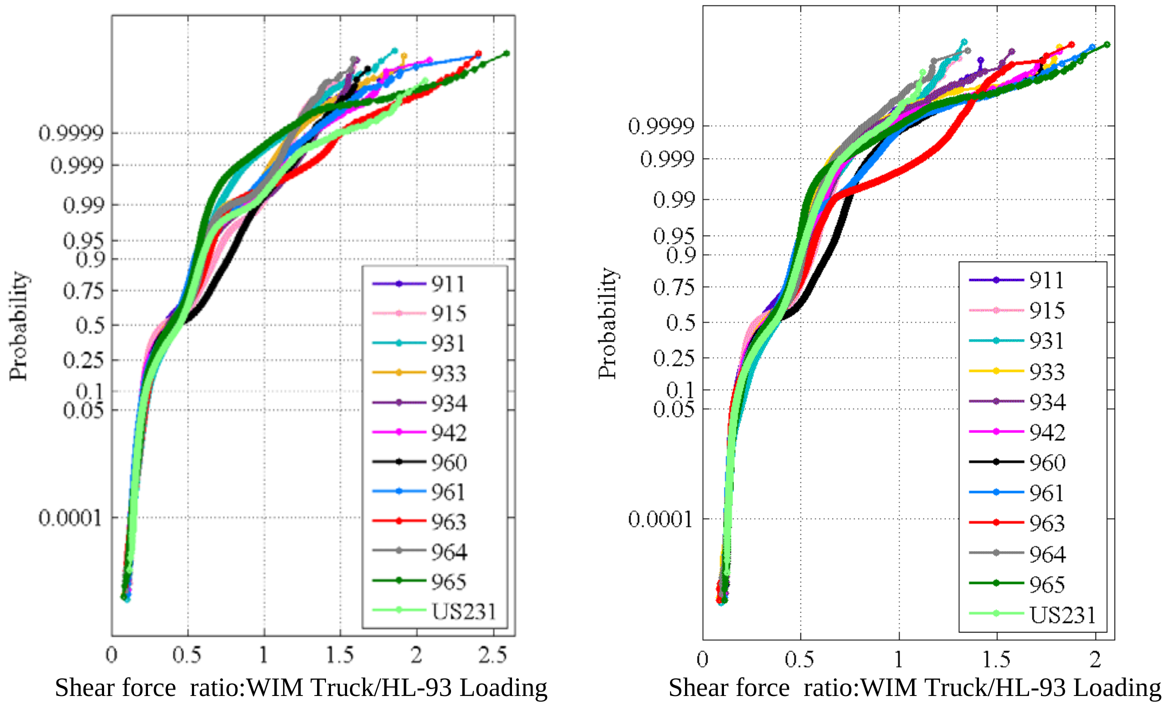


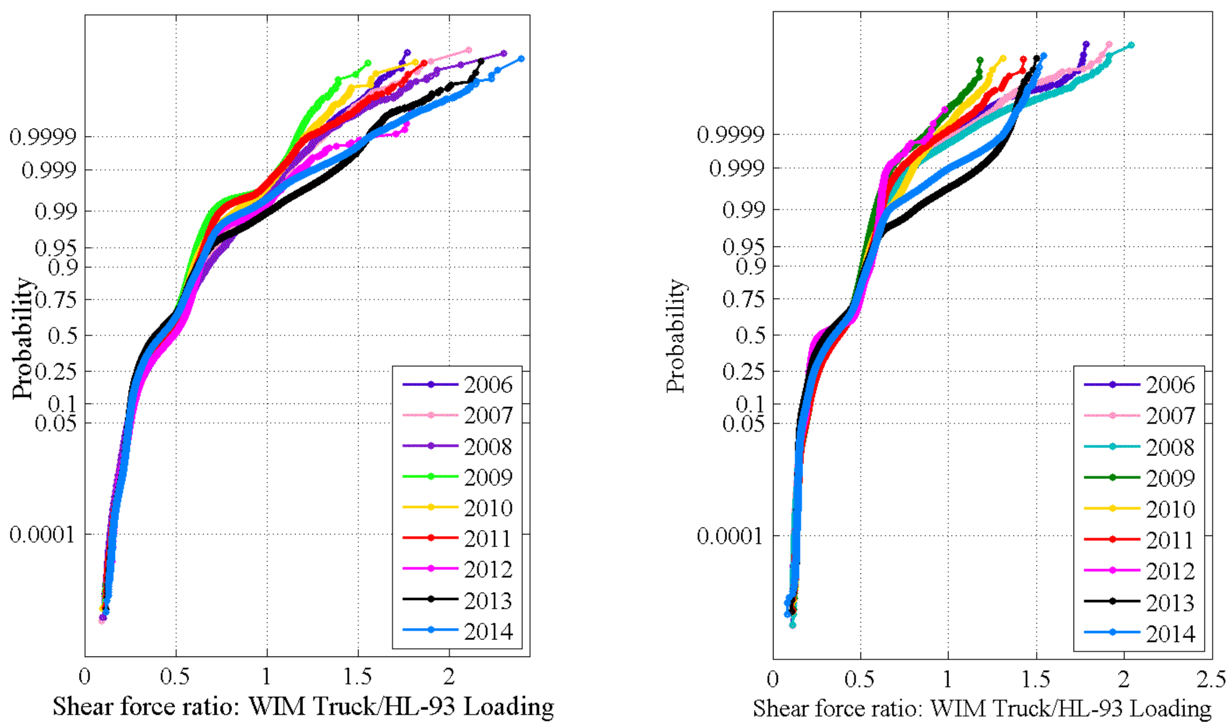
Figure 64: HL-93 Loading Case for Shear Force

The CDF's of the computed non-dimensional ratios for shear forces were plotted on the normal probability paper for each location and year. CDF's of shear force ratios for all available locations are shown in Figures 65a and 65b for 30 and 200ft span respectively. Similarly, shear force ratios with regard to the years of taking records are presented in Figures 66a and 66b for 30 and 200ft span respectively. The shapes of CDF's of shear force ratios are mostly similar to corresponding CDF's of moment ratios (Figures 37-45, 46 and 47). The mean value for the moment ratio varies from 0.3 to 0.5 for all considered span lengths. The maximum value for each moment ratio is 1.0 to 2.5 for most cases.



a) **b)**

Figure 65: CDF plot for ALDOT WIM database shear force ratio for 30ft (a) and 200ft (b) span for all available locations



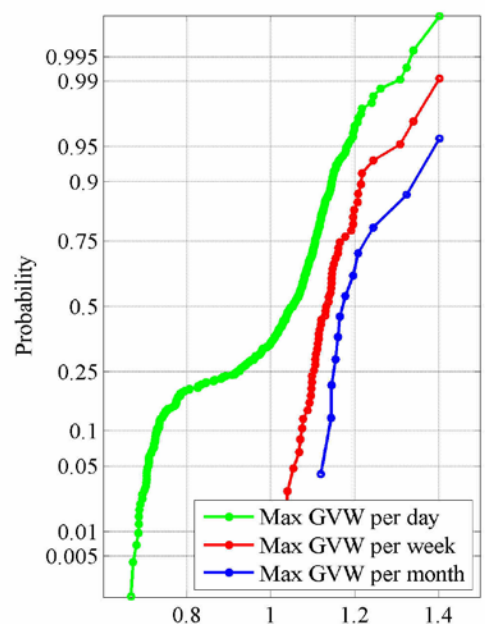
a) **b)**

Figure 66: CDF plot for ALDOT WIM database shear force ratio for 30ft (a) and 200ft (b) span for all period of taking records

5.2.Maximum Daily/Weekly/Monthly Live Load Shear Forces

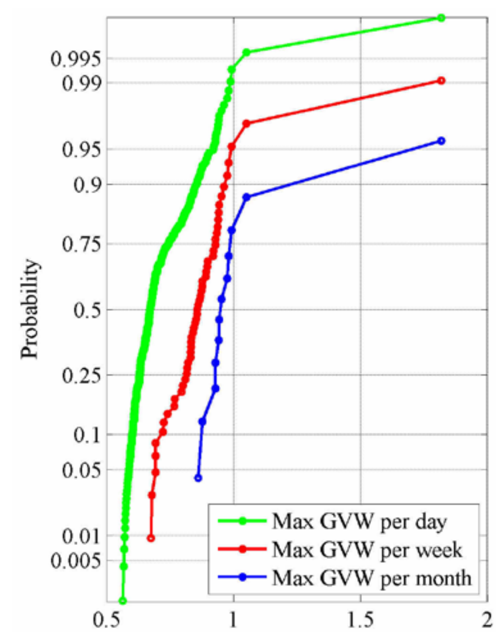
In the considered database, for each day, the maximum GVW was recorded, and bias factor for the maximum shear force ratio was calculated. Similarly, the maximum weekly and monthly ratios were found for all the span lengths. The shape of CDF's for shear forces is similar to the corresponding CDF's of moment ratio. Thus, resultant CDF's of the maximum daily, weekly and monthly shear force ratios are plotted only for years 2006 and 2014 in Figures 67 and 68 respectively. As in the case of moment ratios all these plots are for a selected location 933 (Muscle Shoals – AL157-US72). CDF's the maximum daily shear force ratio for all years are plotted in Figure 69a and b for 30ft and 200ft span respectively.

The mean maximum daily values vary from 0.9 to 1.0 for short span shear force ratios. The daily maximum values vary from 1.2 in 2008-2010 to 1.9 in 2006. The mean values for the maximum weekly GVW's vary from 130 to 160 kips for the same period. From the Figure 65, it is clear that GVW for location 933 was higher in 2011. At the same time, the maximum moment ratio for short spans (30ft) tended to increase from 1.3 in 2006-2009 to 1.8 in 2010-2014. Conversely, the maximum moment ratio for longer spans (200ft) decreased from 1.8 in 2006 to 1.2 in 2007-2014. Such difference clearly reflected the changes in traffic mix happened between 2006 and 2014.



Shear force ratio: WIM truck/HL-93 Loading

a)



Shear force ratio: WIM truck/HL-93 Loading

b)

Figure 67: Maximum values of shear force ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2006

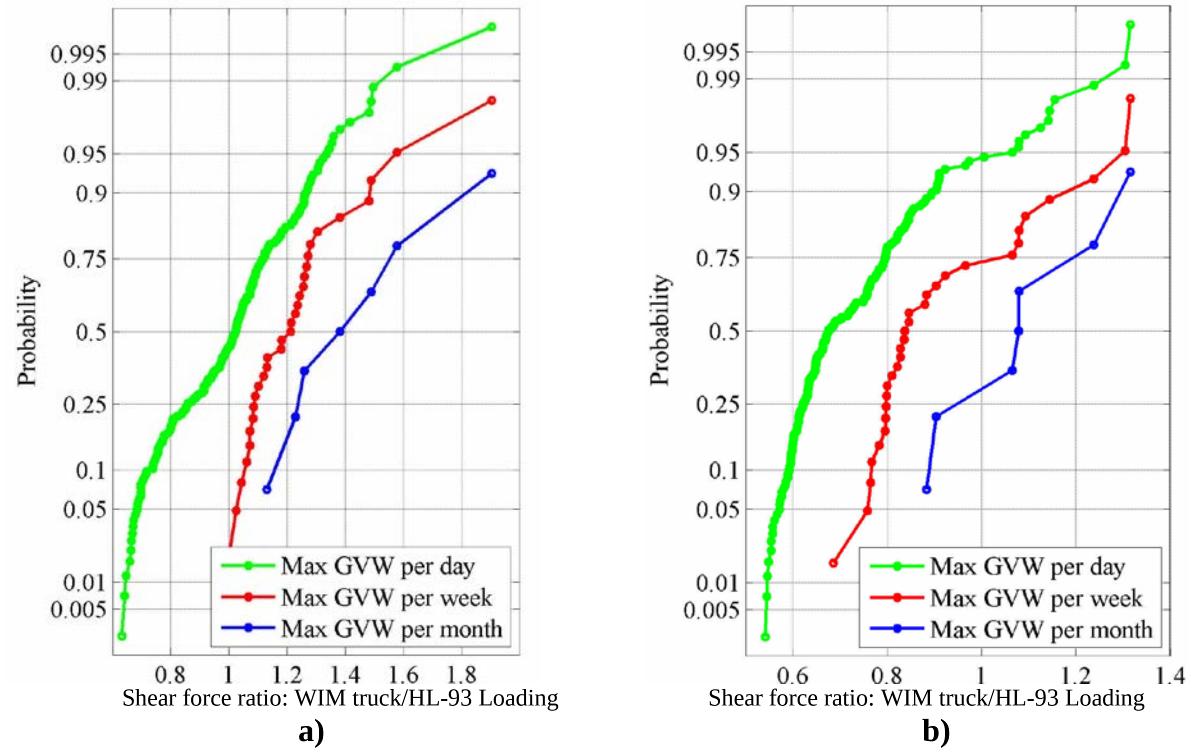


Figure 68: Maximum values of shear force ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2014

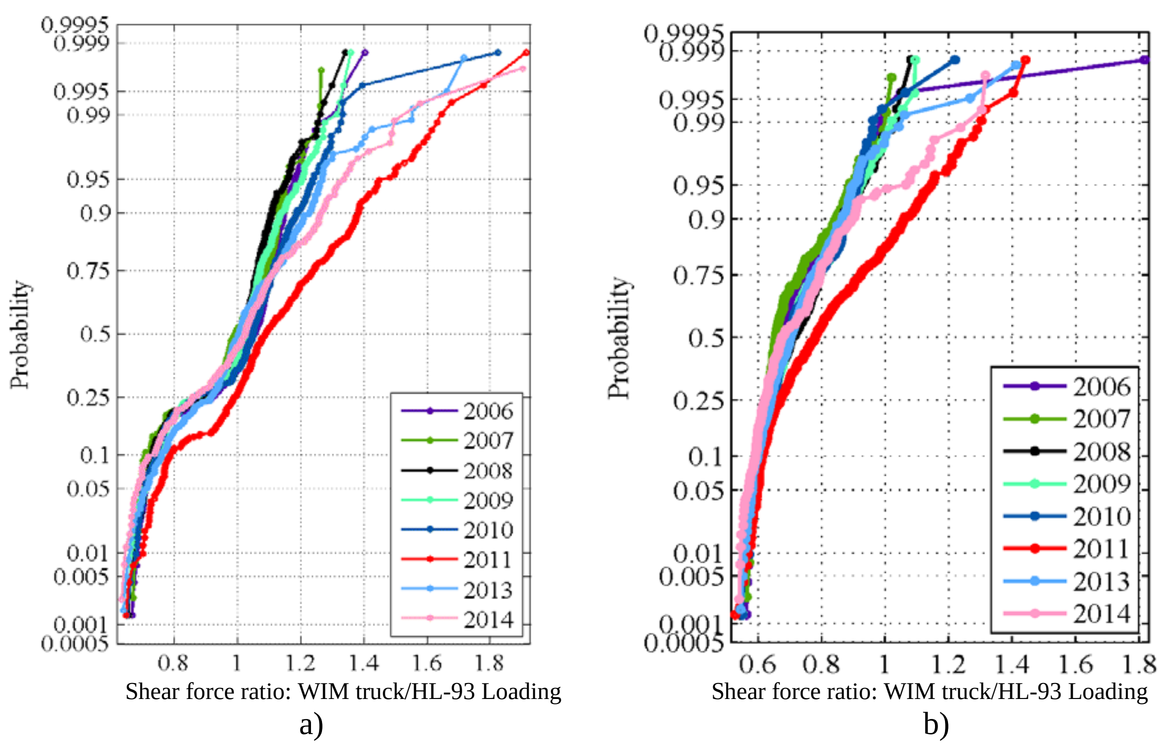


Figure 69: Maximum values of shear force ratios for 30ft (a) and 200ft (b) span length for the location 933 – 2006-2014

5.3.Summary

Shear forces were calculated for all available WIM data for 13 locations in Alabama. It is assumed that the recorded traffic is representative of the state. Nevertheless, the following has to be noted:

- Similarly to the moment ratio, there are considerable differences in shear force distribution between locations (site-specific differences);

- For short spans (30 ft), there is a considerable variation in maximum shear force statistics. The largest values of moment ratio and shear force ratio (Truck/HL-93 Loading) were computed for two locations: 963 (Figure 61 a, b) and US-231, (Figure 62 a, b);

- Similarly to GVW, a considerable change in shear force ratios distribution was indicated in the period from 2008 till 2013 at location 963.

6 ANALYSIS OF TRUCK TRAFFIC DISTRIBUTION

6.1.Potentially harmful trucks

Live load parameters such as bending moment and shear force ratios are very sensitive with regards to the span length and vehicle configuration. In particular, vehicles which create the extreme live load effects for the different span length (Figure 37 and 45) were considered.

Special consideration is required for shorter span case. For example, the maximum moment ratio for 30 ft span varies from 2 to 2.5 (the mean value is 0.5). The mean and maximum values of GVW are 20 kip and 300 kips respectively.

Moments strongly depend on truck axle configuration and total load distribution on axles rather than on magnitude of the GVW itself. The reason is that most of the overloaded trucks belong to class 9-13, with a total length of more than 30 ft. Therefore, in most cases, all loaded axles cannot be within a short span simultaneously, and only a portion of the truck weight can affect the actual live load. Short vehicles (less than 30 ft in this case) regardless of the class were considered more carefully, as well as longer trucks (the total length of the truck base is greater than the span length).

The frequency of occurrence of the extreme load effect was also taken into account to select the potentially harmful vehicles. The analyzed was performed for the ALDOT WIM database after applying the first set of filtering criteria but including the permit and illegally overloaded vehicles (Figure 4).

The WIM data for all locations was reviewed to identify and separate vehicles which cause the moment ratios greater than 1.5. This upper limit was gradually increased to 2.0 to analyze the portions of different vehicle classes causing high load effect. The configurations of the most harmful trucks were selected based on the vehicle class, a number of axles, mean values of the axial loads and spacings. Thus, the schematic drawings of the vehicles causing the greatest load effects to 30-60ft spans and high probability of occurrence are shown in Figures 70, 71, 73 and **75**. The corresponding distribution of GVW and moment ratios for selected vehicle class and all considered span lengths are shown in Figures 72, 74 and 76.

A substantial number of trucks potentially harmful for short spans have the total base length shorter than considered 30ft span length and GVW greater than 100kips. These vehicles mostly belong to class 7 or 9 (Figure 26).

Class 13 vehicles control the extreme load effects for the longer spans (90-200ft). A wide range of multi-trailer vehicles with more than 7 axles is covered by Class 13. Thus there is a certain configuration of class 13 vehicle which causes the maximum moment and shears to the particular span up to 200ft. The most frequent configuration causing the maximum effect to the 200ft span is shown in Figure 77. The CDF's of GVW and moment ratios are shown in Figure 78.

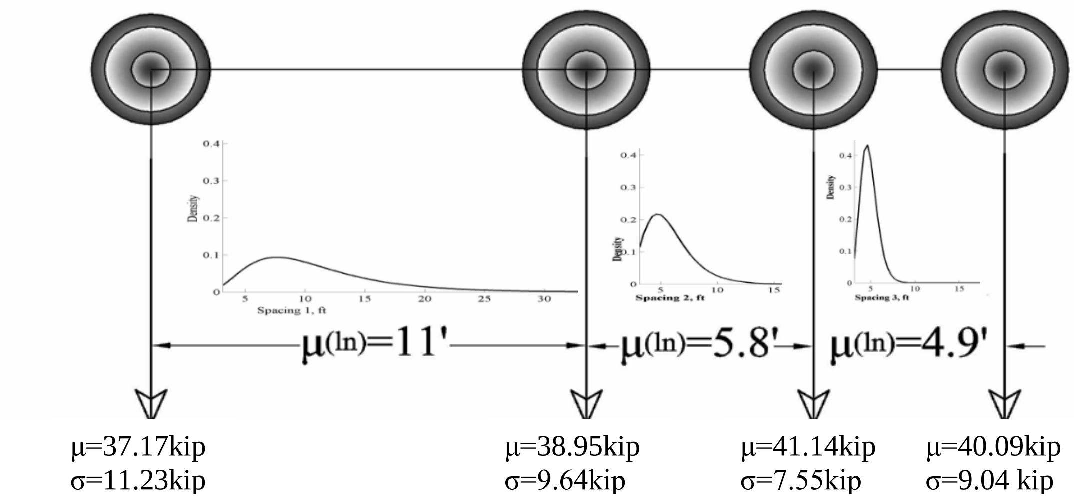


Figure 70: Configuration of potentially harmful vehicle for 30ft span (Class 7, μ_{GVW}=157 kips,)

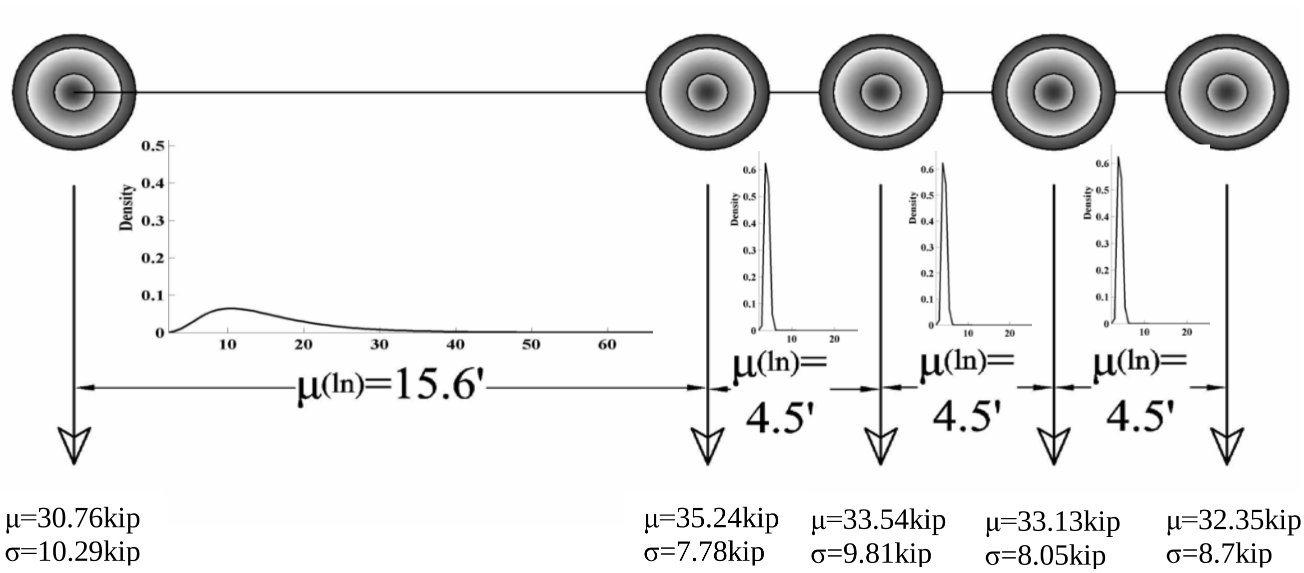
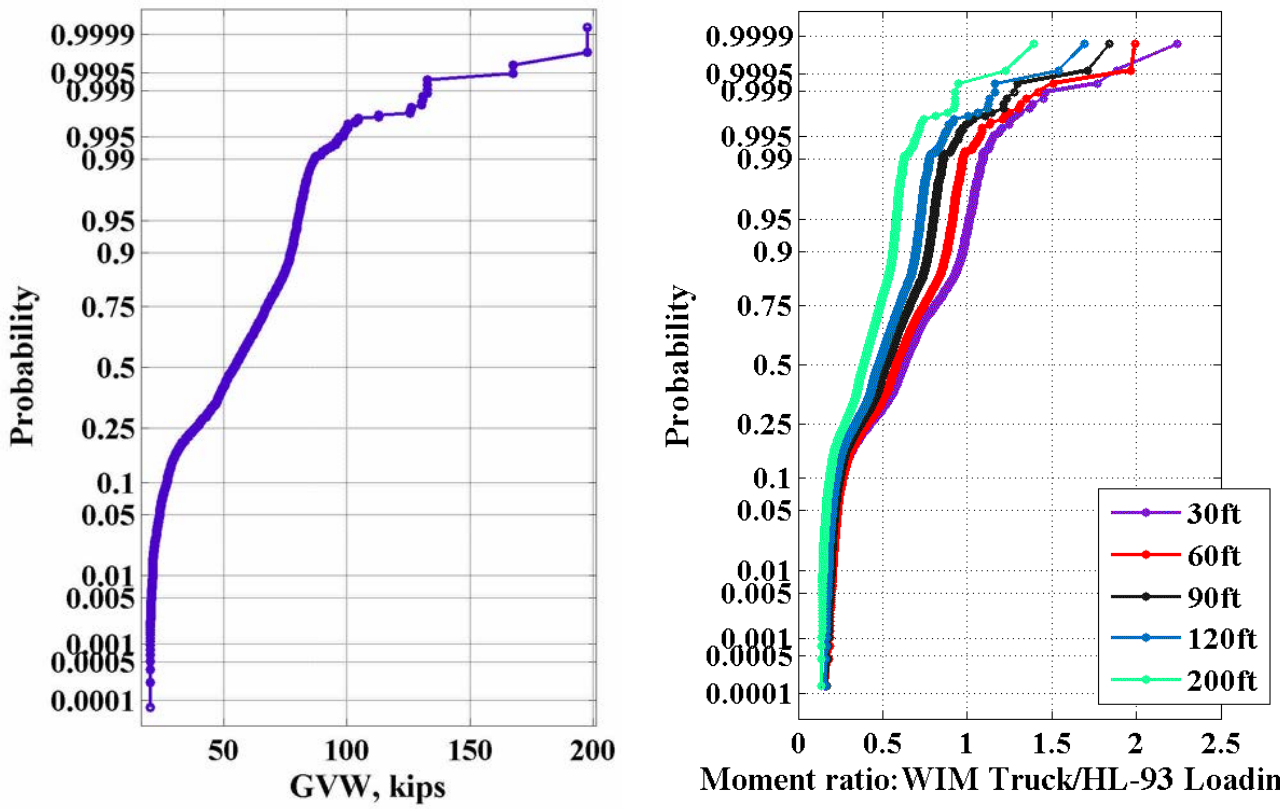


Figure 71: Configuration of potentially harmful vehicle for 30ft span (Class 7, μ_{GVW}=167 kips)



a) b)

Figure 72: CDF's of GVW (a) and moment ratios (b) caused by vehicles of class 7

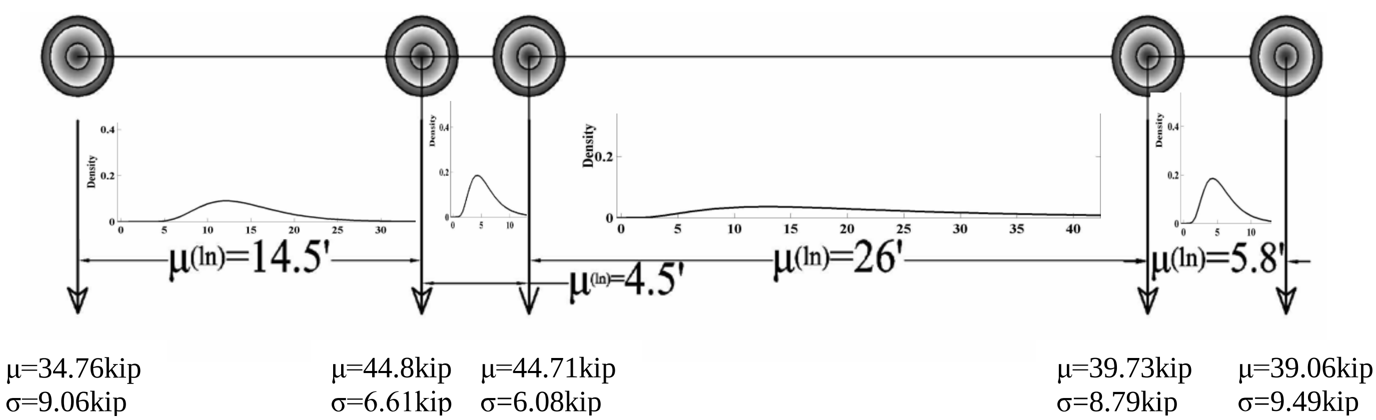


Figure 73: Configuration of potentially harmful vehicle for 30ft span (Class 9, μ_{GVW}=203 kips)

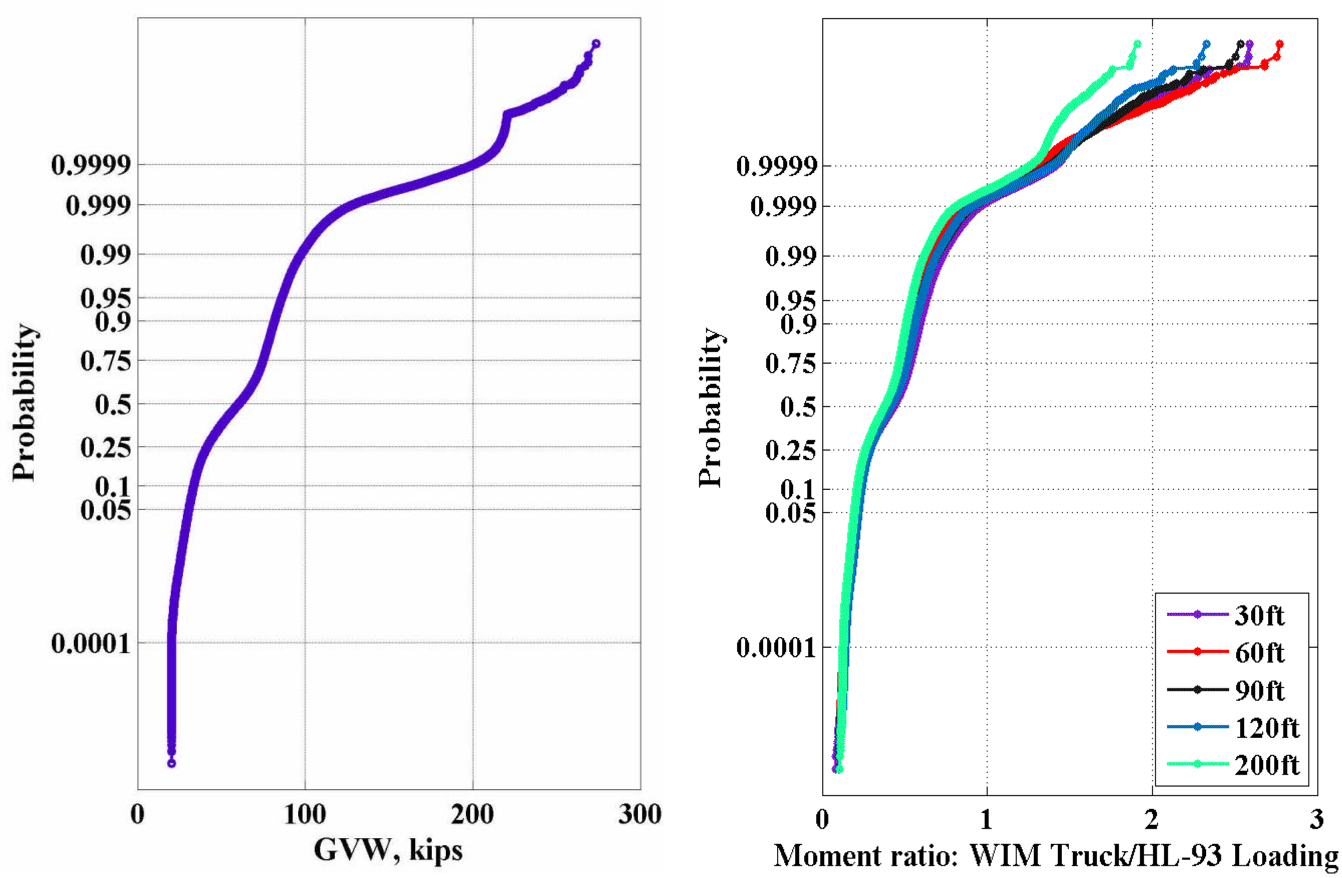


Figure 74: CDF's of GVW(a) and moment ratios(b) caused by vehicles of class 9

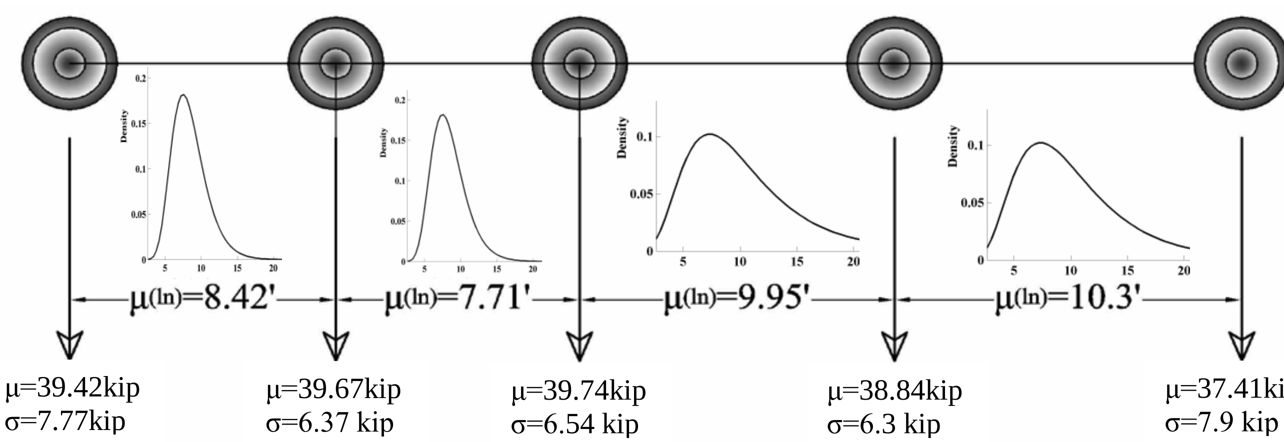


Figure 75: Configuration of potentially harmful vehicle for 30-60ft span (Class 11, μ_{GVW}=197 kips)

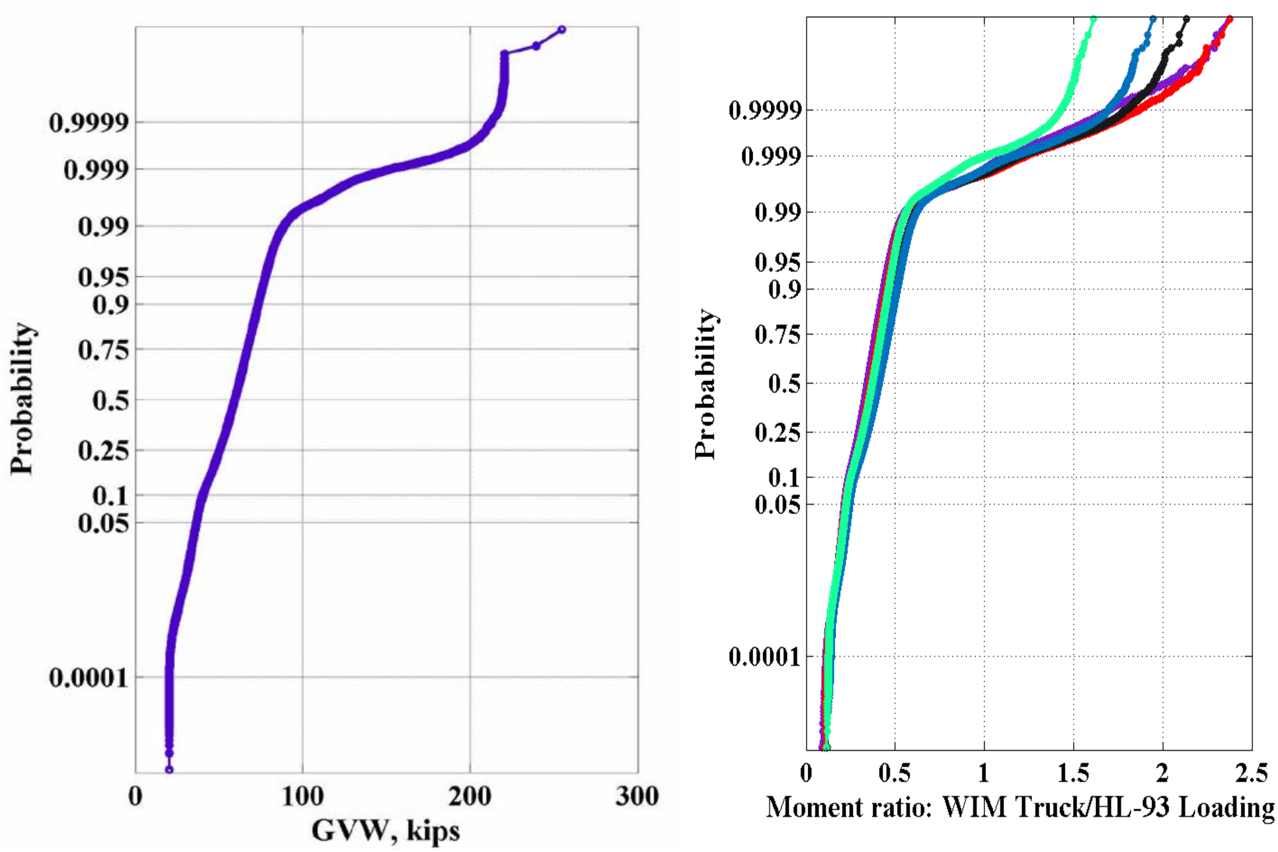


Figure 76: CDF's of GVW(a) and moment ratios(b) caused by vehicles of class 11

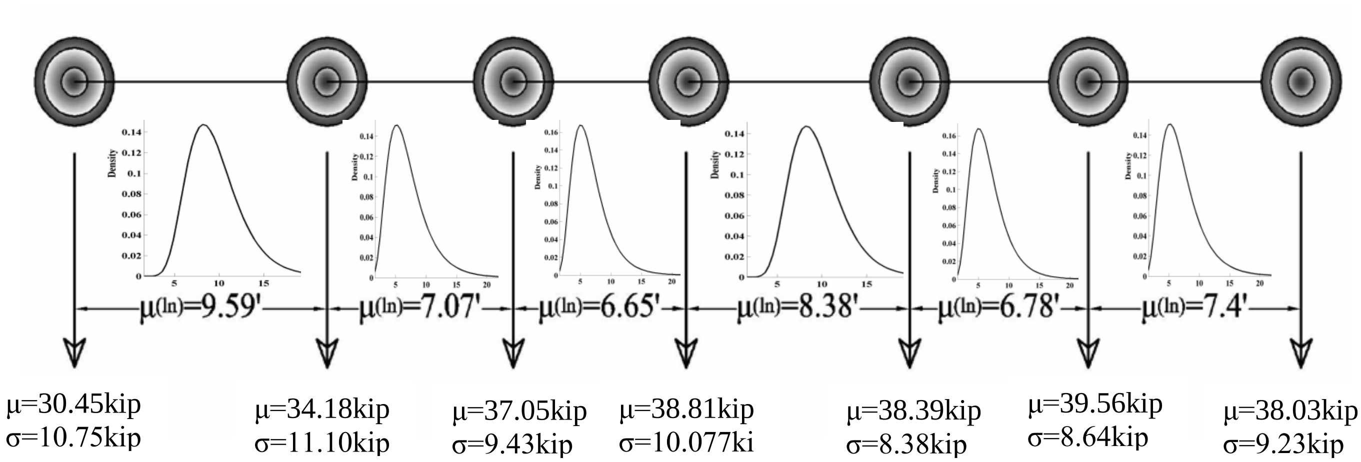


Figure 77: Configuration of potentially harmful vehicle for 30ft span (Class 13, μ_{GVW}=268 kips)

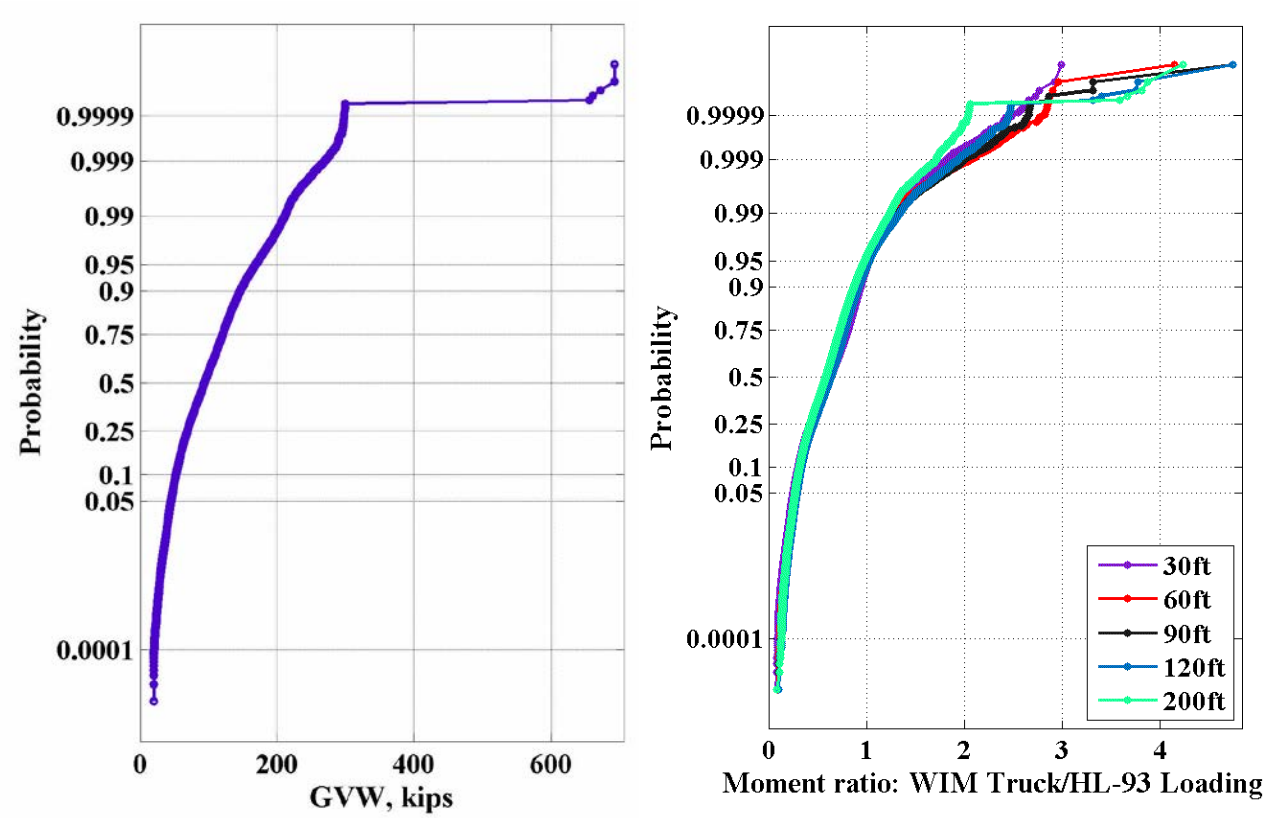


Figure 78: CDF's of GVW(a) and moment ratios(b) caused by vehicles of class 13

6.2.Vehicle Subtypes Causing Analysis

Based on the results considered in previous chapters it was decided to investigate the categories of vehicles which cause the maximum effect for different span lengths. The bending moments and share force ratios were considered with respect to the vehicle class (Figure 26). Taking into account that the distribution of moment and shear force ratios is similar for all location and years analyzing bending moments is only enough to make reasonable conclusions. According to Figures 57 and 58 vehicles that belong to class 7 (single-unit, 4 or more–axle truck) generate the most damaging load effect to the short span bridges. However, longer spans are mostly affected by long multi-trailer trucks of class 13 (multi-trailer, 6-axle trucks).

Based on the FHWA Vehicle Classification Scheme (Figure 26) some vehicle classes cover a range of trucks with a different number of axles. A more detailed analysis showed that there is also a difference in configuration of axle spacing and axial loads within a single class of vehicles. Thus, it was decided to:

- select certain sub-types within a class based on the number of axles and axial spacing configuration;
- investigate live load effects caused by different sub-types of vehicles;
- identify the subtype that governs for each vehicle class.

The most representative vehicle classes for this criterion are 7, 12 and 13 as shown in Figures 57 and 58. Therefore, these types of trucks were taken as an example. In addition, live load effects caused by vehicle classes 4 and 9 were analyzed as unique and the most representative types of vehicles. The filtering criteria were selected using a number of axles and axial spacing configuration as shown in Table 20. Moment and share force ratios caused by the trucks of sub-types listed in Table 20 were plotted on the normal probability paper. The analysis was performed for 2009-2014 WIM database.

For example, CDF's of the moment ratio for vehicle class 4 (buses), subtype A and B are shown in Figures 79 and 81, respectively. Examples of vehicles of subtype A and B are shown in Figures 80 and 82, respectively. The mean value for the moment ratio varies from 0.17 to 0.7 (subtype A) and from 0.25 to 0.45 (subtype B) for all considered span lengths. The maximum value of moment ratio is from 0.35 to 0.75 for subtype A and from 0.9 to 1.4 for subtype B.

Table 20: Sub-types of the selected vehicle classes

Vehicle Class	Subtype of vehicle	Number of trucks	Parameters	
			Number of axles	Axial spacing less than
Class 4	A	244,153	2	25 ft
	B	175,706	3	30ft / 8ft
Class 7	A	86,648	4	16ft / 8ft /8ft
	B	1,894	5	15-35ft / 8ft / 8ft / 8ft
Class 9	A	8,902,005	5	20ft / 8ft / 45ft / 8ft
	B	12,134,937	5	20ft / 8ft / 45ft / 10-15ft
Class 12	A	8,388	6	15ft / 8ft / 8ft / 40ft / 8ft
	B	12,127	6	45ft / 15ft / 8ft / 35ft / 15ft
	C	68,399	6	35ft / 8ft / 25ft / 15ft / 30ft
Class 13	A	21,312	7	Multiple configurations
	B	3,820	8	Multiple configurations
	C	1,688	9	Multiple configurations

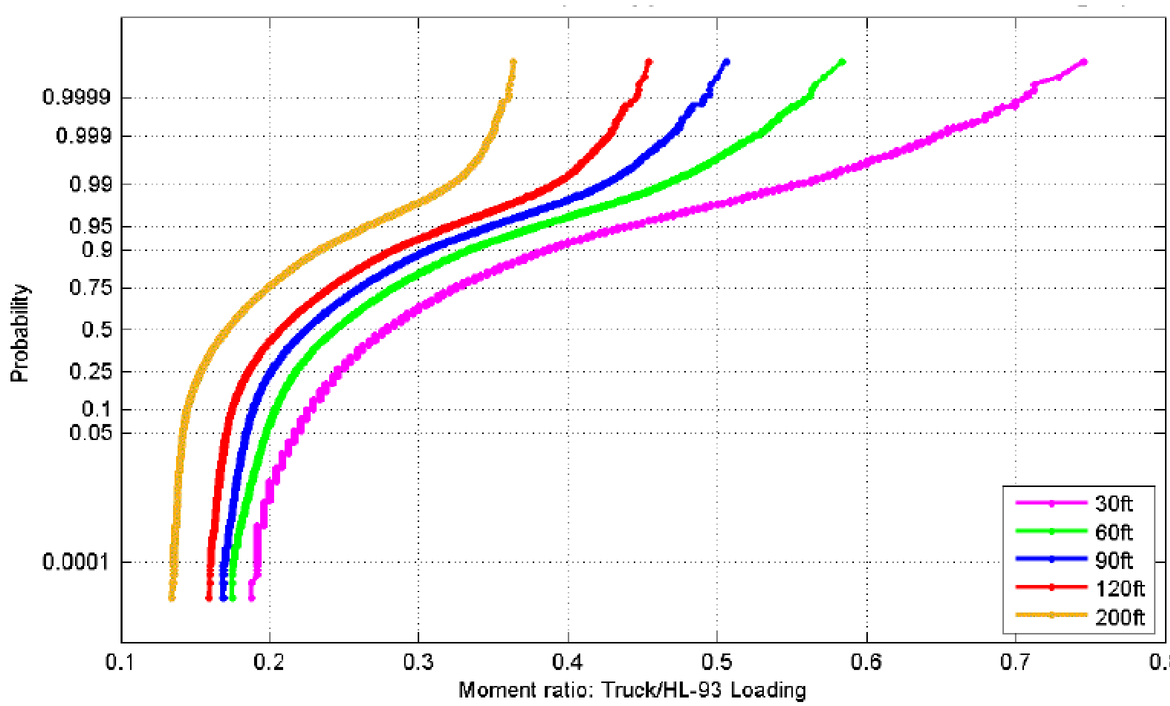


Figure 79: CDF's of moment ratios caused by vehicles of Class 4 (A) 2014

Figure 80: Example of vehicles of Class 4 (subtype A) 2014

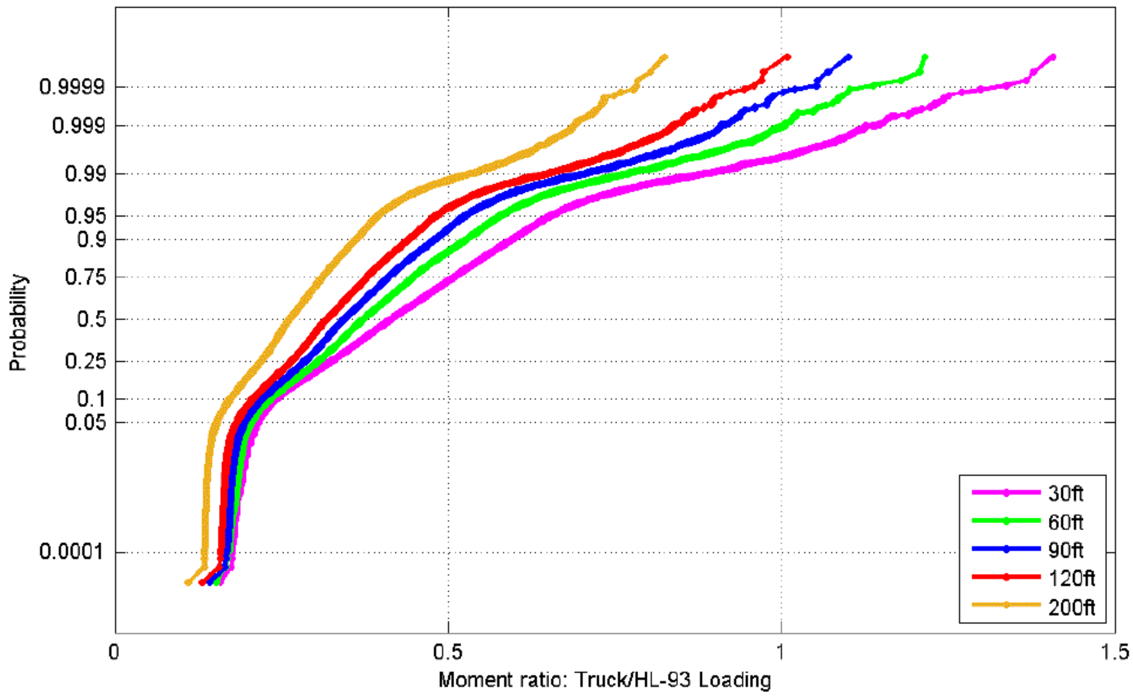


Figure 81: CDF's of moment ratios caused by vehicles of Class 4 (B) 2014

Figure 82: Example of vehicles of Class 4 (subtype B) 2014

CDFs of moment ratio for vehicle class 7, subtype A and B are shown in Figures 83 and 85 respectively. The examples of vehicles of subtype A and B are shown in Figures 84 and 86 respectively. The mean value for the moment ratio varies from 0.17 to 0.7 (subtype A) and from 0.25

to 0.45 (subtype B) for all the considered span lengths. The maximum value of moment ratio is from 0.35 to 0.75 for subtype A and from 0.9 to 1.4 for sub-type B.

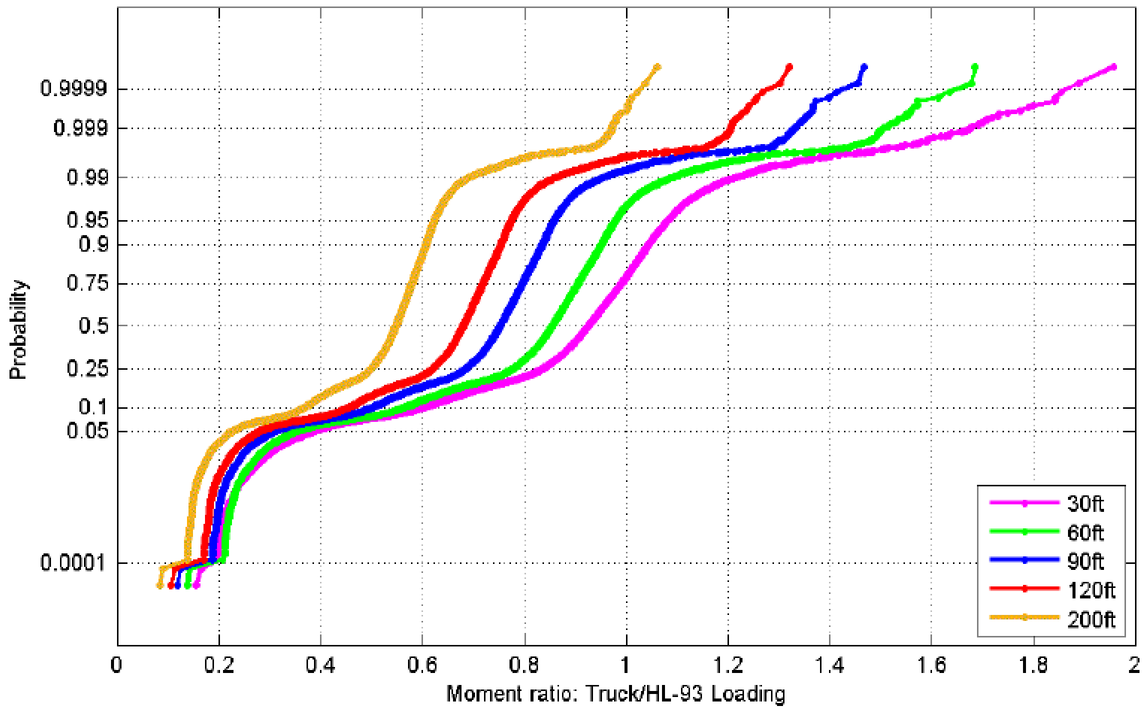


Figure 83: CDF's moment ratios caused by vehicles of Class 7 (A) 2014

Figure 84: Example of vehicle of Class 7 (subtype A) 2014

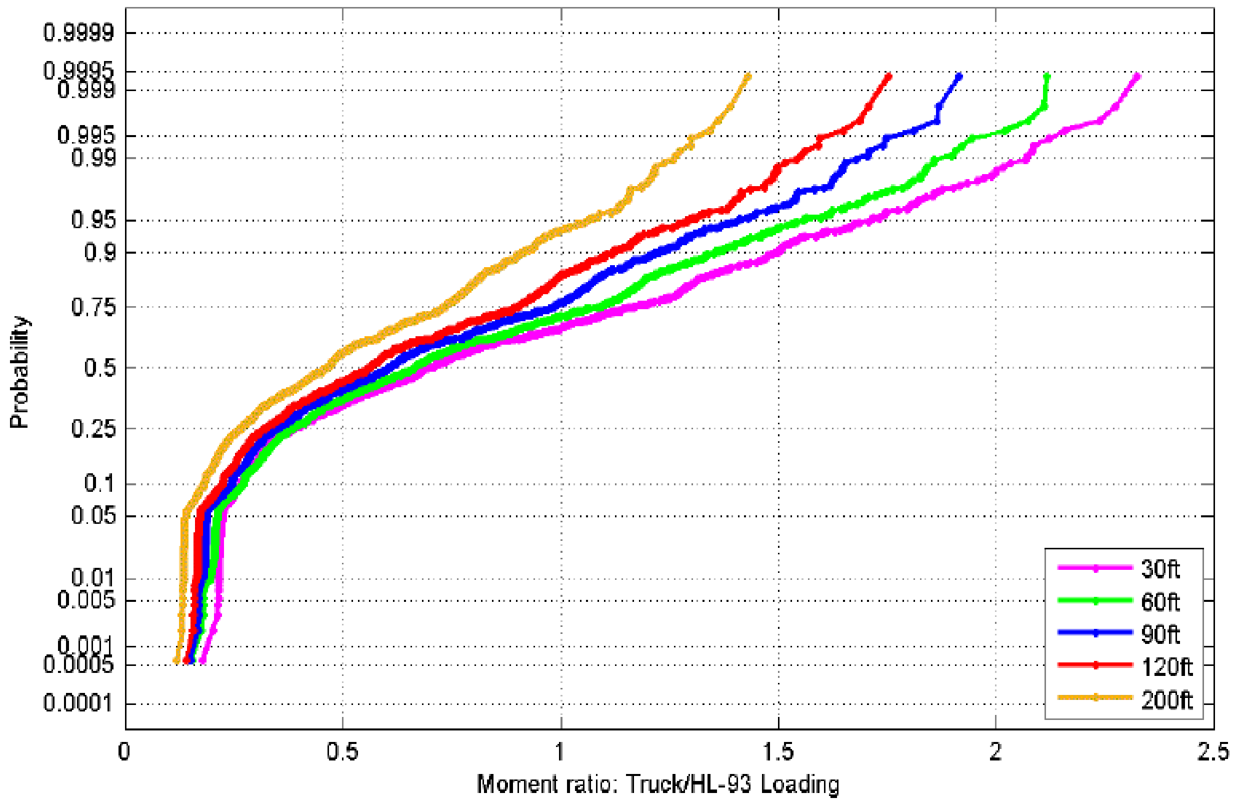


Figure 85: CDF's of moment ratios caused by vehicles of Class 7 (B) 2014

Figure 86: Example of vehicles of Class 7 (subtype B) 2014

More precise vehicle classifications based on the existing FHWA Vehicle Classification Scheme (Figure 26) were performed for the rest of the classes (5th, 6th, 8th, 10th, and 11th) and live load effects caused by different subtypes of vehicles were investigated. The remaining filtering criteria are based on the number of axles and the configuration of the axle spacings.

The classes of vehicles which were taken into consideration and processed were summarized in Table 21.

Table 21: Subtypes of FHWA vehicle classes

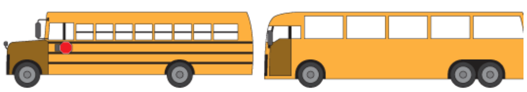
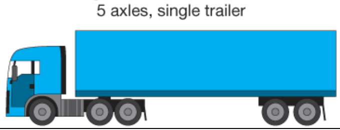
Vehicle Class	Subtype of vehicle	Number of vehicles	Properties	
			Number of axles	Axial spacing less than
4. Buses 2 or 3 axles, full length 	A	244,153	2	20-30 ft
	B	175,706	3	30ft / 8ft
5. Single Unit 2-Axle Trucks 2 axles, 6 tires (dual rear tires), single-unit 	A	833,754	2	30ft
6. Single Unit 3-Axle Trucks 3 axles, single unit 	A	574528	3	20ft/8ft
7. Single Unit 4 or More-Axle Trucks 4 or more axles, single unit 	A	86648	4	16ft / 8ft /8ft
	B	1894	5	15-35ft / 8ft / 8ft / 8ft
8. Single Trailer 3- or 4-Axle Trucks 3 or 4 axles, single trailer 	A	1335	3	20ft / 8ft
	B	267269	3	20ft / 45ft
	C	379140	4	25ft/45ft/8ft
	D	168074	4	25ft / 45ft / 45ft
9. Single Trailer 5-Axle Trucks 5 axles, single trailer 	A	8902005	5	20ft / 8ft / 45ft / 8ft
	B	12134937	5	20ft / 8ft / 45ft / 10-15ft
10. Single Trailer 6 or More-Axle Trucks 6 or more axles, single trailer 	A	100747	6	30ft /8ft /30ft/8ft/8ft
	B	494	7	30ft /8ft /30ft /8ft /8ft /8ft

Table 22: Subtypes of the selected vehicle classes - Continued

	A	345348	5	15ft / 25ft / 15ft / 25ft
	A	8388	6	15ft / 8ft / 8ft / 40ft / 8ft
	B	12127	6	45ft / 15ft / 8ft / 35ft / 15ft
	C	68399	6	35ft / 8ft / 25ft / 15ft / 30ft
	A	21312	7	Multiple configurations
	B	3820	8	Multiple configurations
	C	1688	9	Multiple configurations

6.3. Truck Loading Analysis

Various algorithms are used for Vehicle Classification during WIM data recording and interpretings, such as human observation, automated interpretation of vehicle image or video, total vehicle length classification, and axle spacing classification using different schemes, etc.

Another method of vehicle classification is based on the indication of vehicle body type according to its average GVW (Figure 87). Based on the idea about the average GVW of each body type of truck, the range of overloading was analyzed. The lowest value of GVW was taken as the filtering criteria, assuming that the remained WIM data reflects the range of loading of trucks in a certain class.

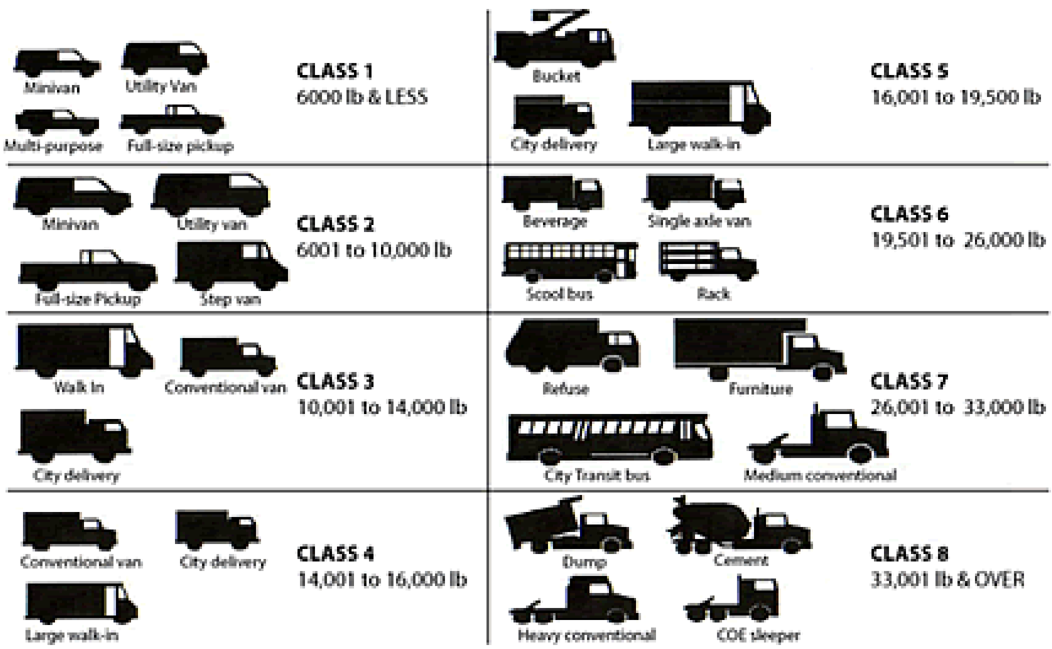


Figure 87: Vehicle Classes based on average GVW, kip

As an example, CDFs of GVW for selected vehicle subtypes for location 915 are plotted on probability paper and shown in Figures 88-93. Based on the shape of CDF curves, it can be concluded that the distributions of truck loading are consistent within the time of taking records. However, they are inconsistent for the different sites and vehicle classes. CDFs of GVW for selected vehicle subtypes (class 8, B) for locations 911-965 are plotted on probability paper. An example is shown in Figure 94. The statistical parameters of vehicle loading distributions, such as mean and maximum values (kip), are summarized in Table 23.

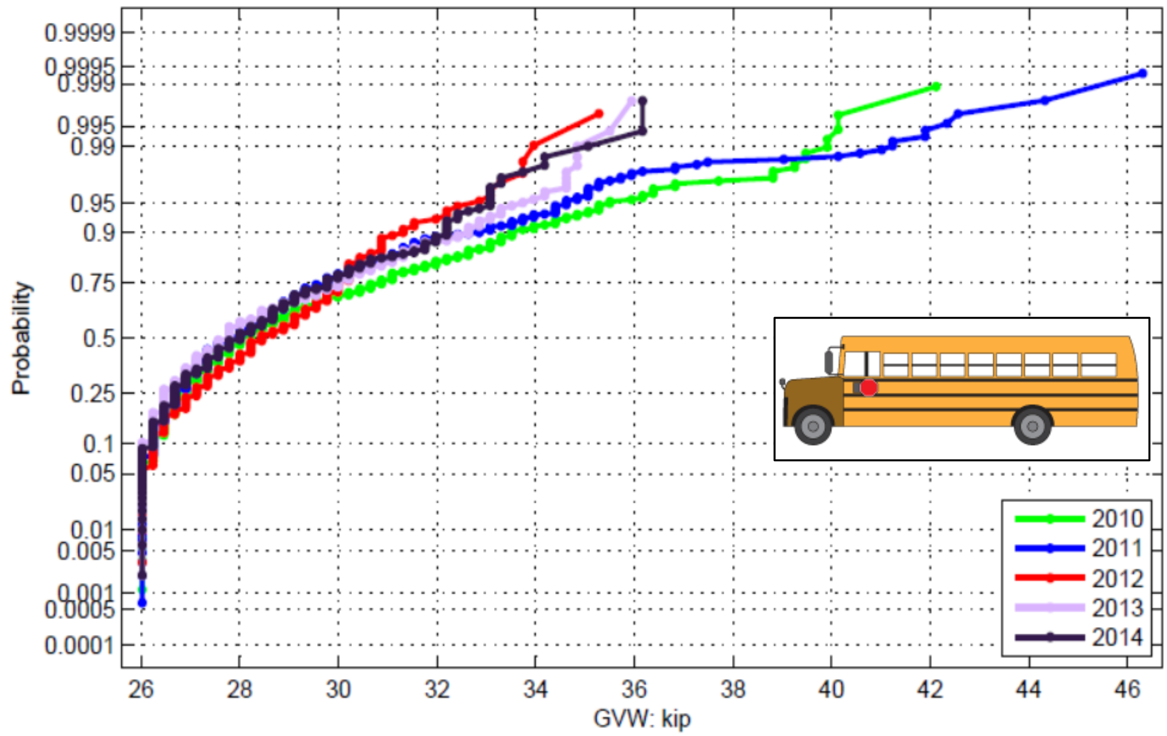


Figure 88: Vehicle loading distribution – Class 4, Subtype A

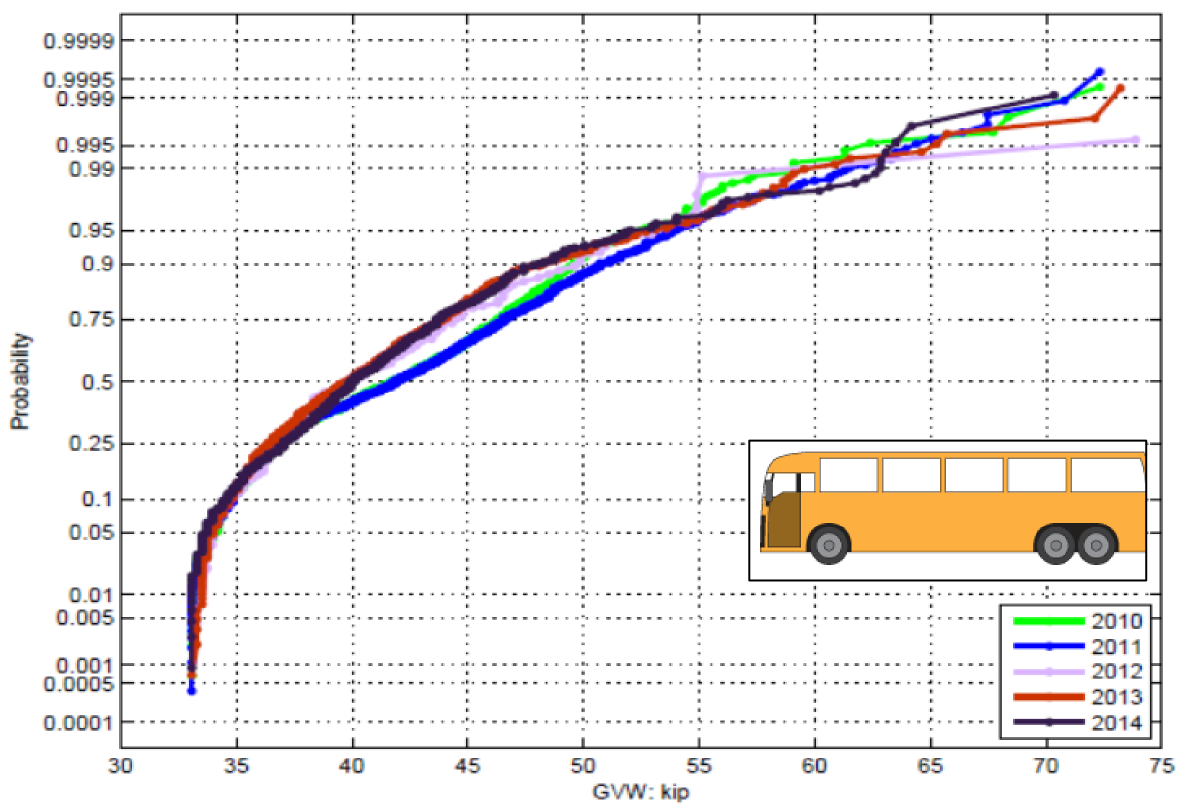


Figure 89: Vehicle loading distribution – Class 4, Subtype B

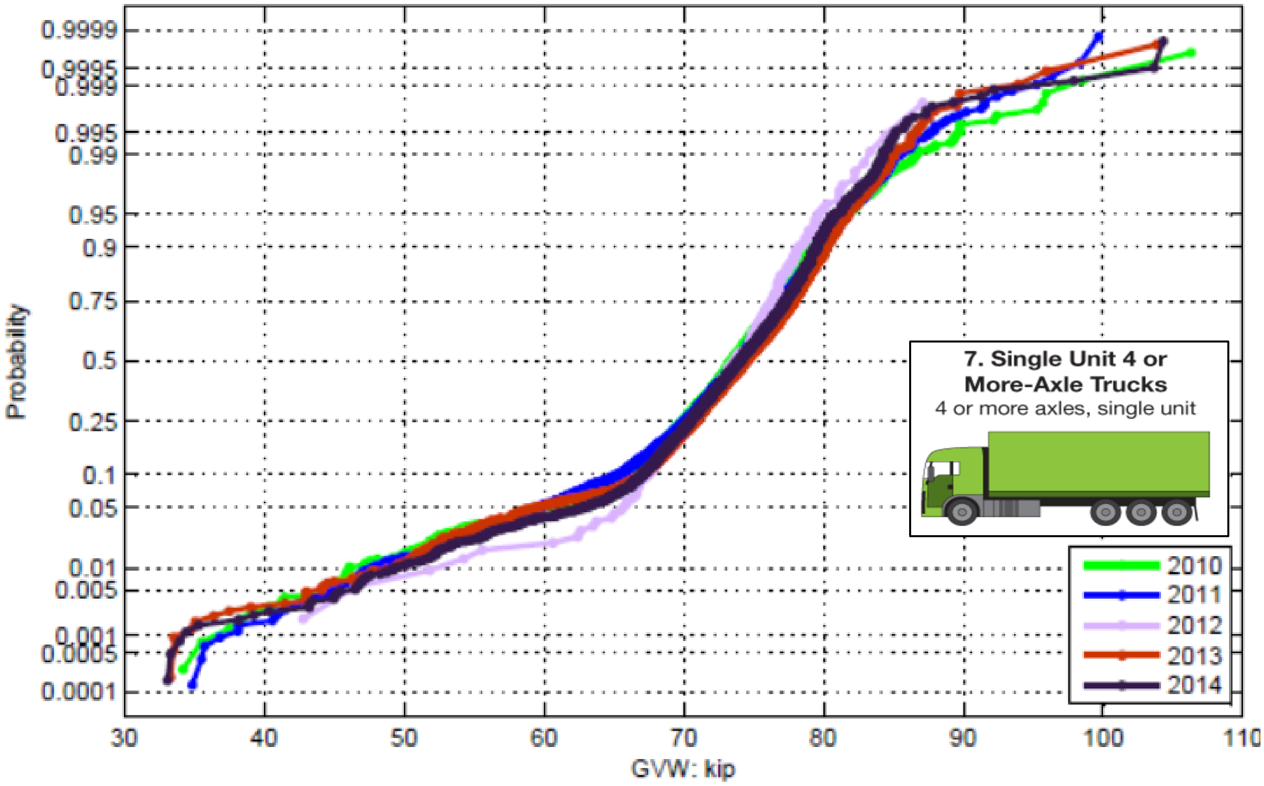


Figure 90: Vehicle loading distribution – Class 7, Subtype A

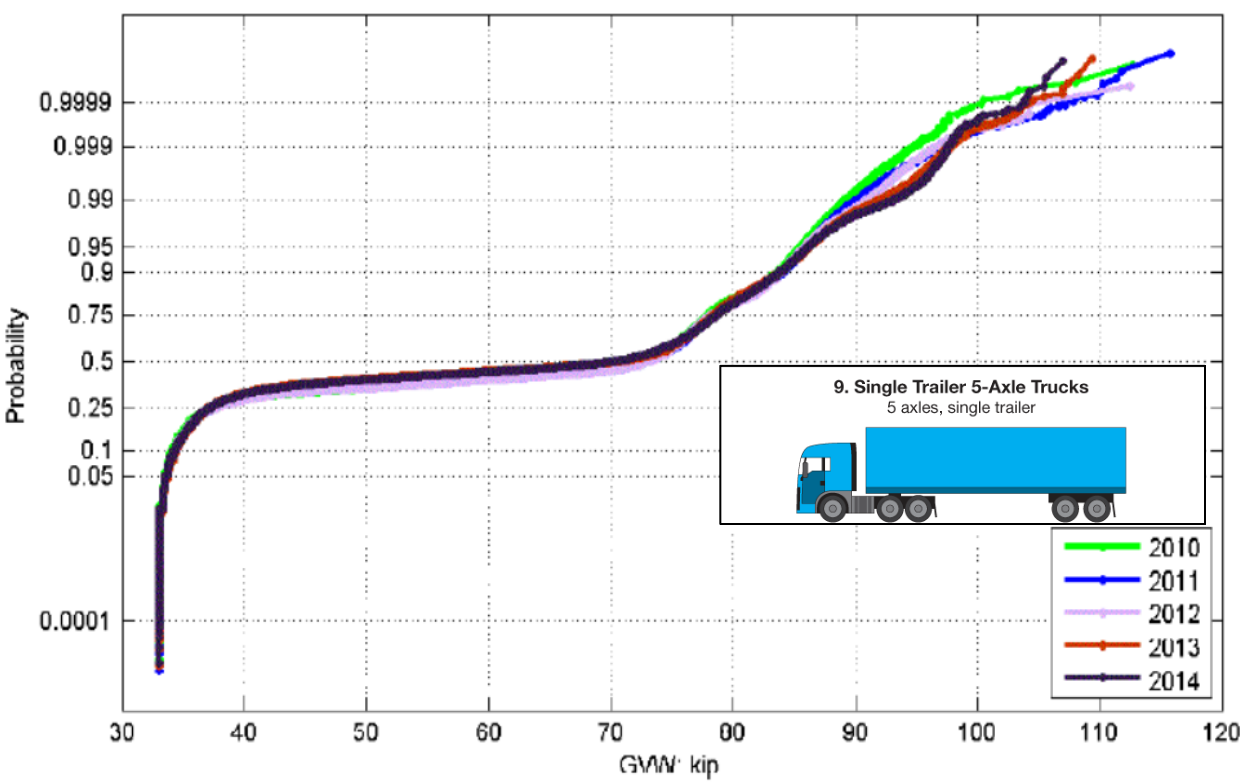


Figure 91: Vehicle loading distribution – Class 9, Subtype A

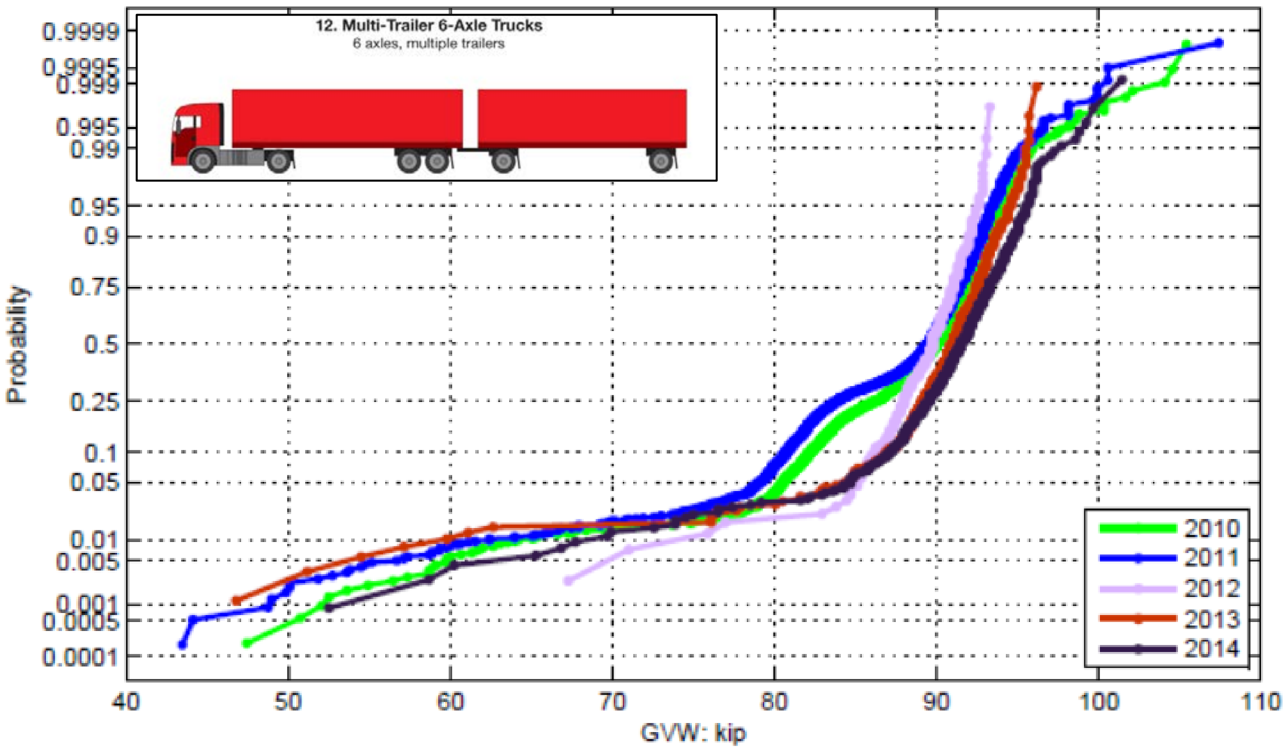


Figure 92: Vehicle loading distribution – Class 12, Subtype A

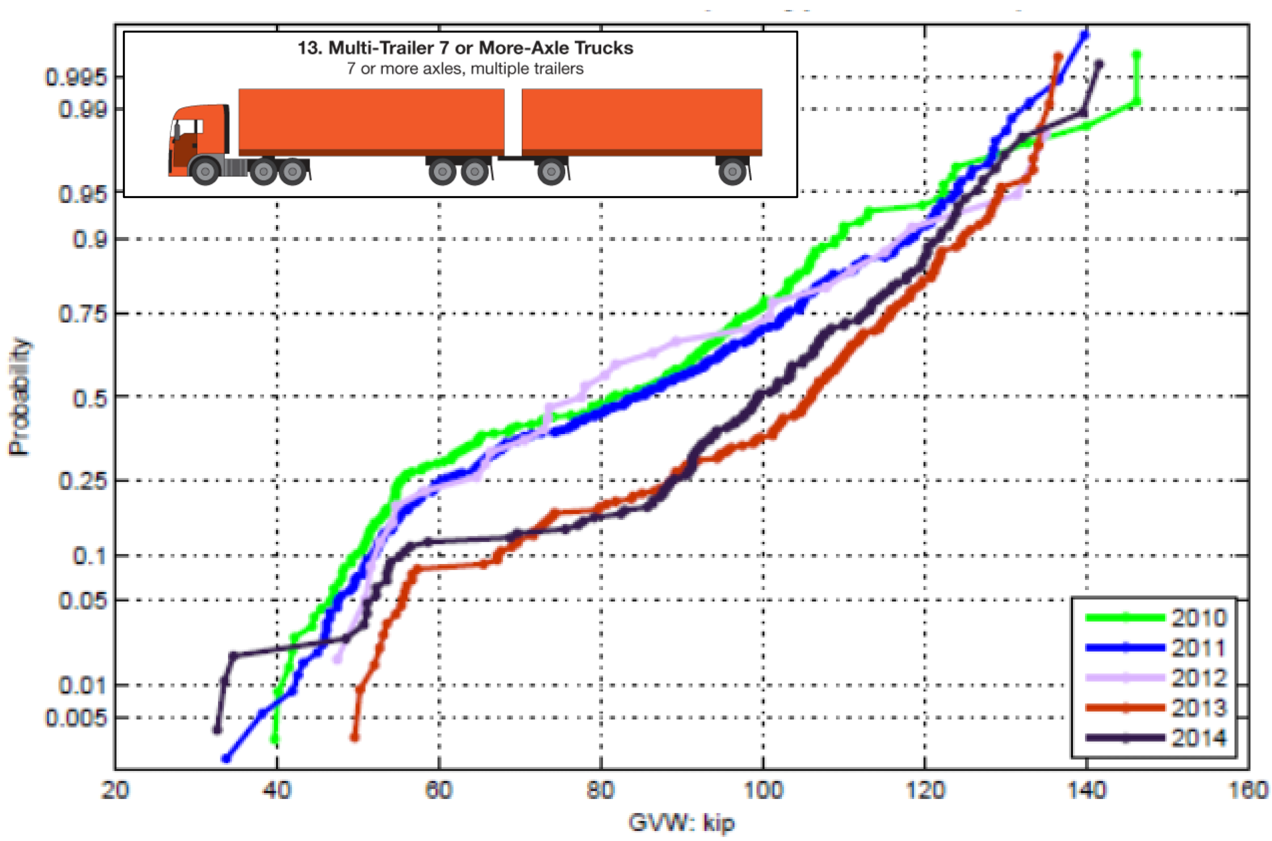
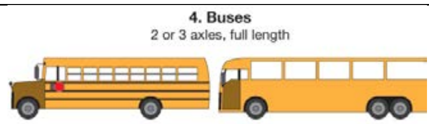
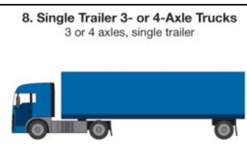
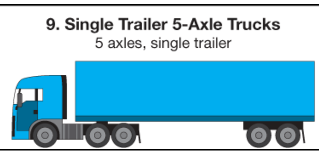


Figure 93: Vehicle loading distribution – Class 13, Subtype A

Table 22: Statistical parameters of vehicle loading for location 915

Vehicle Class	Subtype of vehicle	Mean value, kips	Max value, kips
	A	27-29	35-46
	B	45	75
	A	30	35-50
	A	35	80-90
	A	75	100-110
	B	70	90
	A	25	35
	B	35	55
	C	40	75-90
	D	35	75-90
	A	80	110-120
	B	75	110
	A	85	120
	B	Not presented	Not presented
	A	55	80
	A	90	110
	B	90	110
	C	85	110
	A	80-100	140
	B	100-140	160
	C	120-160	180

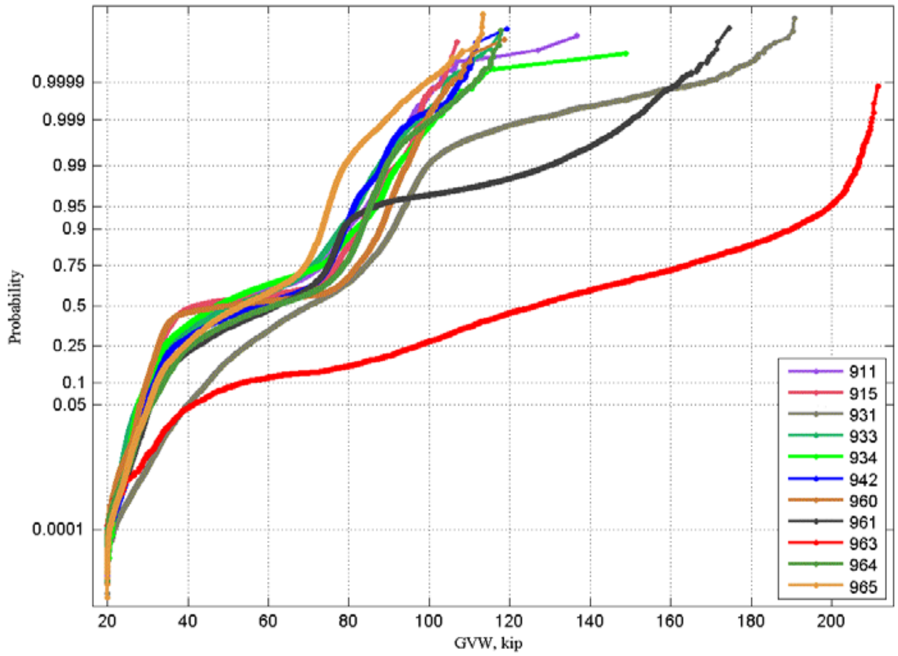


Figure 94: Vehicle loading distribution – Class 8th, Subtype B

6.4.Questionable Data

The presented results can be considered as representative for the state. Nevertheless, the following remained questionable:

a) The range of loading of some vehicle classes (4th – 2 or 3-axle Buses – Figures 88, 89): mean value – 45 kip and maximum value – 75 kip (subtype B, 3-axle). The mean value for the moment ratio varies from 0.25 to 0.45 for all considered span lengths. The maximum values of moment ratio are from 0.9 to 1.4 (Figures 79 and 81).

   The accuracy of classifying vehicles is dependent upon two things: the accuracy of the measurements and the relevance of the classification parameters to the vehicle population. Accordingly to the Traffic Monitoring Guide, Scheme F modified algorithm (based on typical axle spacing configuration) was used by ALDOT for vehicle classification. Since different vehicle classes can have similar axle spacing configurations, there is no precise way to identify the parameters, and certain error is possible.

b) Some vehicle configurations were found not corresponding to the photos (Figures 95, 96 and 97) - Vehicle class (column 8) and GVW (column 11). This type of inaccuracy in records was common for longer trucks which, in some cases, cannot be clearly identified based on FHWA classification scheme (Figure 26).

Year	Month	Day	Hour	Minute	Second	Speed	Class	# of axles	GVW	1st axle w-t	2nd axle w-t
2014	1	3	11	45	0.5980	64.9000	5	2	41.3400	10.6900	30.6400

Figure 95: The example of vehicle of Class 5 (subtype A – 2 axles, GVW – 41.34 kips) 2014

Year	Month	Day	Hour	Minute	Second	Speed	Class	# of axles	GVW	1st axle w-t	2nd axle w-t
2014	1	9	8	49	54.0470	45.4000	6	3	32.3100	5.6670	13.3200

Figure 96: The example of vehicle of Class 6 (subtype A – 3 axles, GVW – 32.31 kips) 2014

Year	Month	Day	Hour	Minute	Second	Speed	Class	# of axles	GVW	1st axle w-t	2nd axle w-t
2014	1	9	8	55	30.8410	47.9000	6	3	30.8900	5.1030	12.8900

Figure 97: The example of vehicle of Class 6 (subtype A – 3 axles, GVW – 31.59 kips) 2014

6.5.Summary

Types of vehicles causing a maximum effect for different span lengths were selected and analyzed in this chapter. Distribution of bending moment ratios was considered for different FHWA vehicle classes, specially selected subtypes and vehicles with a different number of axles. Proportions of trucks which meet Federal Bridge Formula requirements as well as load effects were also analyzed. After all, the following should be noted:

- The potentially most harmful vehicles are short and heavy trucks, in particular for spans of 10-20m (30-60ft).
- Vehicles of class 7 (single-unit, 4 or more–axle trucks) cause maximum load effect for short (30ft) span bridges, while class 13, multi-trailer, 6-axle trucks, are the most damaging for longer (200ft) spans;

- In most cases, there are several subtypes within one FHWA class with regard to the number of axles and axle spacing configuration. Distributions of load effects caused by different subtypes are not similar.
- Based on the average GVW of the of vehicle body type the range of loading as well as a percentage of empty trucks was considered.
- A substantial number (50%) of vehicles of class 4 (2 or 3-axle buses) are loaded from 45 to 75 kips. This indicates a certain inaccuracy of the recording devices in FHWA vehicle class determination.

7. COMPARISON WITH OTHER STATES

7.1.Gross Vehicle Weight

To compare GVW of the traffic in Alabama, CDF's of GVW for different locations all over the United States were considered. WIM data obtained from FHWA (trucks recorded from special pavement study (SPS)) as well as from NCHRP projects are summarized and discussed in Chapter 2.3 "WIM Data for the US." The CDF's of GVW for all available states are plotted on the probability paper, as shown in Figure 98. The maximum values of GVW and a range of the mean value of GVW are summarized in Table 23.

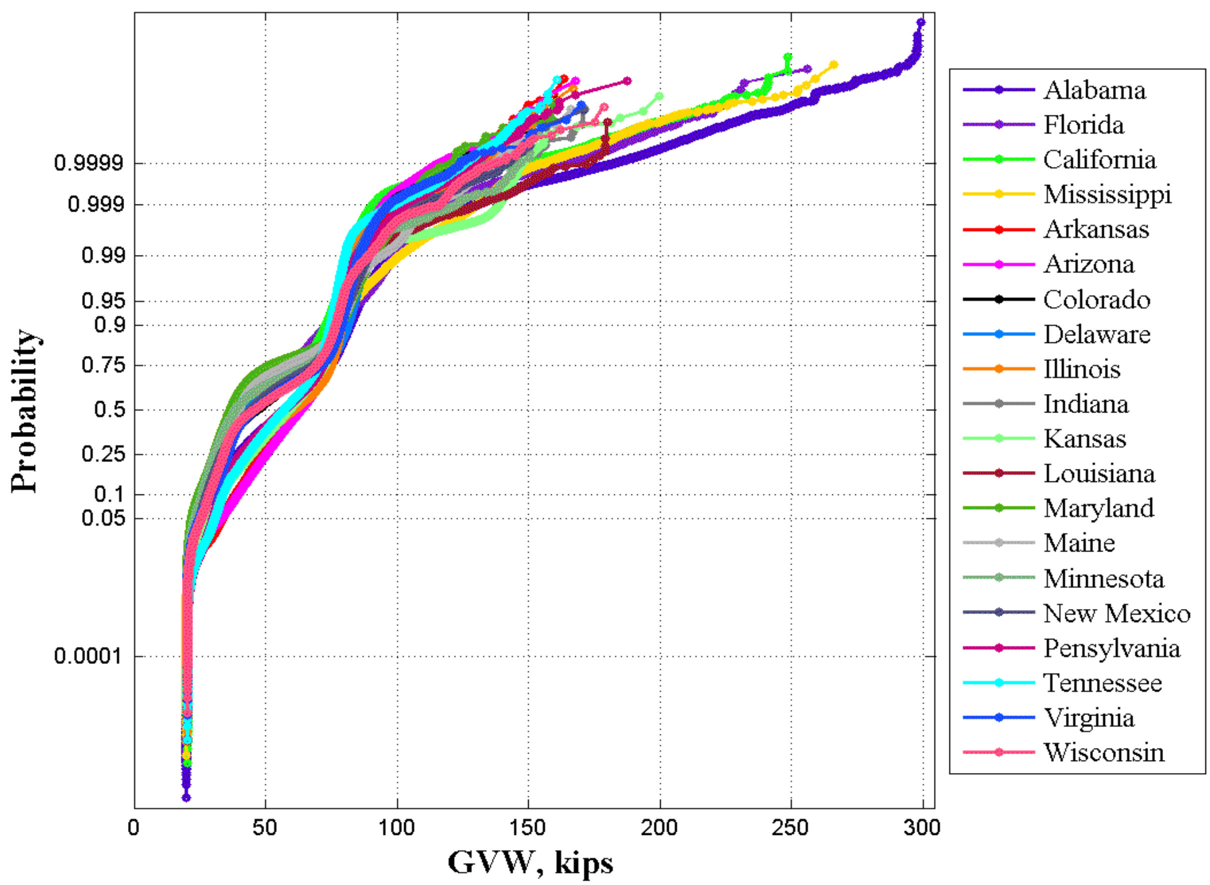


Figure 98: Comparison of WIM data for Alabama with other states in the US

The shapes of CDF curves for different states are mostly similar except the upper tails that represent the heaviest vehicles. As shown in Figure 98, only from 0.01% to 0.001% of vehicles in each location exceeds GVW of 100 kips and from 0.001% to 0.0001% of vehicles exceed GVW of 150 kips. The number of records for the considered WIM locations can be site-specific. Thus, 0.01% is

5730 trucks for Alabama but 5 trucks for Minnesota; and 0.0001% is 57 vehicles for Alabama and less than 1 vehicle for New Mexico, Maine, Minnesota, Maryland, Indiana, Illinois, Delaware, Colorado, Virginia and Wisconsin.

Table 23: Summary of the WIM data for the United States for years 2006÷2014

State	Number of locations	Total number of vehicles	Months of data	Maximum GVW(kips)*	Mean-Value Range (kips)*
Alabama	14	57,307,424	9 (years)	300	23-60
Oregon	4	725,382	4 (months)	200	43-52
Florida	5	4,143,162	12 (months)	250	20-50
Indiana	5	185,267	12 (months)	250	20-57
Mississippi	5	5,914,950	12 (months)	260	38-57
California	2	13,458,818	7 (months)	250	40-50
New York	7	343,603	12 (months)	380	35-50
Arkansas	1	1,675,349	12 (months)	160	55
Arizona	2	1,466,033	12 (months)	160	70
Colorado	1	343,603	12 (months)	150	45
Delaware	1	201,677	12 (months)	170	45
Illinois	1	854,075	12 (months)	160	75
Indiana	1	185,267	12 (months)	160	45
Kansas	1	477,922	12 (months)	200	45
Louisiana	1	328,778	12 (months)	175	60
Maryland	1	183,576	12 (months)	150	45
Maine	1	55,572	12 (months)	160	40
Minnesota	1	1,466,033	12 (months)	160	45
New Mexico	2	725,382	12 (months)	165	40
Pennsylvania	1	1,495,741	12 (months)	160	60
Tennessee	1	1,622,320	12 (months)	160	55
Virginia	1	259,190	12 (months)	170	45
Wisconsin	1	226,943	12 (months)	175	35

According to Figure 98, the heaviest vehicles (up to 300 kips) were recorded in Alabama (Locations 918, 933, 960, 961, 963 and 964). However, GVW distribution is strongly site-specific. So, excluding mentioned locations, the maximum GVW for Alabama State is about 250 kips.

Although the WIM data from New York was not considered, the configuration of the heaviest recorded vehicle from that state is shown in Figure 99. GVW, total length, and configuration of axles indicate that it was a permitted vehicle. The WIM recording system categorizes those vehicles as Class 13 and 14. Similarly, trucks of Class 14 were recorded in Alabama in years 2006 to 2008.

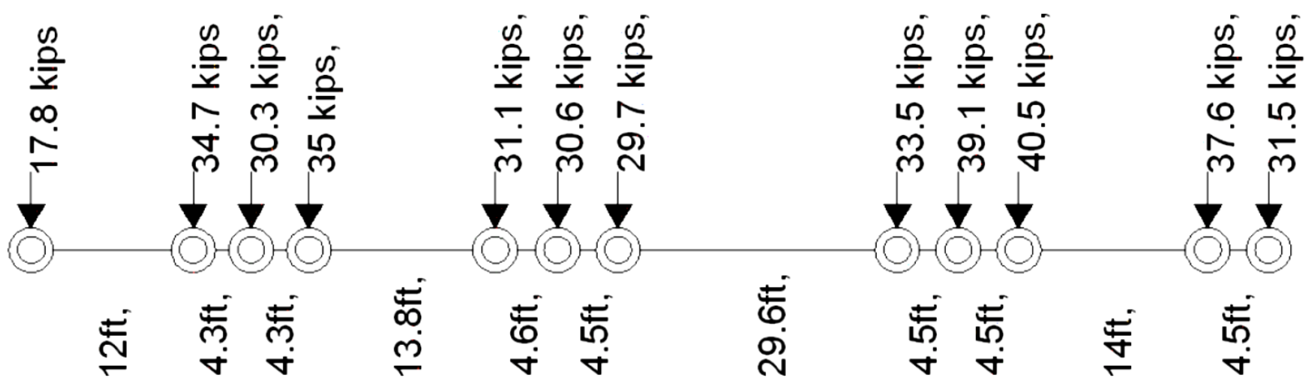


Figure 99: The heaviest vehicle in FHWA database (Port Jervis, NY) – GVW 391 kips, L=100.6 ft

7.2. Vehicle Class Analysis

The proportion of each FHWA vehicle class, as well as the distribution of GVW, was considered for all available states in the US. The classification of vehicles according to FHWA is shown in Figure 26. The distribution of GVW was considered separately for each vehicle class. Similar analysis was performed for WIM data for Alabama and described in Chapter 3.4 “Vehicle Class Analysis”. The percentage of each type of vehicle for each location was calculated 37 locations all over the United States and shown as a bar chart in Figure 100 are Table 24. Obviously, five-axle, single trailer trucks classified by FHWA as class 9 vehicles are governing for all considered states.

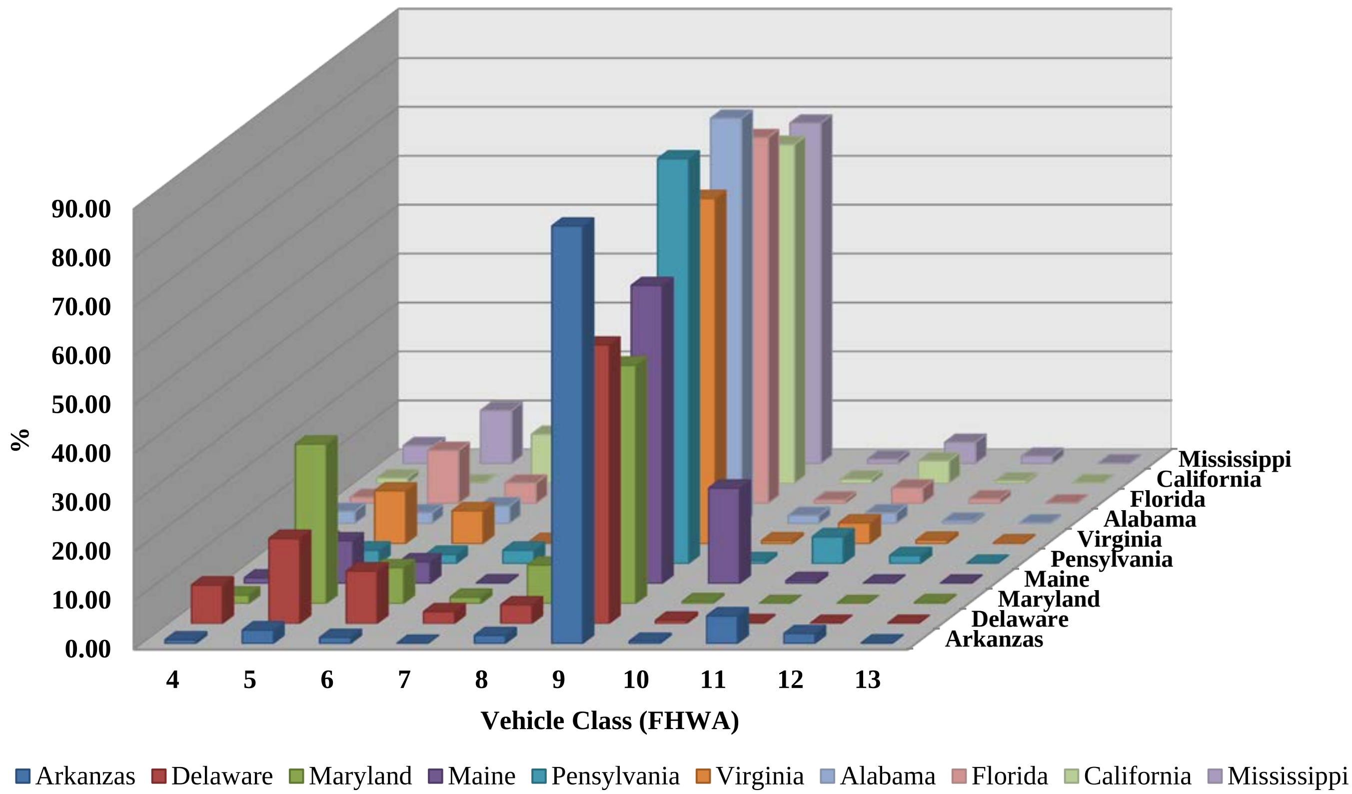


Figure 100: Percentage of each vehicle class in the United States

Table 24: Percentage of vehicles in each class for WIM locations in the United States

	AR	DE	MD	ME	PA	VA	AL	FL	CA	MS
	2008	2008	2007-2009	2008	2008	2008	2006-2014	2005-2006	2006-2007	2006
4	0.75	7.85	1.74	1.16	0.83	0.86	2.46	1.25	1.15	3.62
5	2.76	17.36	32.56	8.72	2.73	10.75	2.20	10.84	0.15	10.81
6	1.23	10.71	7.33	4.43	1.83	6.65	3.59	4.17	10.04	3.78
7	0.07	2.42	1.28	0.14	2.72	0.37	0.58	0.47	0.17	0.04
8	1.65	3.83	7.84	4.53	1.46	5.36	3.91	3.58	3.08	5.44
9	85.29	56.88	48.67	60.87	82.68	70.45	82.80	74.77	69.29	69.56
10	0.45	0.66	0.38	19.47	0.59	0.56	1.65	0.71	0.89	0.88
11	5.63	0.19	0.01	0.58	5.46	4.21	2.15	3.15	4.64	4.30
12	2.04	0.04	0.01	0.04	1.63	0.68	0.51	0.95	0.56	1.47
13	0.12	0.05	0.18	0.08	0.07	0.10	0.15	0.12	0.15	0.09

However, in some states vehicles of the other classes create a substantial portion of the traffic mix. Thus, class 5 (single unit, 2-axle trucks) is from 10 to 30 % of a total number of trucks in Delaware, Maryland, Florida, Mississippi and Virginia. Similarly, class 6 (single unit, 3-axle trucks) is 10% of a total number of trucks in Delaware and California, and class 10 (single trailer, 6 or more axle trucks) is 20% in Maryland (Fig. 92 and Table 25).

The distribution of GVW with regard to vehicle class was considered for Alabama in Chapter 3.4. For comparison, CDF's for GVW for California, Florida and Mississippi were plotted in Figures 101, 102 and 103. From Figures 101-103 it is obvious that most of the vehicle classes (4-12, except class 9, 10, 11 and 12) have GVW less than 100kips. The mean values vary in range from 7.5 (lower GVW cutoff in SHRP2 R19B report, 2015) to 50-70 kips. Vehicles of class 13 (multi-trailer, 7 or more-axle trucks) are the heaviest in FHWA and NCHRP WIM databases. The mean value varies from 80 to 100 kips, while the maximum GVW reaches 250kips. These statistical parameters are very similar to the corresponding values for Alabama WIM data (Figures 28, 29 and 30). This allows generating a representative vehicle class distribution pattern for the state.

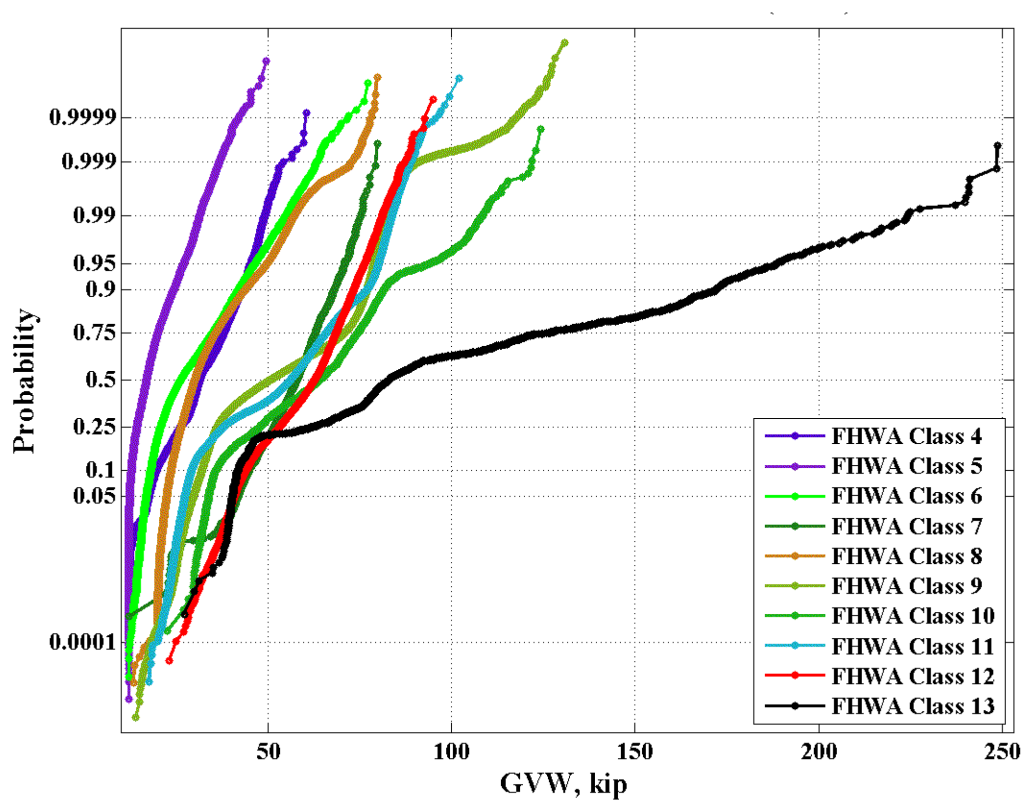


Figure 101: CDF's of GVW for vehicle classes 4-13 for California – 2008

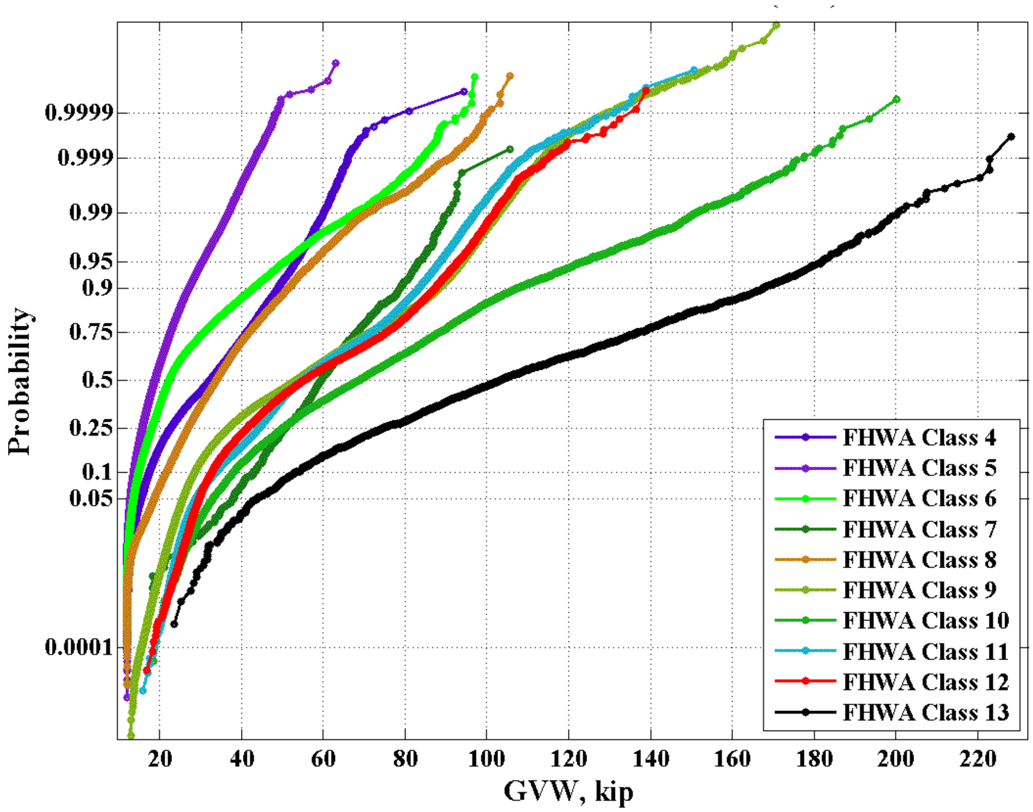


Figure 102: CDF's of GVW for vehicle classes 4-13 for Florida– 2008

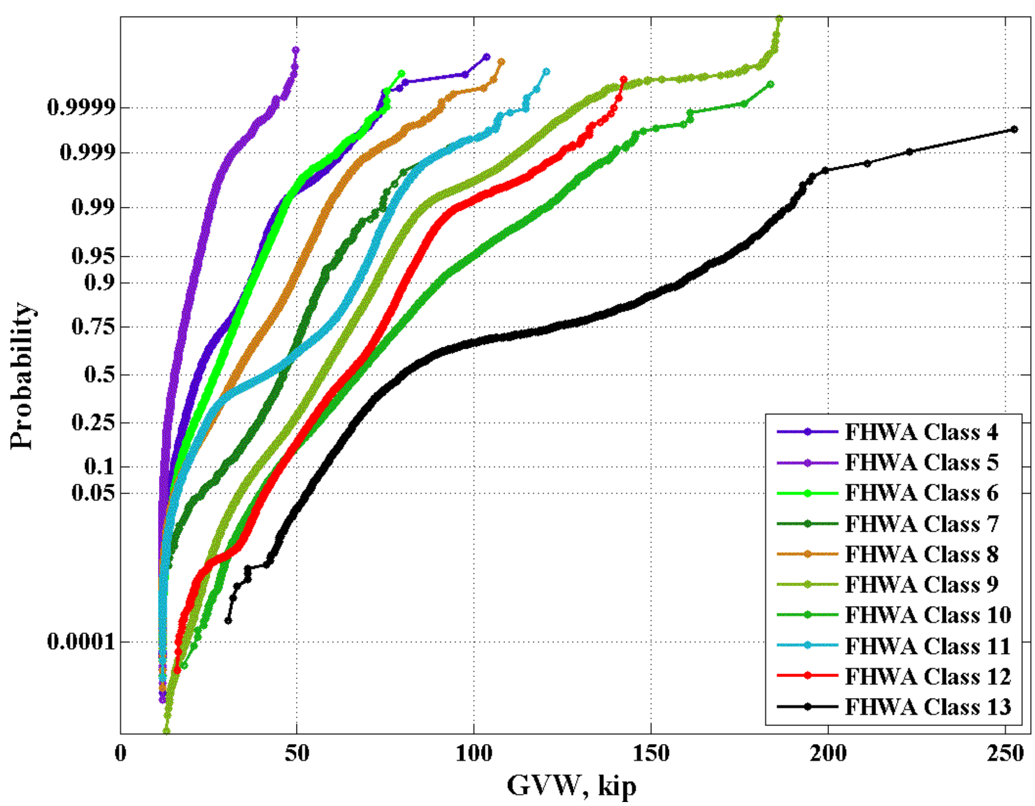


Figure 103: CDF's of GVW for vehicle classes 4-13 for Mississippi – 2008

7.3. Statistical parameters for live load effects

To compare load effects of the traffic in Alabama, CDF's of moment and shear force ratios were calculated for 30ft, 60ft, 90ft, 120ft and 200ft for all available locations in the United States and plotted using probability scale. Examples are shown in Figure 104 for 30 (a) and 200ft (b) spans. Similarly, CDF's of shear force ratios are shown in Figure 105a and b for the shortest and longest considered span length respectively. The shapes of CDF curves for different states are mostly consistent except the upper tail of Alabama that includes about 60 million records.

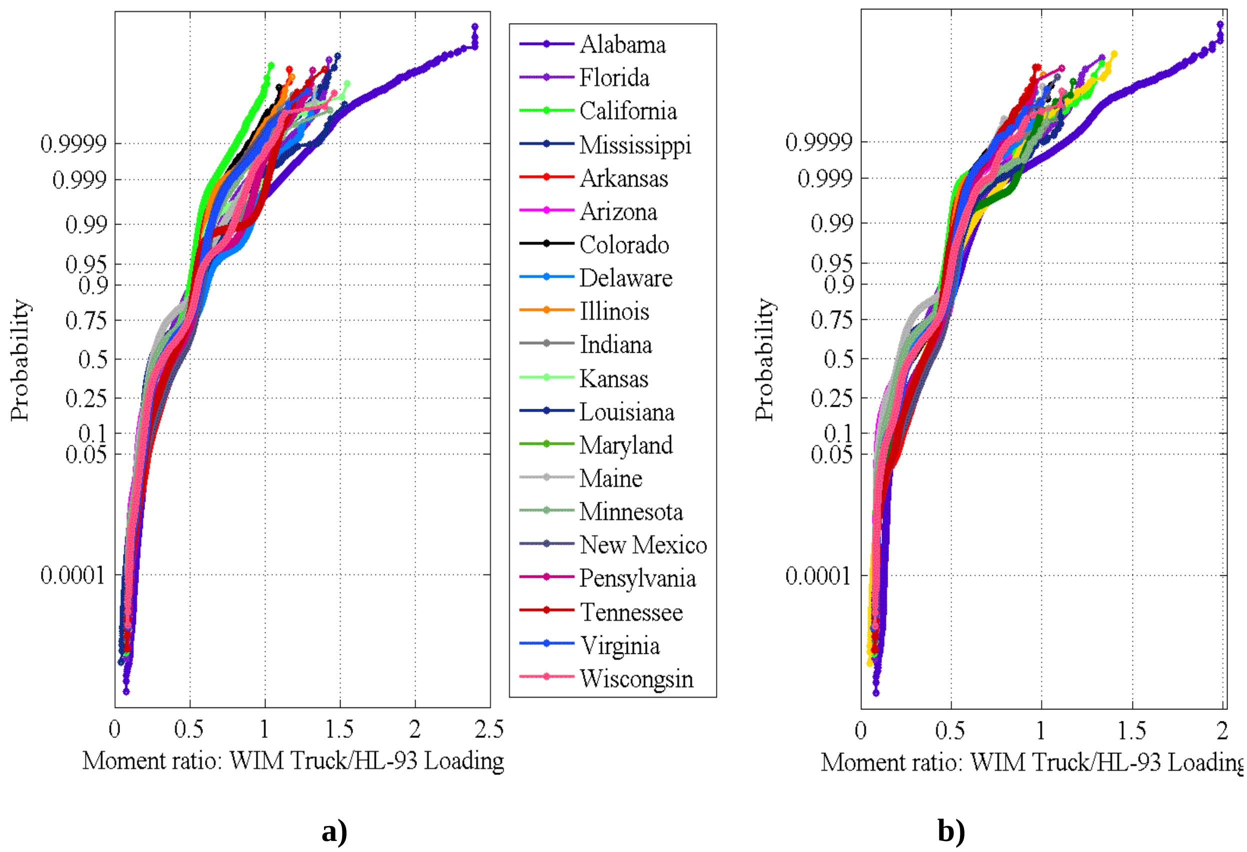
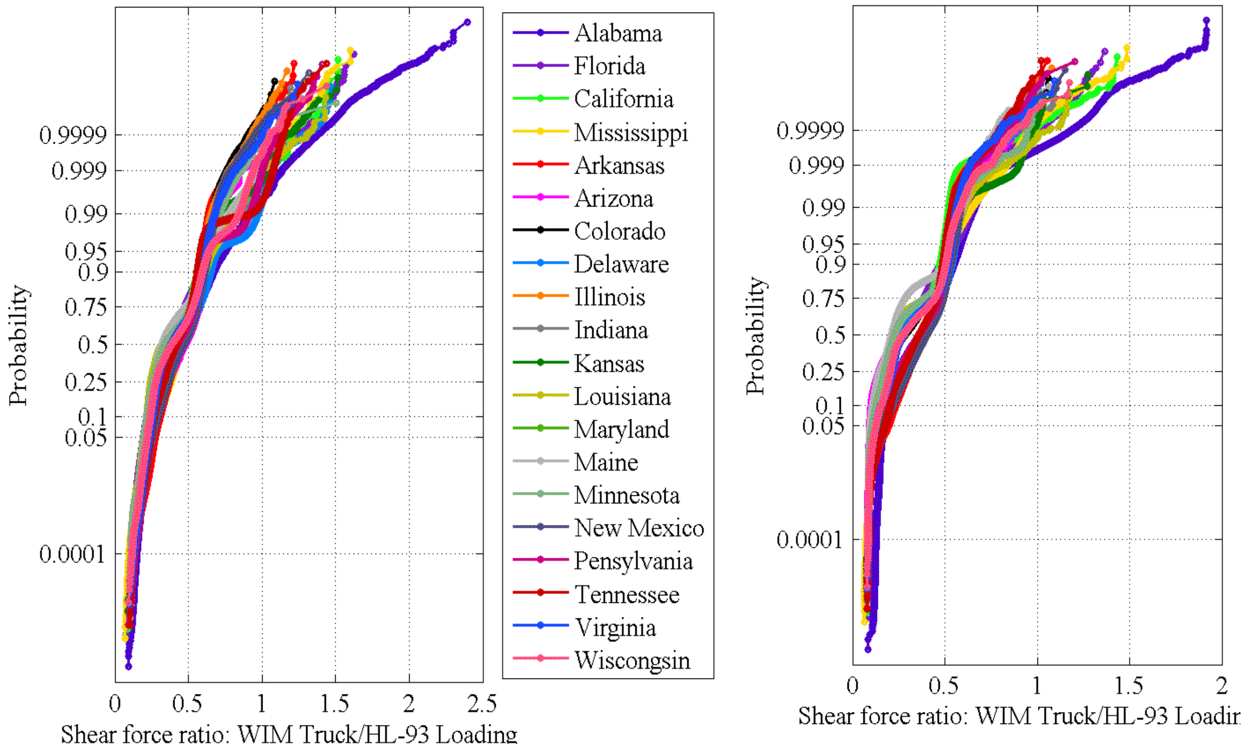


Figure 104: CDF's of moment ratios for moment ratio for 30ft (a) and 200ft (b) span length for all available locations in the United States (2006-2014)

The mean value for the moment ratio varies from 0.2 to 0.5 for short and from 0.2-0.4 for short spans for all considered locations in the US. The maximum value of moment ratio curves is below 1.5 for 30ft and below 1.4 for 200ft span for most cases, except Alabama. The maximum moment ratio is in the range from 2.4 to 2, going down with the increase of span length.



a) b)

Figure 105: CDF's of shear force ratios for moment ratio for 30ft (a) and 200ft (b) span length for all available locations in the United States (2006-2014)

According to Figure 104 and 105, the shapes of distributions of moment and shear force ratios are similar for all considered spans. The mean value is mostly below 0.5 for all considered span length and locations (including Alabama). The maximum shear force ratios vary from 1.1 to 1.6 for 30ft and from 1.0 to 1.5 for 200ft span respectively for most states. Based on ALDOT WIM data the maximum shear force ratio reaches 2.5 in the case of short span length.

Since the shapes of CDF's are mostly similar, the outlying upper tail of the load effects curves can be a result of the difference in the number of records for available states (Tables 12 and 13). FHWA as well as NCHRP WIM data mostly contains records from only one location in the state during one year. At the same time, distribution of moment and shear force ratio, as well as GVW, is strongly site-specific. Thus, considering the most representative locations in ALDOT WIM data (excluding US 231, 931, 933, 961 and 963) resulted in the maximum moment and shear force ratios below 1.4.

According to Figure 104, only 0.0001% of vehicles in Alabama cause moment higher than 1.4 of HL-93 loading. The probability of a WIM moment exceeding 1.0 is less than one present for all considered spans.

7.4. Statistical Parameters for Permit/Illegally Overloaded Data (Comparison)

To compare load effects of the permit or illegally overloaded traffic in Alabama, CDF's of moment ratio for the same spans and different locations in the United States were plotted on the probability paper. The examples are shown in Figures 106 and 107 for 30ft and 200ft span, respectively. The shapes of CDF curves for different states are mostly similar except the data from Alabama which includes significantly more records (Table 25). The mean value for the moment ratio varies in the range from 0.5 to 1.2 for all considered span lengths. The maximum value for each moment ratio is below 2.6 for most cases, except Alabama (3.0 for 30ft and up to 4.5 for 200ft span).

Table 25: Number of vehicles removed after applying filtering criteria II (FHWA and NCHRP records)

#	State	Total # of records	Permit or Illegally Overloaded Vehicles	%
1	AL	97,928,679	143,504	**0.1465393**
2	MS	5,914,950	19	**0.0003212**
3	CA	13,458,818	1	**7.43E-06**
4	FL	4,143,162	1,983	**0.047862**
5	AR	1,675,349	-	**-**
6	AZ	1,466,033	-	**-**
7	CO	343,603	-	**-**
8	DE	201,677	14	**0.0069418**
9	IL	854,075	-	**-**
10	IN	185,267	12	**0.0064771**
11	LA	85,702	75	**0.0875125**
12	KS	477,922	106	**0.0221794**
12	MD	328,778	7	**0.0021291**
13	ME	183,576	-	**-**
14	MN	55,572	5	**0.0089973**
15	NM	725,382	5	**0.0006893**
16	PA	1,495,741	8	**0.0005349**
17	TN	1,622,320	5	**0.0003082**
18	VA	259,190	-	**-**
19	WI	226,943	1	**0.0004406**

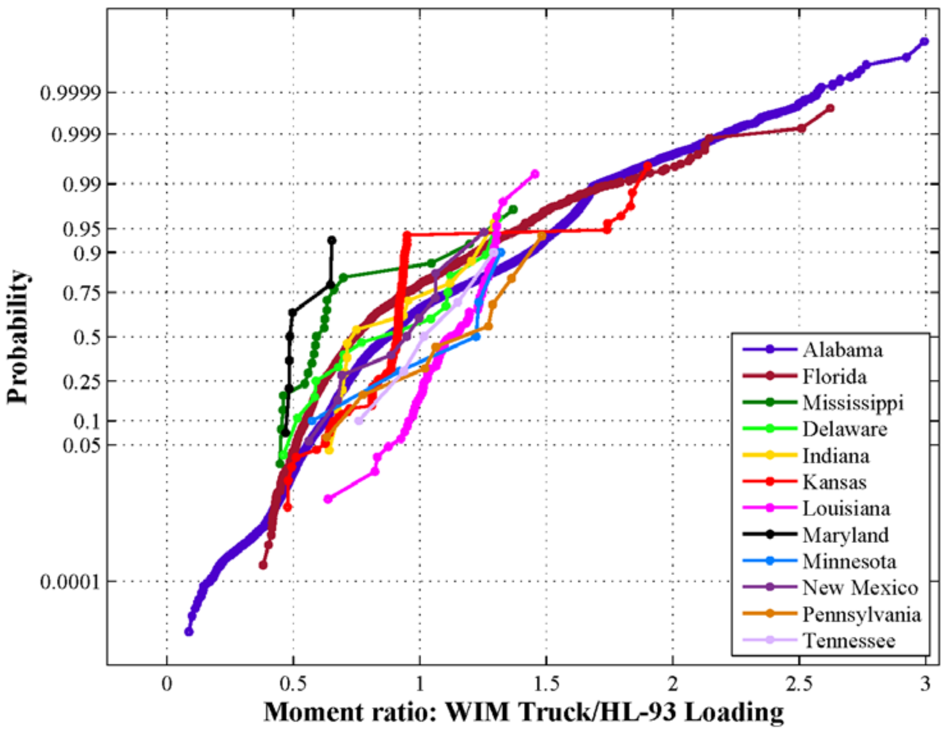


Figure 106: CDF plot for available WIM permit database moment ratio for 30ft span for all available states in the US

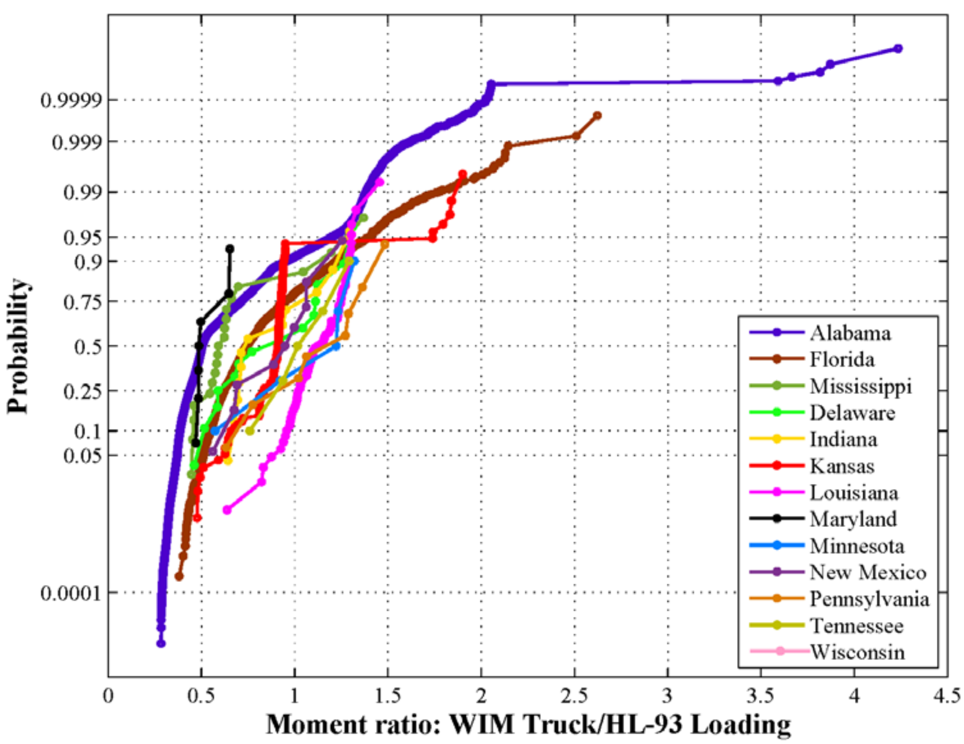


Figure 107: CDF plot for available WIM permit database moment ratio for 200ft span for all available states in the US

7.5.Outlying data

The changes in the truck traffic parameters happened in the location 963 (I10 Mobile) during 2008-2013 were already discussed in Chapters 3.6 and 4.5. Since this WIM station is located at the interstate I-10, the traffic flow can be considered in comparison with Mississippi and Florida. I-10 interstate goes through these states and there are two locations in NCHRP WIM database which contain the records during 2008. The conclusions regarding changes in live load in Alabama can be important for the other states.

To truck the changes in live load in I-10, the CDF's of GVW were plotted for Florida, Alabama, and Mississippi for 2008 as it is shown in Figure 108. Since ALDOT WIM records cover 9 years, the CDF of GVW for Alabama in 2013 was added to the main plot (Figure 108) for comparison. Recent WIM data (after 2008), for MI and FL, is not available.

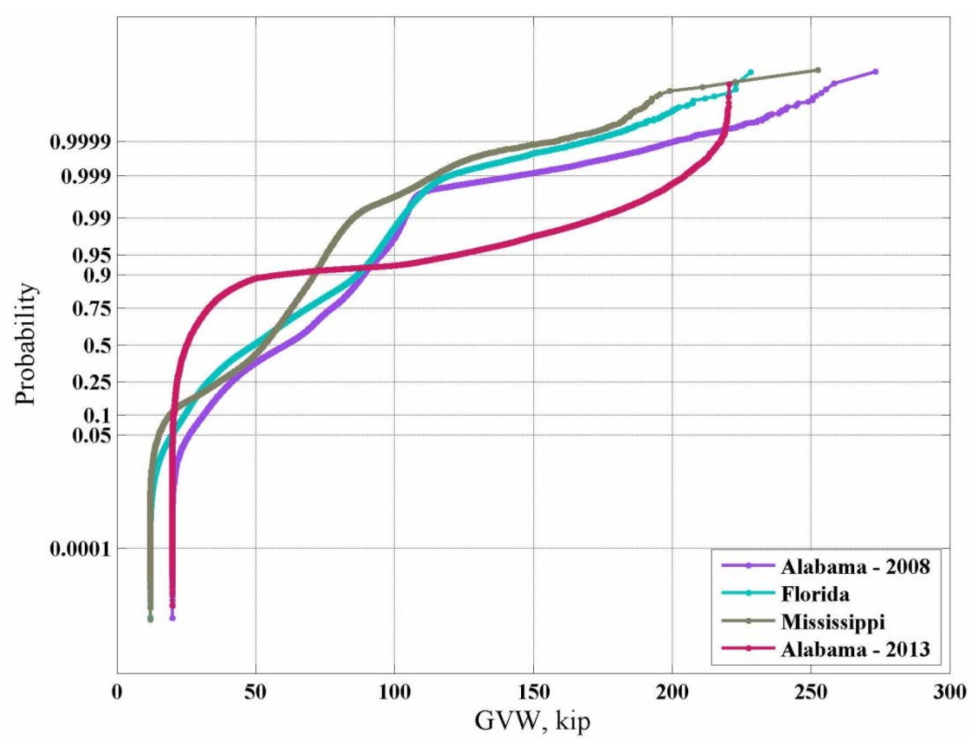


Figure 108: CDF's for GVW for WIM stations located along the road I-10

From Figure 108 it is clear, that there is no significant difference in CDF's shapes for locations along the interstate I-10 (Florida – Alabama – Mississippi) in 2008. However, the shape of CDF for location 963 (Alabama – 2013) demonstrates a dramatic change in the period from 2008 till 2013.

The mean value of GVW decreased from 60 kips in 2008 to 25 in 2013 as well as maximum GVW (from 250 to 220 kips).

7.6. Maximum Moments for Different Time Periods for Alabama

The maximum moment ratios were determined using the methodology previously used in SHRP2 R19B report (*SiWIM Bridge Weigh-in-Motion Manual: 4th Edition* 2011). The same procedure was applied to the available ALDOT WIM data to obtain the statistical parameters for live load effects in Alabama.

Since, moment ratio is a random variable the shape of the CDF depends on the period of time, ADTT, and distribution of traffic. Ehe mean value of the maximum moment for any period of time and ADTT can be determined based on the maximum number of vehicles (*N*) expected during the considered time period. For each considered ADTT and period of time (in days) the expected or mean value of the maximum moment is equal to the moment corresponding to probability $\{1-F[1/N(T)]\}$, where $F(x)$ is the CDF of WIM moments, which is $F^{-1}[1 -1/N(T)]$, where F^{-1} is the inverse of CDF.

The WIM data per each lane is available for multilane roads in ALDOT WIM database. Thus, the actual ADTT was determined for each location and lane and summarized in Table 26. The lane with maximum ADTT is taken for the further analysis.

Table 26: Lane ADTT in ALDOT WIM database for years 2006÷2014.

	Lanes				
Location	**1**	**2**	**3**	**4**	**ADTT***
911	755	62	49	460	755
915	545	74	49	308	545
918	5508	3538	256	-	5508
931	2809	317	246	2019	2809
933	1216	318	155	661	1216
934	2092	148	47	240	2092
942	1667	193	87	1080	1667
960	787	432	-	-	787
961	2862	395	204	754	2862
963	3305	907	1118	757	3305
964	829	179	141	799	829
965	3611	587	319	2359	3611
US 231					890

* ALDOT data is for multilane cases, lane with maximum ADTT is listed

The shapes of CDF curves are similar regardless the number of records and actual ADTT at the location. Only upper tails of each CDF representing the maximum values vary depending on the number of recorded vehicles. Thus, for each CDF (each location) the maximum moment (Z_{max}) can be determined by the vertical (probability axis) coordinate depending on selected ADTT (Eq. 1):

$$Z_{max}=-\Phi^{-1}(\frac{1}{N}) \tag{1}$$

where: $-\Phi^{-1}$ – is the inverse standard normal distribution function;

N – number of records for the period of time T (in days) and certain $ADTT$ (Eq 2).

$$N=(T)(ADTT) \tag{2}$$

The analysis was performed for ADTT summarized in Table 26. Values of Z_{max} for the considered ADTTs and time periods from 1 day to 100 years are summarized in Table 27.

Table 27: Vertical Coordinates for the Mean Maximum Moment

	Period of time									
Location	**1 day**	**2 weeks**	**1 month**	**2 months**	**6 months**	**1 year**	**5 years**	**50 years**	**75 years**	**100 years**
911	3.01	3.73	3.93	4.09	4.33	4.49	4.82	5.26	5.33	5.38
915	2.90	3.65	3.85	4.02	4.26	4.42	4.75	5.20	5.27	5.33
918	3.57	4.21	4.38	4.53	4.75	4.89	5.20	5.61	5.68	5.73
931	3.38	4.05	4.23	4.39	4.61	4.76	5.07	5.50	5.57	5.62
933	3.15	3.85	4.04	4.20	4.44	4.59	4.91	5.35	5.42	5.47
934	3.30	3.98	4.17	4.32	4.55	4.70	5.02	5.44	5.51	5.57
942	3.24	3.93	4.12	4.27	4.50	4.65	4.97	5.40	5.47	5.53
960	3.02	3.74	3.94	4.10	4.34	4.49	4.83	5.27	5.34	5.39
961	3.39	4.06	4.24	4.39	4.62	4.76	5.08	5.50	5.57	5.62
963	3.43	4.09	4.27	4.42	4.65	4.79	5.10	5.52	5.59	5.64
964	3.03	3.76	3.95	4.11	4.35	4.51	4.84	5.28	5.35	5.40
965	3.45	4.11	4.29	4.44	4.67	4.81	5.12	5.54	5.61	5.66
US 231	3.06	3.77	3.97	4.13	4.37	4.52	4.85	5.29	5.36	5.41

Specially developed MATLAB code was designed the way to obtain the corresponding maximum moment ratio directly by reading it from the distribution curve for each ordinate (Z_{max}). In the case of its absence on the actual CDF, it generates values using the power fitting function to the upper tail of the distribution curve.

The statistical parameters can be easily obtained from the plot by direct reading the maximum mean values as it is shown in Figure 109. The standard deviation of the maximum mean values can be determined from the graphs (slope of the CDF). Since ALDOT WIM data consists of 13 locations around the state, it is assumed to be unbiased. The mean of these maximum mean values can be considered as the mean maximum live load for the state of Alabama. The resultant curves are plotted separately for each considered span length in Figures 110– 114.

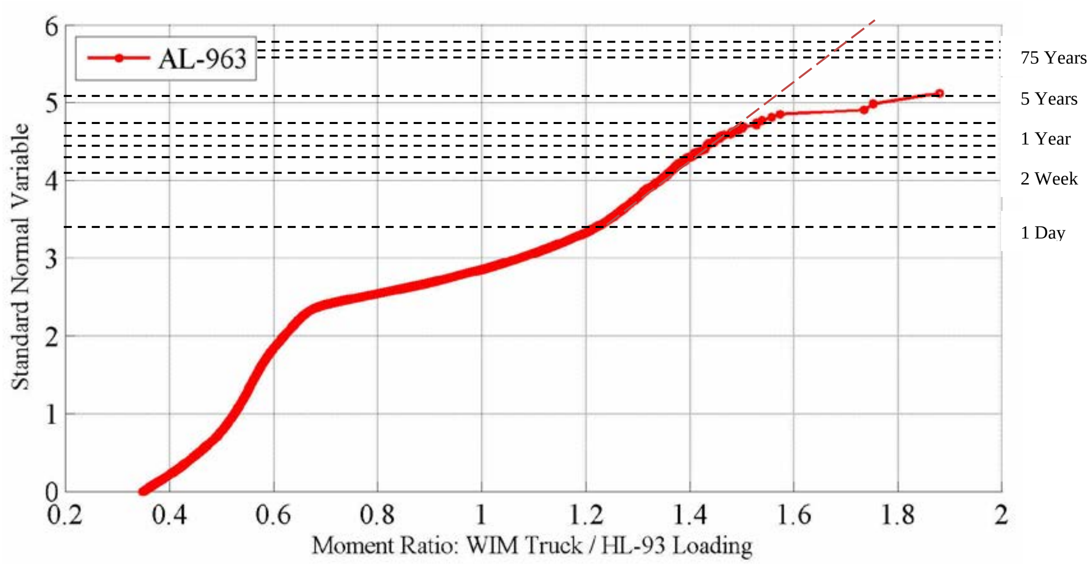


Figure 109: Vertical coordinates for different time periods for 963 (Grand Bay, I-10) and span=200 ft.

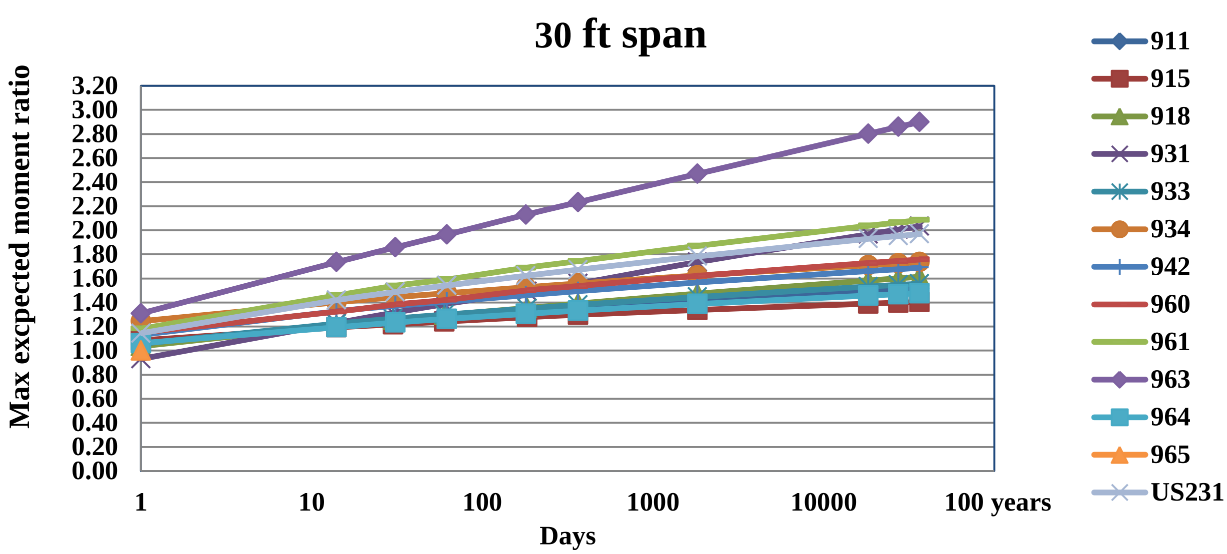


Figure 110: Maximum moment ratios for 30ft span length expected in different periods of time

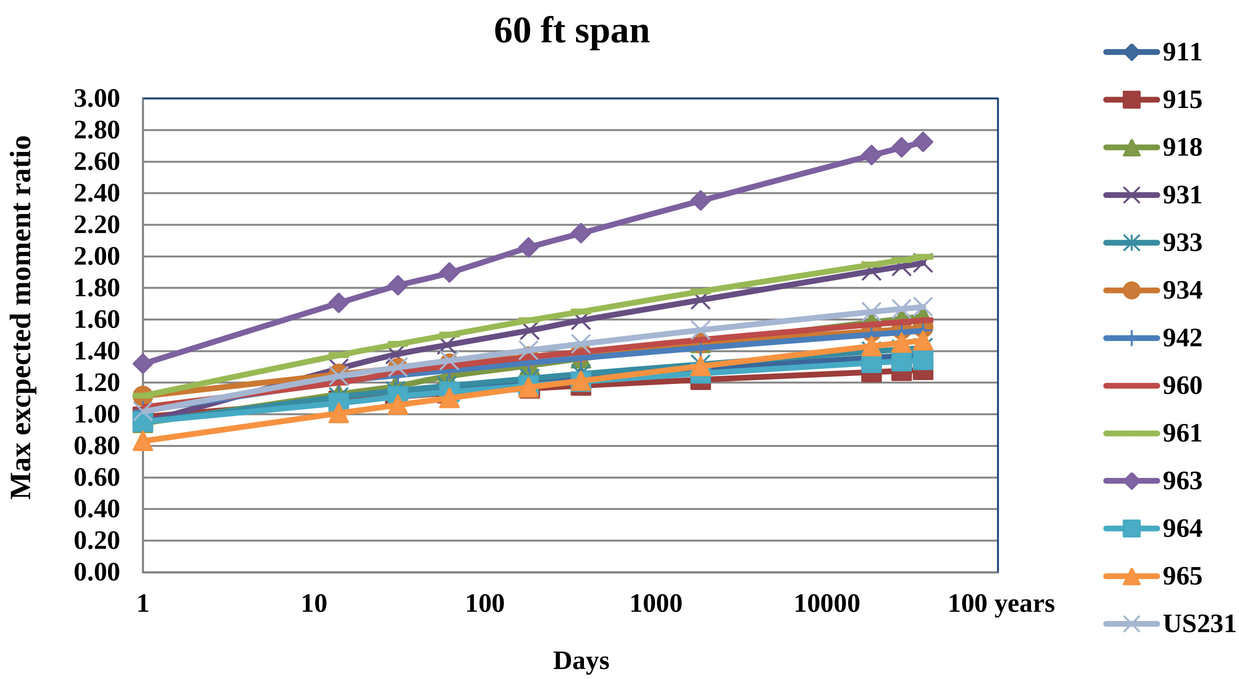


Figure 111: Maximum moment ratios for 60ft span length expected in different periods of time

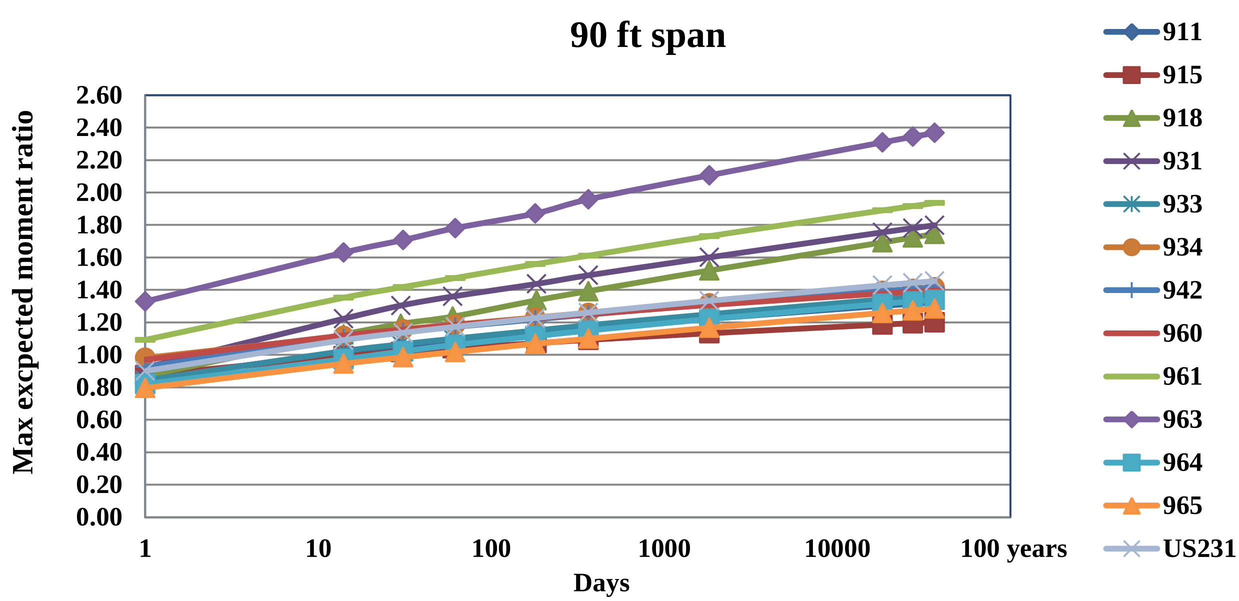


Figure 112: Maximum moment ratios for 90ft span length expected in different periods of time

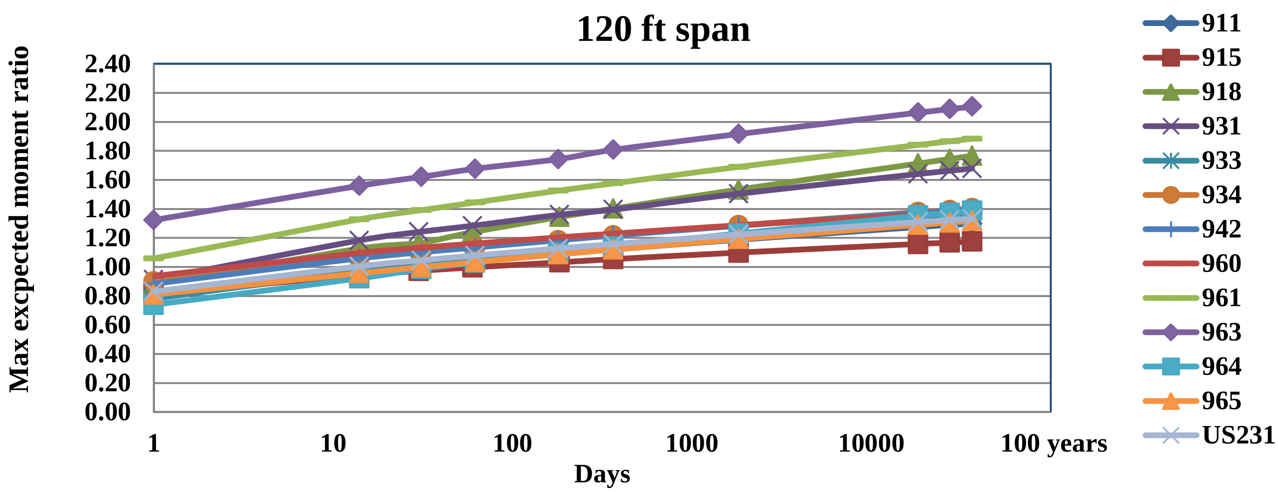


Figure 113: Maximum moment ratios for 120ft span length expected in different periods of time

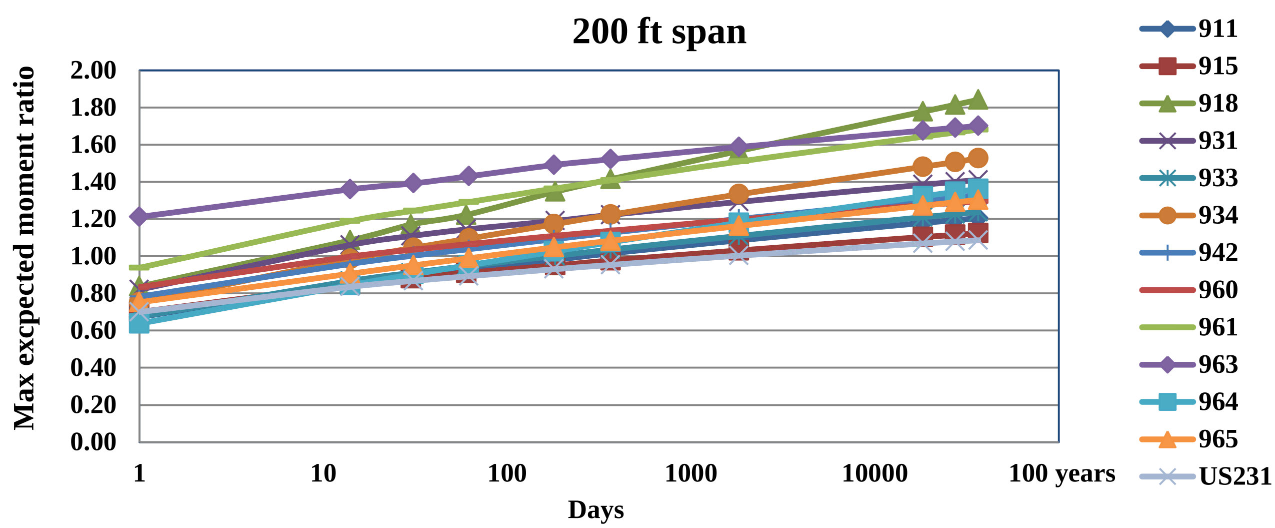
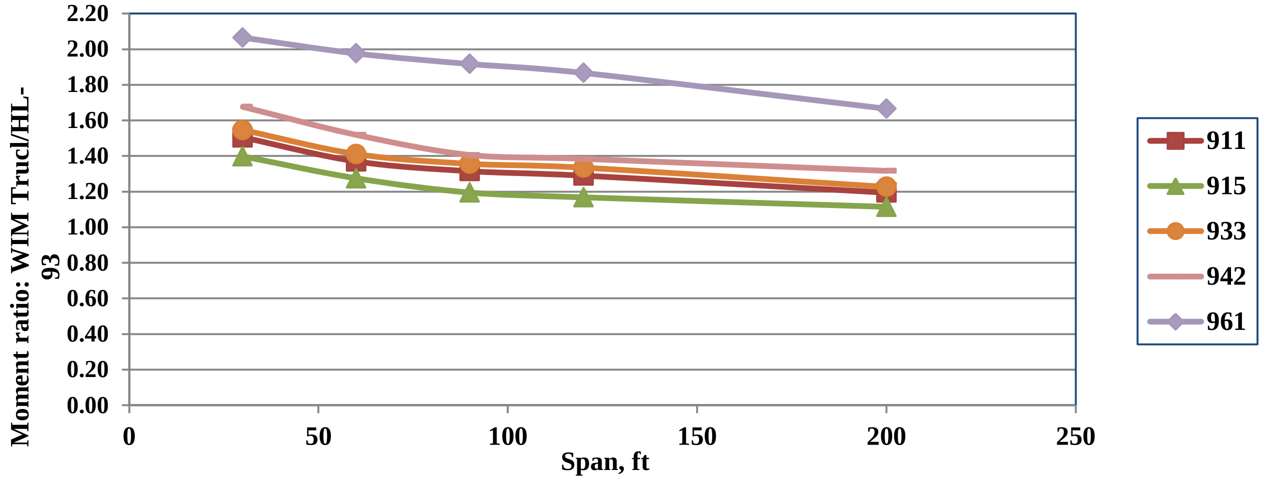


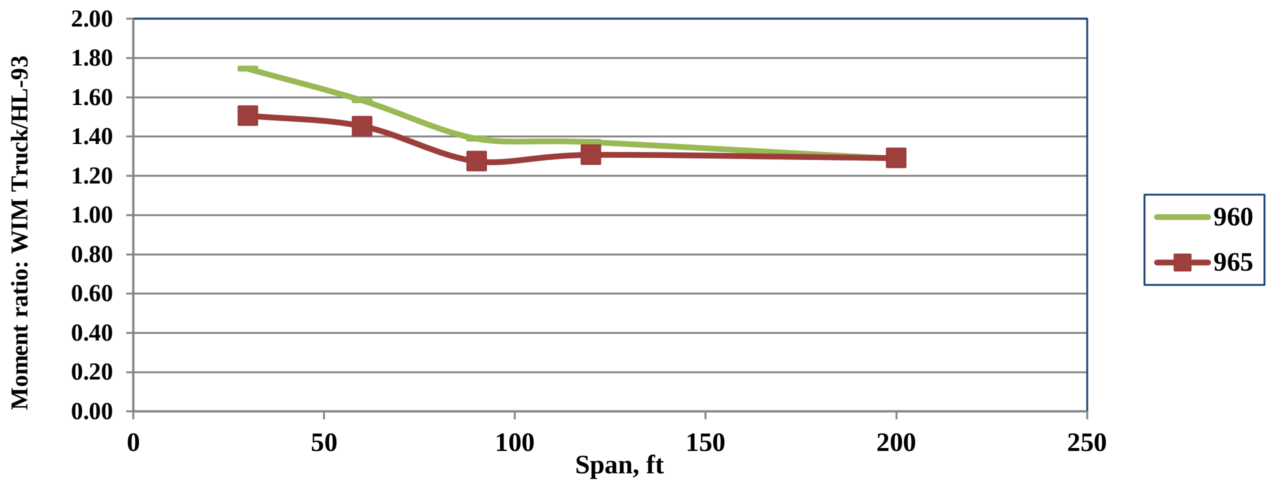
Figure 114: Maximum moment ratios for 200ft span length expected in different periods of time

Live load statistical parameters such as maximum mean values for 75 years for most of the locations in Alabama were grouped due to the shape of the curves and plotted versus considered span lengths as it is shown in Figure 115. The maximum moment is below 1.6 for most of the locations and span length. However, in locations 961, 931, 918 and 963 the 75 years-moment ratio may exceed 2. A similar trend of high 30ft moment ratio was observed in almost all cases.

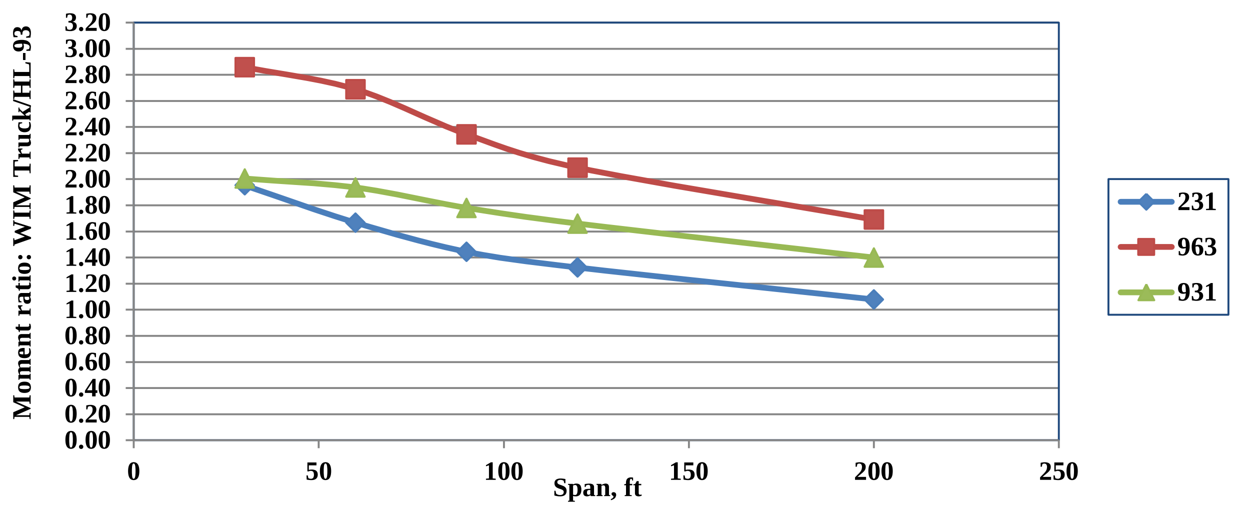
The outlying data were plotted separately in Figure 116. The increase of the load effect to the longer space due to the specific trucks configuration was observed in two locations 918 (Bucksville – I20 Tuscaloosa Co.) and 934 (US78 Walker Co.).



a)



b)



c)

Figure 115: Maximum moment ratios expected in different periods of time for different locations

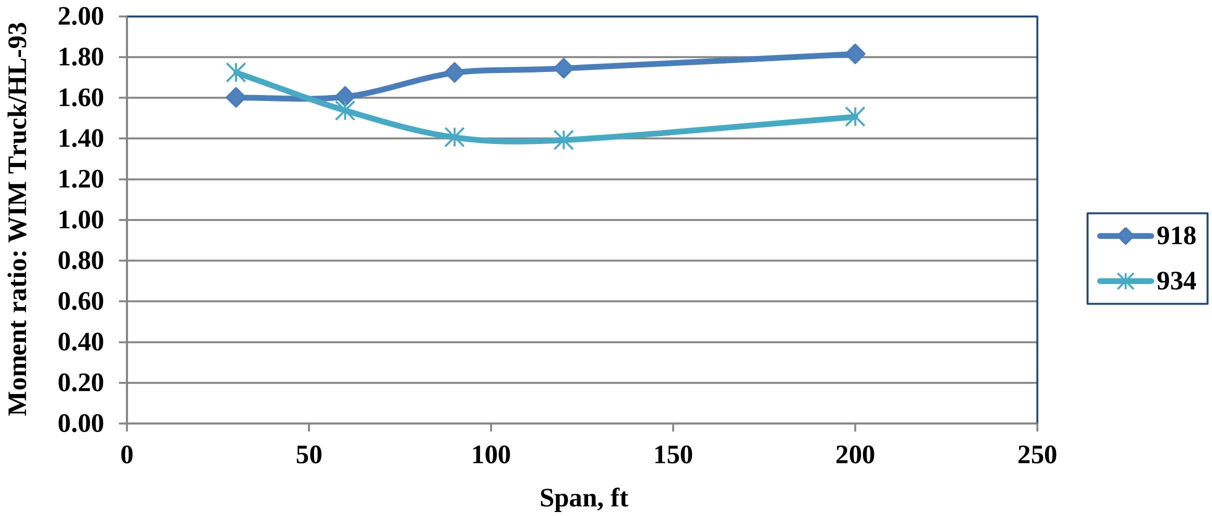


Figure 116: Maximum moment ratios expected in different periods of time for different locations

7.7. Comparison of the Alabama State and National Live Load Model

The national live load model was developed based on FHWA and NCHRP WIM database. To generalize the model the values of Z_{max} for were computed for the ADTTs of 250, 1000, 2500, 5000 and 10000 as it is shown in Table and time periods from 1 day to 100 years are summarized in Table 27.

Table 28: Vertical Coordinates for the Mean Maximum Moment

Time Period	ADTT				
	250	1000	2500	5000	10000
1 Day	2.65	3.09	3.35	3.54	3.72
2 Weeks	3.44	3.8	4.02	4.18	4.33
1 Month	3.65	4.00	4.20	4.35	4.50
2 Months	3.82	4.15	4.35	4.50	4.65
6 Months	4.09	4.39	4.59	4.73	4.87
1 Year	4.24	4.55	4.73	4.87	5.01
5 Years	4.59	4.87	5.05	5.18	5.31
50 Years	5.05	5.31	5.47	5.60	5.72
75 Years	5.13	5.38	5.55	5.67	5.78
100 Years	5.18	5.44	5.60	5.72	5.83

WIMM FHWA and NCHRP WIM databases consist of records collected from 32 locations. Thus, the maximum load effect ratios are obtained directly from the probability plot with 32 curves. The example is shown in Figure 117 for 8 locations in Florida and California.

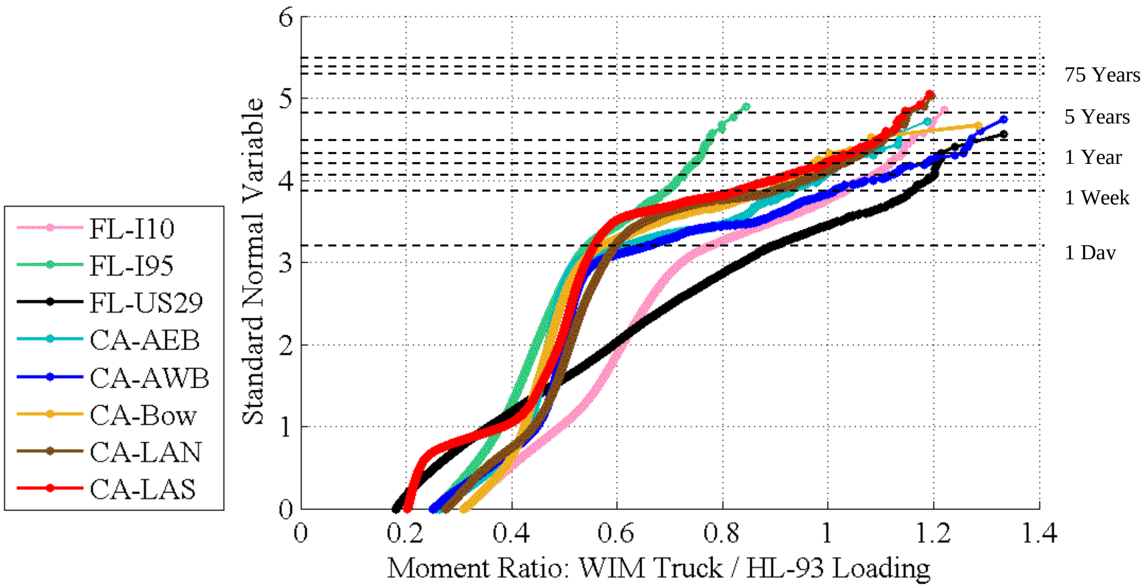


Figure 117: Vertical coordinates for different time periods for ADTT =1,000 and span=200 ft.

The resultant bias factors (mean-to-nominal values) for 75-years period are plotted versus span length for all considered ADTTs. The maximum actual 30ft-moment ratio calculated for FHWA and NCHRP trucks is 1.57(Figure 118). However, the maximum value for the same span length and ADTT=10,000 expected in 75-years is 1.68. The mean maximum value for the same period varies from 1.2 to 1.5 for most of the cases. The standard deviation is consistent and can be averaged to 1.2.

There a number of vehicles in ALDOT database causing extremely high load effects for all considered spans (Figures 110 and 114). The maximum expected moment ratio for 30ft span reaches 3.0 in the locations 963(Grand Bay, I-10) and 2.2 in 931(Athens, I-65), 961(Mobile, I-65) respectively. The maximum ratio for 200ft is 1.8 in the location 918(Bucksville, I-20). At the same time, less than 0.005% of a regular truck traffic produces the load effect ratio higher than 1.5. These trucks mostly belong to the permit or illegally overloaded category of vehicles due to the GVW and axial configuration. Excluding these vehicles will result in the maximum expected live load effects 1.78 for 30ft span and 1.48 for 200ft with 10,000 ADTT. It is similar to live load model developed based on FHWA and NCHRP WIM database, except short span cases.

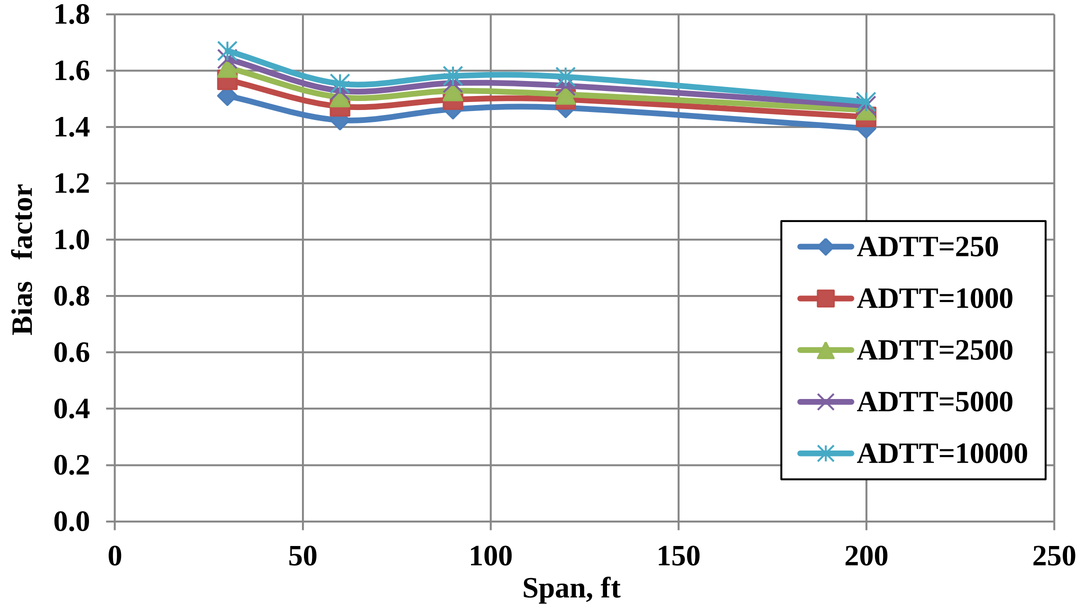


Figure 118: Bias factor for moment vs. Span Length for the Maximum 75 year for FHWA and NCHRP database

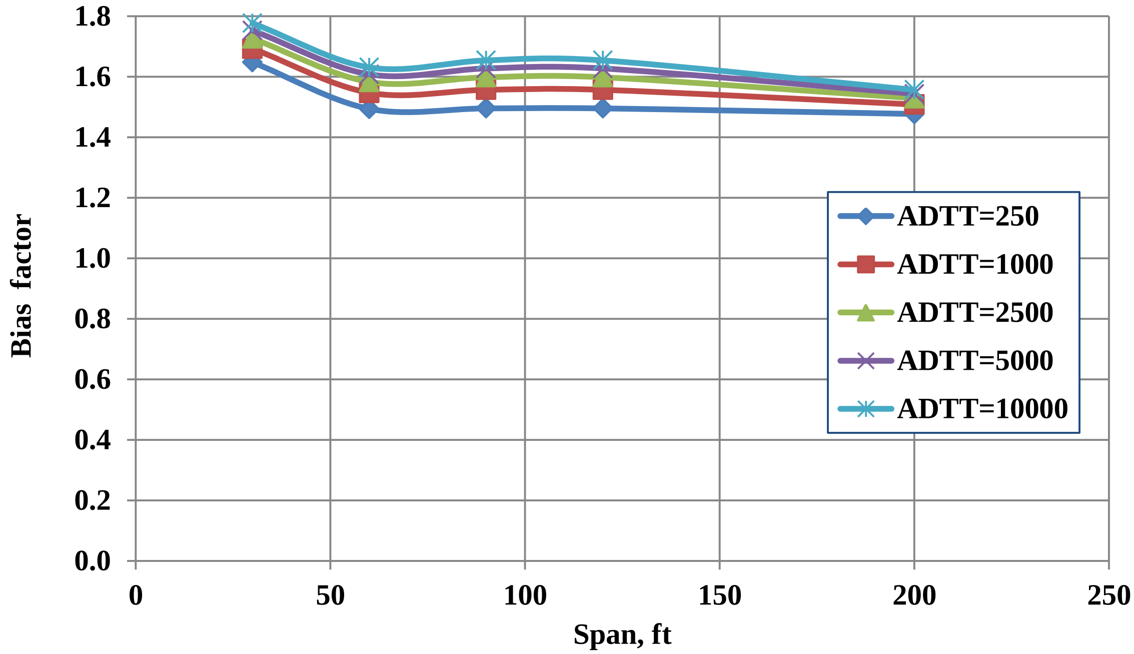


Figure 119: Bias factor for moment vs. Span Length for the Maximum 75 year for ALDOT database

7.8. Summary

ALDOT WIM data including 13 locations and 9 years of records was compared with FHWA and NCHRP data containing WIM records from 18 states in the US. in Alabama and compared with 37 locations in the United States (previously used in *Bridges for Service Life Beyond 100 Years: Service Limit State Design* 2015) . The resulting CDF's of GVW, as well as live load effects, were plotted for all available sites and analyzed. The conclusions are summarized below:

- A number of records and locations is different for each state. Thus, statistical parameters determined for the database from a particular location may not be representative for the state in general.

- On average, about 10% of all recorded vehicles are heavier than 80 kips. The heaviest vehicles with GVW of about 300 kips were recorded in Alabama in 2006-2008.

- The shapes of CDF curves for different states in the US are mostly similar except the upper tails that represent the heaviest vehicles.

- The results confirm that vehicle class 9, i.e. five-axle semi-trailer is the most frequent type of truck on Alabama roads as well as in other states.

- The shapes of CDF's are mostly similar, and the outlying upper tail of the load effects curves can be a result of the difference in the number of records for available states

- Location 963 – no significant difference in CDF's for GVW for locations along the road I-10 (Florida – Alabama – Mississippi) in 2008. At the same time, the shape of CDF for location 963 (Alabama – 2013) demonstrates a dramatic change in the period from 2008 till 2013

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Overarching Conclusions Regarding Live load

The WIM database for Alabama includes 97 million vehicles. After filtering to eliminate vehicles lighter than 20kips and questionable records, the data was reduced to 57 million. The collected records were provided from 13 WIM stations and they cover a period of 9 years (2006-2014). The statistical parameters are determined for GVW and live load affects such as moment and shear forces.

1. The data can be considered as representative for the state of Alabama.
2. About 50% of the original database was filtered out as light weight vehicles or incorrect readings. In particular, this percentage varies from 5% (934 – Sumiton, US78 and 965 – Shorter, I85) to 80% (US-231).
3. Permit trucks and illegally overloaded vehicles were identified using the filtering criteria II previously developed and used in SHRP2 R19B and NCHRP 12-83. The percentage of permit trucks and illegally overloaded vehicles is less than 0.1% for most locations, but about 1% for 963(Grand Bay, I-10).
4. According to permit criteria listed in the Alabama code (2015) about 10% of recorded truck traffic (data remained after Filtering I) requires either regular or special permit. Location wise about 5% of the truck/traffic requires a permit. However, in locations 915 (Sunflower, US-43), 942 (Pine Level, US-231) and 963 (Grand Bay, I-10).
5. On average, about 10% of all recorded vehicles are heavier than 80 kips. The mean value of truck GVW varies from 30 to 60 kips. The heaviest vehicles with GVW of about 300 kips was recorded in Alabama in 2006-2008.
6. There is no significant variation in GVW with regard to the time of taking records. However, the maximum values of GVW decreased from 300 kips in 2006-2008 to 220 kips in 2009-2014. The most recent records have a cut-off region at the upper tail of the CDF curves. It indicates a certain limitation of the maximum recorded truck weight.
7. Vehicle class 9 (five-axle, single trailer truck) is the most common type for Alabama as well as in other states. However, class 9 is not the dominating type for location 963 and years 2013 and 2014. The heaviest vehicles in this location mostly belong to class 13 (multi-trailer, 7 or more-axle trucks).

8. CDF's of the bending moment ratios demonstrate certain changes with regard to the time and region. Thus, during 2006-2007 the distribution curves show a similar shape for all considered span lengths for all locations (mean value – below 0.5, maximum – around 2). In 2008, a significant increase in the maximum moment ratios for locations 961(Mobile, I-85) and 965(Shorter, I-85) for all span length (2.5 for 30ft span and above 2 for 200ft). Since 2009, long span moment ratios are mostly around 1 for most locations, while short span ratio decreased to 1.5 in most locations and then increased to 2-2.5 for locations US-231 and 963 (Grand Bay, I-10). However, 2009-2012 WIM database was represented by a few locations, the shapes of CDF's for the same locations are consistent.
9. Vehicle class 7 (single-unit, 4 or more–axle truck) caused the highest bending moment for short (30ft) spans, while class 13 (multi-trailer, 6-axle trucks) controls longer spans. The changes in moment ratio distribution are mostly caused by changes in traffic mix over the years. Thus, the population of the vehicles of class 7-10 with GVW over 100kips is highest (%) in 2013-2014 in location 963 (Grand Bay, I-10).
10. There is a visible change of traffic at location 963 (I-10) from 2008 to 2013. In 2008, the CDF's of GVW were about the same for three WIM stations on I-10, one in Alabama, one in Florida and one in Mississippi. The 2013 records show that even though the maximum GVW decreased, but the moment and shear force ratio drastically increased, for short spans from 1.5 to 2.1.
11. State load model developed based the extrapolation of the upper tail of the moment and shear ratios CDF's. This approach allowed calculation of the maximum live load effect fo different periods of time. Thus, the maximum moment ratio for 75 years is below 1.5 for most locations and span lengths. The maximum expected moment ratio for 30ft span reaches 3.0 in the locations 963(Grand Bay, I-10) and 2.2 in 931(Athens, I-65), 961(Mobile, I-65) respectively. The maximum ratio for 200ft is 1.8 in the location 918(Bucksville, I-20).
12. The slope of the CDF's upper tail is sensitive to the number of records in the database. It also represents the distribution of less than 1% of all records. These trucks mostly belong to the permit or illegally overloaded category of vehicles due to the GVW and axial configuration. Excluding this 0.005% of records will result in the maximum expected live load effects 1.67 for 30ft span and 1.45 for 200ft with 10,000 ADTT. It is similar to live load model developed based on FHWA and NCHRP WIM database.

8.2. Recommendations

1. *Continue WIM data collection*. Weight-in-Motion data is an important source of information about the actual traffic load presented in the particular region or state. Traffic records are also weighty in terms of the frequency and configuration of vehicles and can be widely used for road planning, bridge evaluation, design live load modeling, damage accumulation models, etc.
2. *Continuous WIM records.* The obtained database was irregular with several years missed. To analyze changes in truck traffic configuration, it is important to operate a permanently collected database.
3. *The accuracy of recording devices.* GVW analysis of the different classes of vehicles indicated a significant percentage of vehicles loaded over its physical limit. The system of vehicle class determination should be verified in the WIM system algorithm. Similarly, data filtering indicated a number of systematic errors in records (0-axle spacing, missing axle loads, partial records of the vehicles and incorrect classification). Thus, the calibration of the WIM systems as well as testing the routine for the data processing is useful.
4. *WIM stations upgrade/calibration priorities.* Analysis of WIM data from locations 961, 963, 964 demonstrated significant changes in truck load distribution over the time of taking records. Thus, these WIM stations should be calibrated prior to the others.
5. *Upgrade WIM stations with cameras to provide visual information.* B-WIM station was initially equipped with the camera and visual information about the traffic configuration was provided to the research group. This data was found useful for verification of the actual WIM records from this site, identification of possible errors and potentially harmful truck configurations.
6. *Real-time WIM data processing.* Substantial changes in truck traffic distribution, as well as the load effects, can be noticed in real-time. The algorithms that can be used in real-time to process the raw WIM data can be useful.
7. *Permits and police citation.* A certain percentage of the recorded vehicles can be classified as permit or illegally overloaded. The actual database of issued permits should be considered along with WIM data records to determine the actual percentage and configuration of illegal vehicles.

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