West Virginia
Department of Transportation

Final Report

RP-271: Evaluation of the Percent of Overloaded Vehicles Receiving Proper Permits

Prepared by:

Marshall University Research Corporation

Nick J. Rahall Appalachian Transportation Institute

May 18, 2015

TECHNICAL DOCUMENTATION

1. Report No.	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle: Evaluation of the percent of overloaded vehicles receiving proper permits		5. Report Date May 13, 2015 6. Performing Organization Code
7. Author(s) Andrew P. Nichols, Chih-Sheng Chou, and Sinaya Dayan		8. Performing Organization Report No.
9. Performing Organization Name and Address Rahall Transportation Institute Marshall University Huntington, WV		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address West Virginia Department of Transportation Division of Highways Charleston, WV		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16.Abstract

All state agencies have truck size and weight restrictions on their roadways based on federal and state legislation. However, drivers can typically apply for special permits allowing those limits to be exceeded, particularly when the load is non-divisible. The permit application often includes the origin and destination of the load, as well as characteristics about the truck's size and weight. This information is used by state highway agencies to evaluate the impact of the loading on the roads and bridges that the vehicle will cross to determine a preferred route and the need for a police escort. The primary objective of this project is to estimate the percentage of overweight trucks on West Virginia highways that are not properly permitted by comparing truck weight data measured by weigh-in-motion (WIM) systems and oversize/overweight permit records. Analysis of the WIM data revealed concerns with the accuracy of the weight data. Therefore, a tuning procedure was developed to adjust the data based on national truck characteristics. The route information in the permit database was processed in GIS to determine which WIM stations the permitted vehicle should have crossed. The percentage of overweight trucks were calculated for five locations using one week of data in 2011. The percentage of overweight trucks without proper permits ranged from 2% to 46% based on the adjusted WIM data.

17. Key Words		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20.Security Classif. (of this page) Unclassified	21. No. of Pages 126	22. Price

DISCLAIMER

This research was funded by the West Virginia Department of Transportation, Division of Highways. The opinions and conclusions expressed or implied herein are those of the Authors. They are not necessarily those of the funding agency.

ACKNOWLEDGMENTS

The authors would like to thank the individuals listed below, who served on the Technical Advisory Committee for this project.

Donald Williams, PE	West Virginia Department of Transportation
Kyle Stollings, PE	West Virginia Department of Transportation
Mike Pumphrey, PE	West Virginia Department of Transportation
C.L. "Butch" Brunty	West Virginia Public Service Commission
Gary Graley, PE	West Virginia Department of Transportation
Wayne Kessinger	West Virginia Department of Transportation
Brian Carr, PE	West Virginia Department of Transportation
Kevin Burgess	Federal Highway Administration

Others contributing to the research in this project included Tiantian Chen, Graduate Assistant at University of Minnesota, Sang Hong Yoo, GIS Data Coordinator at Washington Metropolitan Area Transit Authority, Tuan Nguyen, Geospatial Analyst at RTI, and Curtis Jones, Geospatial Analyst at RTI.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Studies have shown that heavy vehicles can be a detriment to the roads and bridges on which they travel. Industries that utilize vehicles with non-divisible loads that exceed the legal limits are eligible to obtain permits for those loads. Examples of non-divisible loads are heavy machinery and components used in construction, such as those shown in Figure 1-1. In West Virginia, the process of acquiring oversize permits (e.g., height, length, and width) and overweight permits(e.g., single axle, tandem axle, gross vehicle weight) is conducted through the Central Permit section and is available on the West Virginia Department of Transportation (WVDOT) website (*1*). Vehicle information, load information, and travel dates are provided by the applicant when applying for a vehicle permit. After review by WVDOT, the approved permit indicates the route to be traveled and the days during which the trip can be completed. Indications are that many oversize and overweight vehicles are not obtaining the proper permits. The reason for this could be the cost of the permit, the time required to go through the process, or the low probability of getting caught without one.

Figure 1-1 Non-Divisible Loads

In West Virginia, commercial vehicle enforcement is performed by the Public Safety Commission (PSC) through the operation of fixed weigh stations and mobile enforcement units. The static weigh stations are relatively ineffective for deterring blatant overweight activity because their operational hours tend to be fixed and truck drivers commonly use their radios to communicate to other drivers about openings and closings. Therefore, it is relatively easy for drivers to evade the weigh station by traveling another route or waiting at a gas station or rest area until the weigh station closes. The mobile enforcement units utilize portable scales to weigh trucks at other locations. These units can sometimes be more effective at catching overweight trucks because they are random, but there are insufficient manpower to adequately enforce the regulations.

The weight limits in West Virginia are:

- Gross vehicle weight – 80,000 lbs (Interstate, US, and WV Routes)
- Gross vehicle weight – 65,000 lbs (Local Routes)
- Single axle weight – 20,000 lbs (Interstate, US, WV, and Local Routes)
- Tandem axle weight – 34,000 lbs (Interstates, US, WV, and Local Routes)

There are additional gross vehicle weight (GVW) limits for other vehicle types that apply to the US and WV Routes. The full regulations are listed in Appendix A. A 10% tolerance is also applied to these weights. Therefore, vehicles on the Interstate can have a GVW up to 88,000 lbs without receiving a citation.

Overweight trucks lead to accelerated damage to the transportation infrastructure, so it is necessary to enforce the hauling limits. Often it is unavoidable if the load cannot be divided into smaller loads, which is why the permit process exists. There can be illegal activity pertaining to both divisible and non-divisible loads. Illegal activity related to permits is defined as:

- hauling an overweight non-divisible load and <u>not obtaining a permit,</u>
- hauling an <u>overweight divisible load</u> that doesn't qualify for a permit (i.e., load can be divided into multiple legal loads, such as gravel or multiple steel coils),
- hauling an overweight non-divisible load on <u>an expired permit</u> (i.e., traveling outside the time window on the permit),
- hauling an overweight non-divisible load along a <u>route not specified</u> on the permit, and
- hauling a load with a <u>permit issued for another</u> vehicle.

In an effort to monitor the traffic volumes and loadings that use the state's roads and bridges, weigh-in-motion (WIM) stations have been strategically deployed across the state by the WVDOT. A WIM station consists of a set of in-pavement sensors installed in each lane and equipment in a roadside cabinet to collect data. WIM systems are capable of measuring the speed, axle-to-axle spacing values, total vehicle length, and axle weights while the vehicle is traveling at normal highway speeds. Various sensor technologies can be used for WIM weight measurement, including piezoelectric sensors (brass linguini, ceramic, and quartz), bending plates, and load cells. West Virginia primarily uses brass linguini piezoelectric sensors and there are 73 locations across the state that WIM systems have either been deployed or planned for deployment.

In West Virginia, the permit data and WIM data are archived in databases. Despite the various functionalities of these databases, they are both archived with similar fields related to the truck's axle attributes. The objective of this research project is to analyze these two databases and estimate the percentage of overweight trucks that have not acquired the proper permits. This information is important to the WVDOT and PSC in determining the level of illegal overweight truck activity. If the overweight truck activity is minimal, then current efforts are likely sufficient. However, if overweight truck activity is high, alternative action may be necessary.

The remainder of the report describes the analysis and findings for this project. The chapters are organized as follows.

- Chapter 2. The location of existing and planned WIM sites in West Virginia are presented.
- Chapter 3. Historical data from WIM sites in West Virginia are analyzed for accuracy. Additionally, a method for tuning WIM data that has questionable accuracy was developed and applied to the data.
- Chapter 4. Historical data from the permit database are analyzed in a geographic information system (GIS) platform to determine the routes taken. This allows the comparison of the permits crossing each WIM station.
- Chapter 5. A data fusion methodology is implemented to compare the WIM data (Chapter 3) with the permit data (Chapter 4) in order to estimate the percentage of overweight trucks.
- Chapter 6. The conclusions and recommendations are summarized.

2. WIM SYSTEMS IN WEST VIRGINIA

Weigh-in-Motion (WIM) systems have been strategically deployed across the state by the WVDOT to monitor traffic volumes and loadings using the state's roads and bridges. A WIM station is a set of in-pavement sensors installed in each lane that measure each vehicle's attributes, including speed, axle-to-axle spacings, and axle weights at normal highway speeds. West Virginia primarily uses piezoelectric sensors for axle spacing and axle weight measurement. An inductive loop is also used to measure overall vehicle length. The standard configuration of a WIM system in West Virginia is depicted in Figure 2-1.

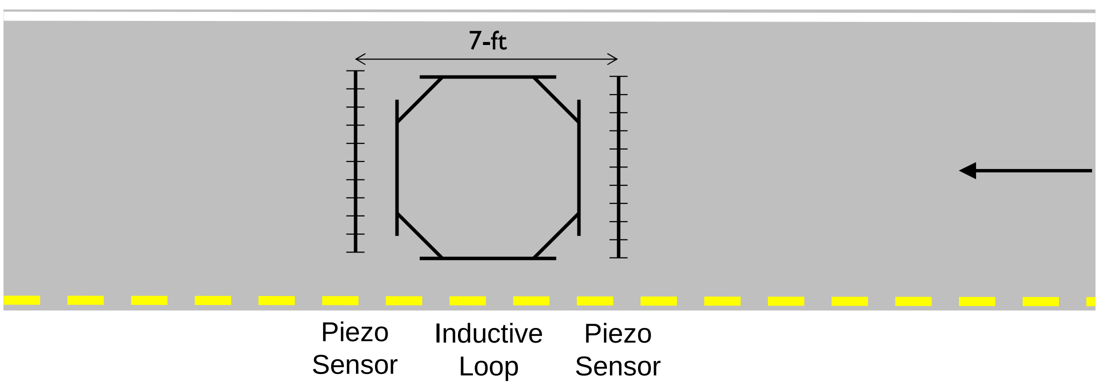


Figure 2-1 Typical West Virginia WIM Station Layout

There are 73 WIM sites installed or planned across West Virginia. These locations were coded into Google Earth based on latitude and longitude. The resulting map is shown in Figure 2-2. There are 20 sites along the Interstate, 28 along US Routes, 23 along WV Routes, and 2 along County Routes. These sites are spread geographically across the state in 37 counties. Distributions of the sites by county are listed in Table 2-1.

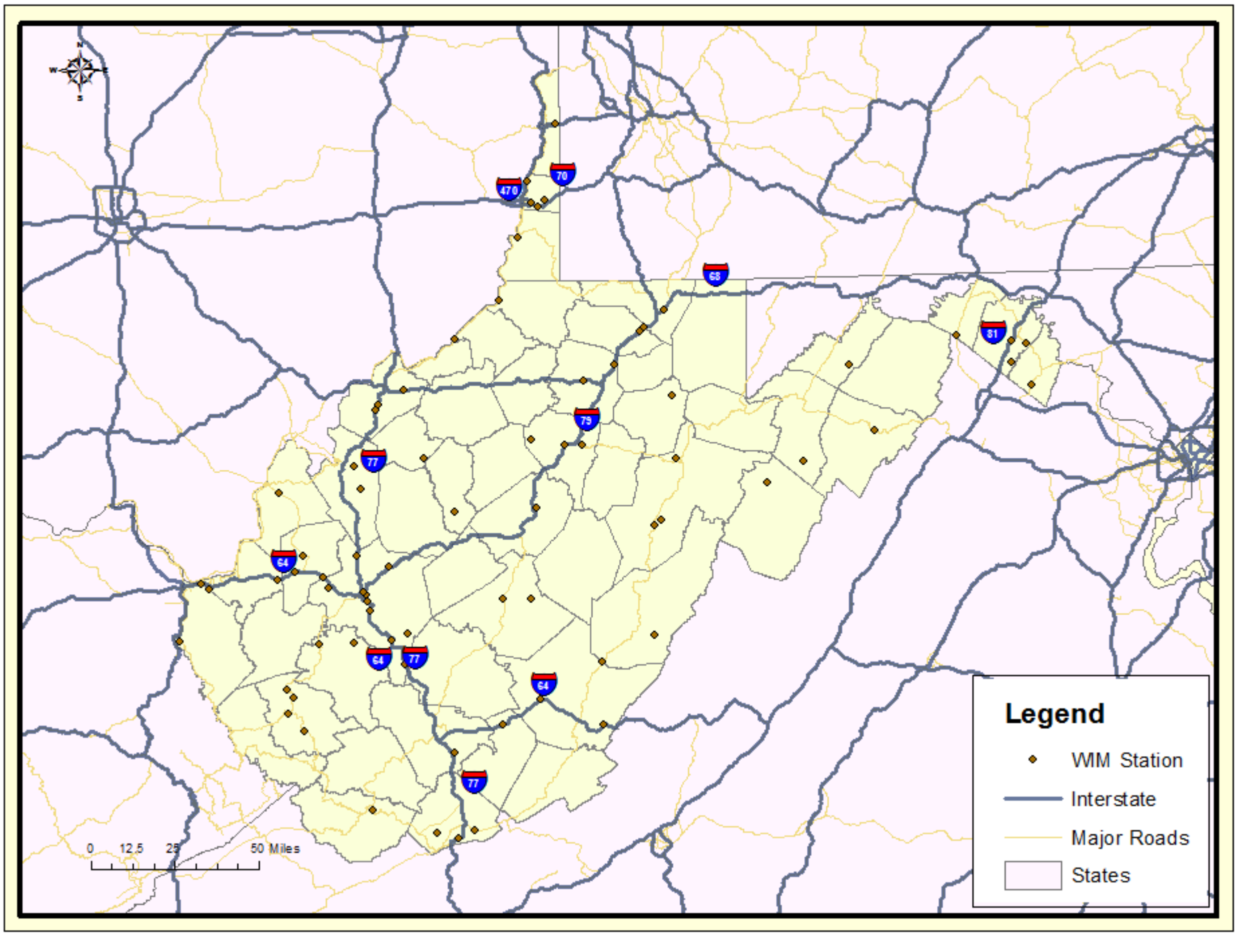


Figure 2-2 73 WIM Sites in WV

Table 2-1 WIM Site Distribution by County

County	# of Sites	County	# of Sites	County	# of Sites	County	# of Sites
Barbour	1	Hardy	1	Morgan	1	Randolph	3
Berkeley	3	Jackson	2	Mineral	1	Summers	1
Boone	2	Jefferson	1	Marion	2	Tyler	1
Braxton	1	Kanawha	11	Marshall	1	Wayne	3
Brook	1	Lewis	3	Nicholas	2	Wetzel	1
Cabell	1	Logan	4	Ohio	4	Wood	3
Calhoun	1	Mason	1	Pendleton	1	Wirt	1
Grant	1	McDowell	1	Pocahontas	1	-	-
Greenbrier	3	Mercer	3	Putnam	2	-	-
Harrison	2	Monongalia	1	Raleigh	1	-	-

At each WIM site, there are sensors in each lane. In this report, each lane is referred to as a WIM station. Each WIM station is considered to be unique since there are an independent set of in-pavement sensors. Thus, the total number of stations at each site varies, as summarized in Table 2-2. For example, there are four WIM stations deployed on Site 8, which is located at US 19 in Nicholas County. There is no WIM station configured at Site 65 yet, which is planned along US 33 in Randolph County. The study period covers 2011. Some sites were not yet collecting data and others that were collecting data were not archiving it in a way that it could be analyzed for this project. This analysis requires "per-vehicle" data where each vehicle produces an independent WIM record with all axle attributes (as opposed to records aggregated over a specific time period for summary weight reporting). In order to save storage space and minimize data transfer times, WIM systems are sometimes configured to only archive data summaries. Details of the historical data analysis during 2011 is presented in Chapter 3.

Some of the WIM sites are located on Coal Resource Transportation System (CRTS) roads where coal haulers may purchase a permit that will allow for GVW up to 120,000 lb (*2*). This permit is not administered through the oversize/overweight permit system and is not included in this analysis. The sites that are located on CRTS routes are denoted in Table 2-2. These sites are included in the WIM summary and WIM accuracy analysis. Only one of the sites that is used in the analysis to estimate the percentage of overweight trucks is on a CRTS route.

Table 2-2 List of WIM Site and Stations in West Virginia

Site	# Stations	Route	County	Site	# Stations	Route	County
1	4	I-64	Summers	**38**	2	WV 61	Kanawha
2	4	I-77	Kanawha	**39**	4	I-64	Putnam
3*	4	I-77	Kanawha	**40**	2	WV 114	Kanawha
4	4	I 79	Harrison	**41**	2	US 119	Kanawha
5	4	I-79	Lewis	**42***	4	I64 / 77	Kanawha
6	4	I-79	Kanawha	**43***	2	WV 44	Logan
7	2	WV 2	Tyler	**44***	2	WV 94	Boone
8*	4	US 19	Nicholas	**45**	2	WV 7	Wetzel
9	4	US 50	Wood	**46**	2	US 250	Randolph
10*	2	US 60	Greenbrier	**47***	4	I-77	Mercer
11*	4	US 119	Boone	**48***	2	WV 20	Mercer
12	4	US 460	Mercer	**49**	2	US 219	Greenbrier
13	2	WV 152	Wayne	**50**	4	I-81	Berkeley
14	4	WV 33	Lewis	**51***	2	WV 55	Nicholas
15	2	US 35	Mason	**52***	2	US 522	Morgan
16	2	US 52	McDowell	**53**	4	I-68	Monongalia
17*	2	WV 10	Logan	**54**	2	US 50	Mineral
18	2	US 219	Randolph	**55**	4	WV 55	Hardy
19	2	CO 21	Jackson	**56**	4	US 340	Jefferson
20	2	US 220	Grant	**57**	4	WV 2	Ohio
21	2	WV 28	Pendleton	**58**	4	US 22	Brook
22	2	US 19	Braxton	**59**	2	US 33	Lewis
23	2	US 19	Raleigh	**60**	2	WV 92	Barbour
24	2	US 40	Ohio	**61**	2	WV 39	Pocahontas
25	2	US 60	Cabell	**62**	4	I-64	Greenbrier
26	2	I-64	Wayne	**63**	2	CO 79/3	Kanawha
27	2	I-64	Kanawha	**64**	4	US 35	Putnam
28*	2	US 52	Wayne	**65**	0	US 33	Randolph
29	4	I-70	Ohio	**66**	4	WV 9	Berkeley
30*	4	US 119	Logan	**67**	2	WV 5	Wirt
31	4	WV 2	Marshall	**68***	4	WV 10	Logan
32	4	US 50	Harrison	**90**	4	I-70	Ohio
33	2	US 33	Jackson	**91**	4	I-79 NB	Marion
34	2	WV 25	Kanawha	**92**	2	I-79 SB	Marion
35	2	WV 16	Calhoun	**93**	4	I-77 NB	Wood
36*	2	US 60	Kanawha	**94**	2	I-77 SB	Wood
37	2	WV 51	Berkeley				

* Denotes site is located on CRTS route

3. HISTORICAL WIM DATA ANALYSIS

3.1. Data Overview

WIM data used for this research were downloaded from the WVDOT Traffic Server website that is used to archive the WIM data (*3*). Data for the year 2011 were downloaded and imported into an SQL database for this analysis. The database scheme utilized is shown in Appendix B. The systems measure and record many attributes for a vehicle as it crosses the sensors, including time, speed, vehicle length, axle-to-axle spacing, and axle weight. Figure 3-1 shows an example of axle weight and spacing attributes of a vehicle.

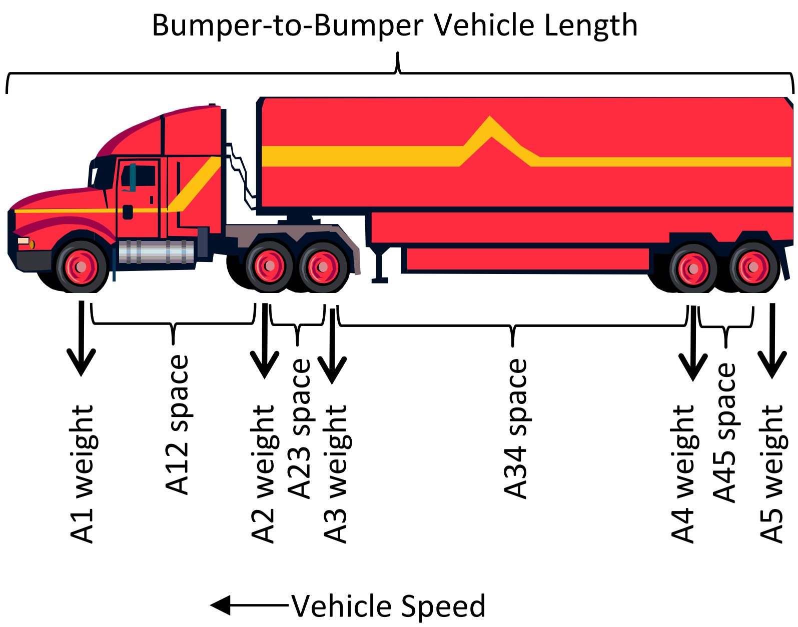


Figure 3-1 Vehicle Attributes Collected by WIM Systems

In the database, each station (lane) is assigned a four-digit identifier. Table 3-1 shows the data availability by site and station during the study period. Among the 73 sites, only 40 had a station reporting data during the study period. The highlighted stations were the ones reporting data. Overall, 109 stations were reporting data and 97 stations were not reporting during the study period in 2011.

Table 3-1 WIM Data Availability by Site and Station (Lane)

Site ID	Station (LOCID)				Site ID	Station (LOCID)			
1	3279	3280	3281	3282	38	3418	3419		
2	3284	3285	3286	3287	39	3421	3422	3423	3424
3	3289	3290	3291	3292	40	3426	3427		
4	3294	3295	3296	3297	41	3429	3430		
5	3299	3300	3301	3302	42	3432	3433	3434	3435
6	3304	3305	3306	3307	43	3437	3438		
7	3309	3310			44	3440	3441		
8	3312	3313	3314	3315	45	3443	3444		
9	3317	3318	3319	3320	46	3446	3447		
10	3322	3323			47	3449	3450	3451	3452
11	3325	3326	3327	3328	48	3454	3455		
12	3330	3331	3332	3333	49	3457	3458		
13	3335	3336			50	3460	3461	3462	3463
14	3338	3339	3340	3341	51	3465	3466		
15	3343	3344			52	3468	3469		
16	3346	3347			53	3471	3472	3473	3474
17	3349	3350			54	3476	3477		
18	3352	3353			55	3479	3480	5589	5590
19	3355	3356			56	3482	3483	3484	3485
20	3358	3359			57	3487	3488	3489	3490
21	3361	3362			58	3492	3493	3494	3495
22	3364	3365			59	3497	3498		
23	5597	5598			60	3500	3501		
24	3368	3369			61	3503	3504		
25	3371	3372			62	3506	3507	3508	3509
26	3374	3375			63	3511	3512		
27	3377	3378			64	3514	3515	3516	3517
28	3380	3381			65				
29	3383	3384	3385	3386	66	3520	3521	3522	3523
30	3388	3389	3390	3391	67	3525	3526		
31	3393	3394	3395	3396	68	3528	3529	3530	3531
32	3398	3399	3400	3401	90	3533	3534	3535	5591
33	3403	3404			91	3537	3538	5592	5593
34	3406	3407			92	3540	3541		
35	3409	3410			93	3543	3544	5594	5595
36	3412	3413			94	3546	3547		
37	3415	3416							

3.1.1. Data Availability by Date

Although a full year of data was downloaded from the WVDOT website, analysis revealed that the only months in which data were available were July and August. A total of 848,925 records were collected from the 109 reporting stations. The availability of data by day for these two months is shown by station in Table 3-2. The highlighted dates indicate data was available and the total column lists the total number of records for that station. There was more than a week of data available for 32 stations and the rest had data for a week or less.

Table 3-2 WIM Data Availability by Day and Station

Sta.	July																														August					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	
3279																																					21240
3280																																					14393
3281																																					1208
3282																																					839
3284																																					17478
3285																																					15474
3286																																					3824
3287																																					993
3299																																					14427
3300																																					19632
3301																																					1757
3302																																					1581
3304																																					20749
3305																																					12123
3306																																					1016
3307																																					848
3312																																					21061
3313																																					9805
3314																																					1071
3315																																					891
3317																																					13943
3318																																					16091
3319																																					2395
3320																																					1786
3322																																					9184
3323																																					10125
3325																																					19444
3326																																					61690
3327																																					1371
3328																																					1407
3330																																					8559
3331																																					7676
3332																																					961
3333																																					661
3335																																					7435
3336																																					8409
3338																																					659
3339																																					422

Sta.	July																															August					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	
3340																																					66
3341																																					112
3343																																					5309
3344																																					4345
3364																																					5214
3365																																					5380
3368																																					4056
3369																																					3676
3372																																					1375
3380																																					7000
3381																																					6910
3383																																					35524
3384																																					40286
3386																																					694
3388																																					3909
3389																																					18785
3390																																					1129
3391																																					717
3398																																					19677
3399																																					29591
3400																																					1639
3401																																					634
3403																																					5198
3404																																					3310
3406																																					2125
3407																																					2377
3409																																					19953
3410																																					19881
3415																																					4637
3416																																					4553
3418																																					2348
3419																																					2368
3422																																					22020
3423																																					4271
3424																																					2851
3426																																					6416
3427																																					3092
3429																																					551
3430																																					1081
3432																																					9497
3433																																					7805
3434																																					1852
3435																																					1461
3437																																					3072
3438																																					2949
3440																																					3177
3441																																					3508
3443																																					964
3444																																					1045
3454																																					862
3455																																					862
3465																																					1801
3466																																					1784
3468																																					19554
3469																																					18828
3471																																					39925

Sta.	July																														August					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	
3472																																					34470
3473																																					5524
3474																																					3363
3476																																					2414
3477																																					2413
3487																																					5849
3488																																					8353
3489																																					994
3490																																					627
3497																																					2046
3498																																					1527
3500																																					505
3501																																					560
3534																																					4440
5591																																					1206

3.1.2. Distribution by Vehicle Classification

Each WIM vehicle record was assigned a vehicle classification based on its axle attributes (i.e., number of axles, spacings, and front axle weight). This assignment was conducted by the WIM equipment in the field using a set of rules programmed in the system. These rules can be customized to suit each state's needs, but it is assumed that the classification rules being used in West Virginia are the WIM vendor's default rules, which are intended to produce the FHWA 13-class scheme depicted in Figure 3-2 (*4*). The FHWA scheme is intended to group similar vehicles based on their type, number of axles and configurations, and number of trailers. Many variations of classification rules and mechanisms exist that are intended to replicate this scheme or other schemes.

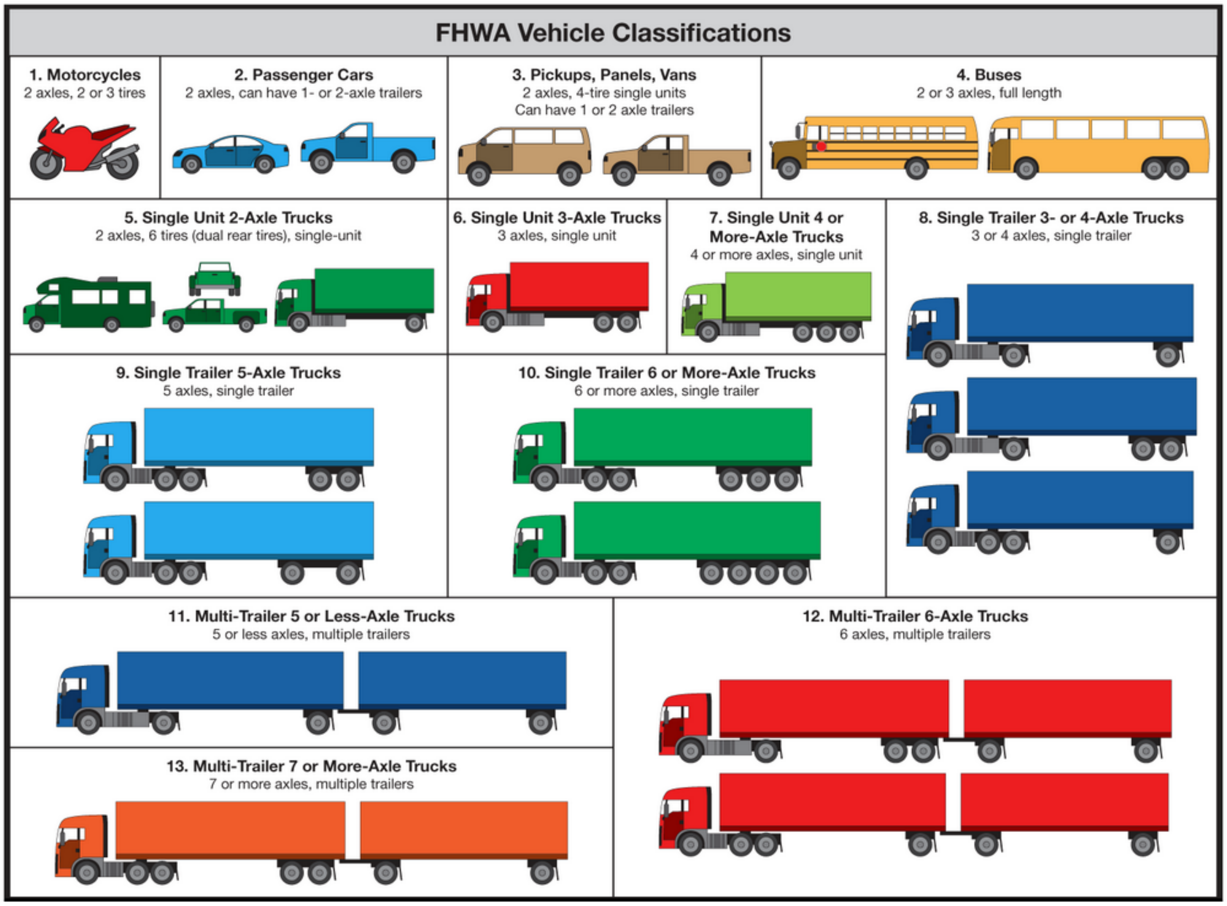


Figure 3-2 FHWA 13-Category Scheme Vehicle Classification (*4*)

The West Virginia WIM vendor's rules classify vehicles with up to 8 axles. These axle-based rules are listed in Appendix C. If a vehicle has more than 8 axles or its axle attributes do not match any of the rules, the vehicle is assigned to Class 14 (unassigned). Class 99 exists to report errors in the WIM system. Figure 3-3 shows percentage distribution of vehicle classes in the study data. Classes 5 and 9 constitute 28.3% and 24.2% of the total vehicle count, respectively. Because most WIM systems are not configured to archive records for Classes 1 to 4, the percentage of these frequently occurring vehicle classes are relatively low.

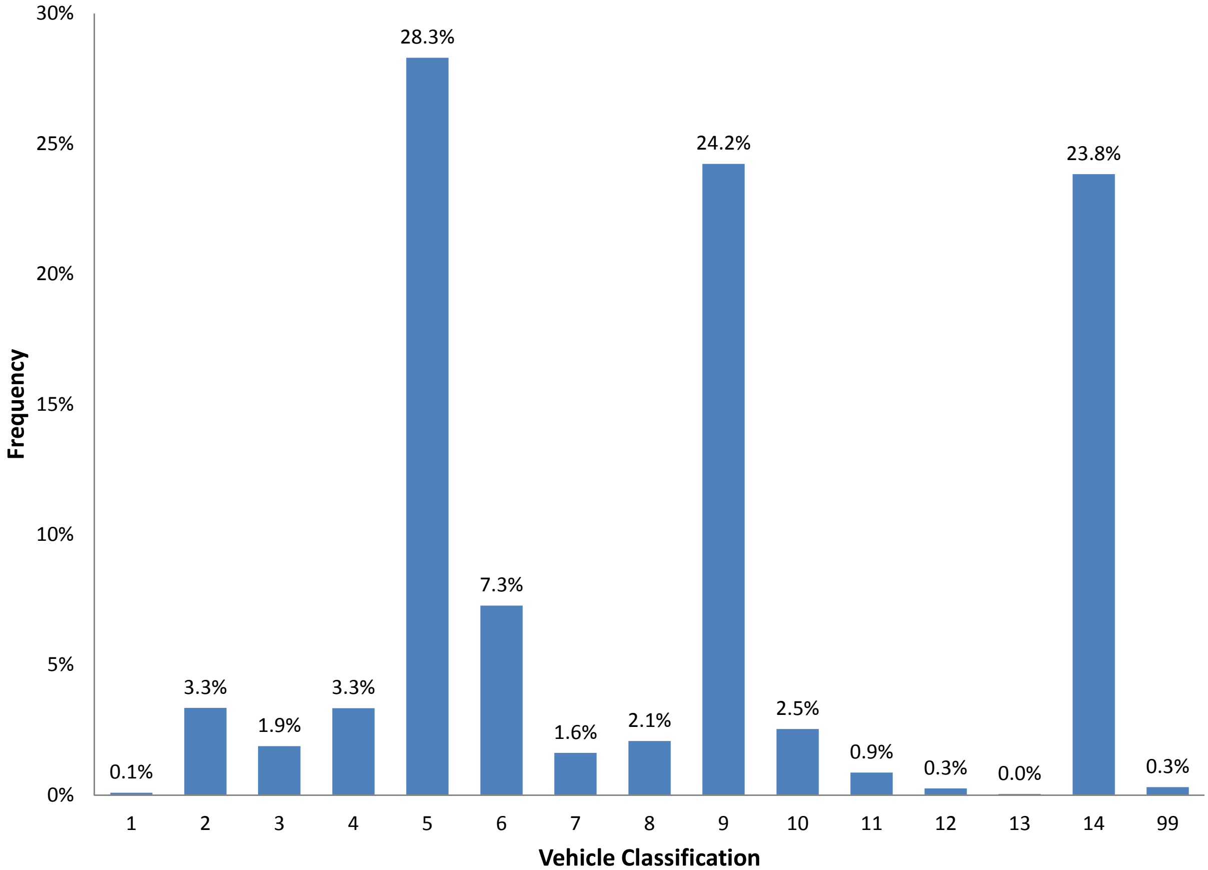


Figure 3-3 Distribution of Vehicle Classification in WV WIM Archive

The classification distribution was further explored at each station as shown in Figure 3-4. It is noted that many stations have relatively high composition of unclassified vehicles (i.e. Class 14), such as station 3279, 3326, 3399, 3471, and 3472. These stations might warrant further inspection in terms of WIM station functionality or calibration accuracy, which can cause mis-classification of vehicles since the measured axle attributes are skewed from the expected attributes. For example, if the axle spacing measurement has a -25% error, all axle spacings will be 25% less than expected and a Class 5 vehicle may be incorrectly assigned to Class 2.

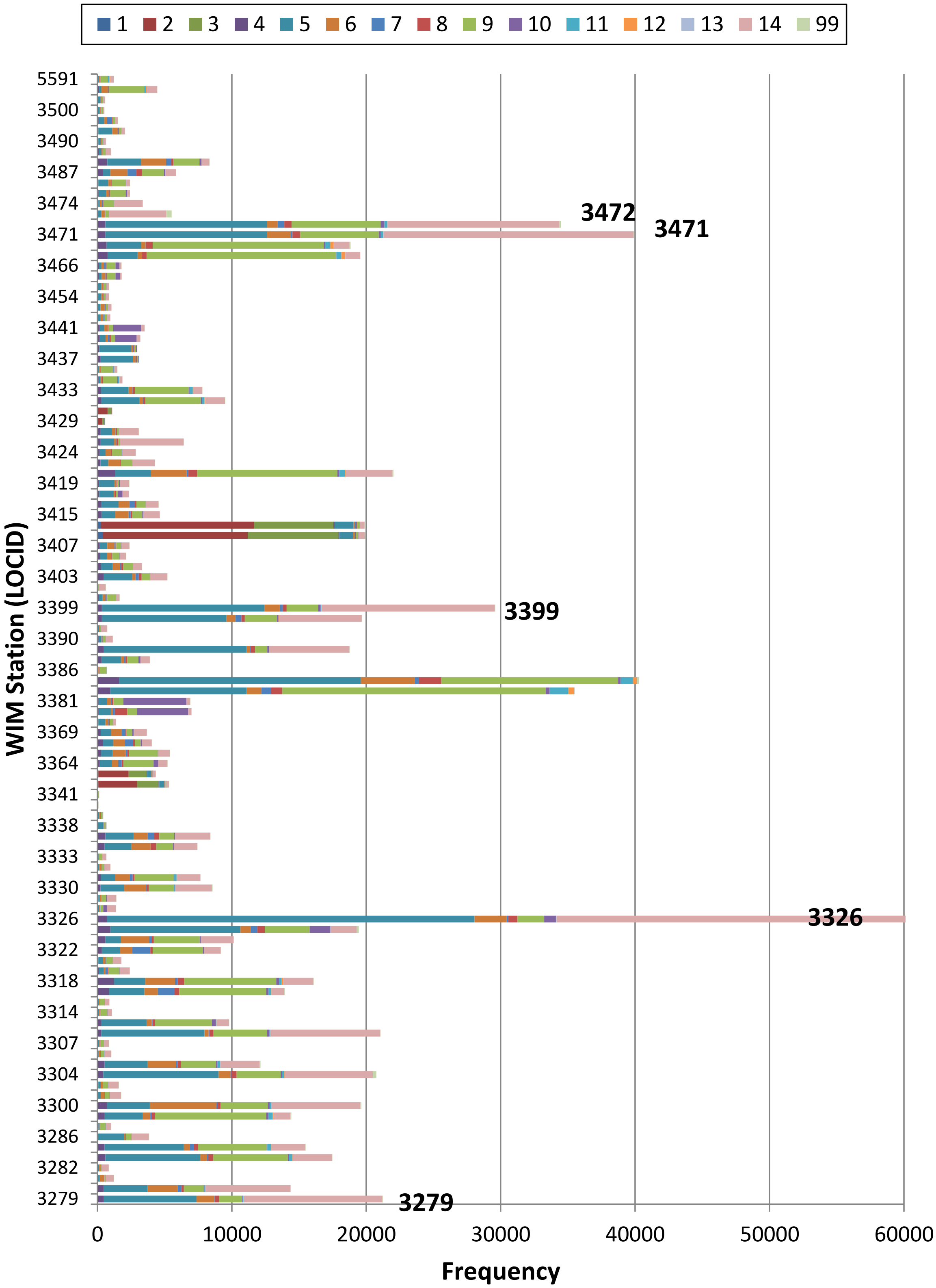


Figure 3-4 Composition of Vehicle Classification by WIM Station

3.1.3. Distribution by Vehicle Pattern

Based on the axle-to-axle spacing attributes, each vehicle is assigned a “Pattern” indicating its axle footprint. This assignment is performed by the WVDOT archive system after the WIM record is imported from the field. The following rules are utilized to determine axle groupings.

- A Single axle is defined as one or more axles within 3.28 feet (1 meter). Thus, if two axles are separated by more than 1 meter, they are in separate axle groups, but if they are 1 meter or less apart, they are in the same axle group and are counted as a single axle.
- A Tandem axle group is defined as two or more axles spanning more than 3.28 feet (1 meter) but no more than 8.00 feet (2.44 meters).
- A Triple (Tridem) axle group is defined as three or more axles spanning more than 8.00 feet (2.44) meters but no more than 9.84 feet (3 meters).
- A Quad axle group is defined as four or more axles spanning more than 9.84 feet (3 meters) but no more than 12.47 feet (3.8 meters).

For example, Pattern “1-2-2” represents a common Class 9 truck with a single-axle in front and two sets of tandem axle groups (see Figure 3-1). The summation of the numbers in a pattern represents the total number of axles. Table 3-3 shows a count of the patterns that exist within each vehicle class (Classes 1 to 13). For instance, there are eight unique patterns in Class 9, and the majority of vehicles are associated with Pattern “1-2-2” and “1-2-1-1”.

Table 3-3 Counts (#) by Vehicle Class and Pattern (Ptn)

Veh Class	1		2		3		4		5	
	#	Ptn	#	Ptn	#	Ptn	#	Ptn	#	Ptn
	401	"1"	47	"0"	15,241	"1-1"	18,895	"1-1"	216,243	"1-1"
	399	"2"	214	"1"	364	"1-1-1"	9,416	"1-2"	836	"1-1-1"
	3	"3"	28,006	"1-1"	1	"1-1-1-1"			1,166	"1-1-1-1"
			112	"1-1-1"	349	"1-1-2"			20,847	"1-1-2"
			9	"1-1-2"	2	"1-1-3"			1,065	"1-1-3"
			49	"2"					113	"1-2"
				"2-1"						
Total		**803**		**28,437**		**15,957**		**28,311**		**240,270**

Veh Class	6		7		8		9	
	#	Ptn	#	Ptn	#	Ptn	#	Ptn
	61,750	"1-2"	4	"1-1-1-1"	8,766	"1-1-1"	23	"1-1-1-1-1"
			3	"1-1-1-1-1"	69	"1-1-1-1"	3	"1-1-1-2"
			138	"1-1-2"	4,698	"1-1-2"	1	"1-1-2-1"
			11	"1-1-3"	4,059	"1-2-1"	545	"1-1-3"
			14	"1-2-1"	2	"1-3"	34,402	"1-2-1-1"
			42	"1-2-1-1"	2	"2-1"	170,710	"1-2-2"
			36	"1-2-2"	10	"2-2"	1	"1-3-1"
			9,794	"1-3"	1	"3-1"	2	"2-3"
			38	"1-3-1"				
			3,711	"1-4"				
Total		**61,750**		**13,791**		**17,607**		**205,687**

Veh Class	10		11		12		13	
	#	Ptn	#	Ptn	#	Ptn	#	Ptn
	4	"1-2-1-1-1"	7,321	"1-1-1-1-1"	2199	"1-2-1-1-1"	1	"1-2-1-1-1-1"
	18	"1-2-1-2"	3	"1-1-2-1"			6	"1-2-1-3"
	1	"1-2-1-3"					4	"1-2-2-1-1"
	20	"1-2-2-1"					2	"1-2-2-1-2"
	2	"1-2-2-2"					2	"1-2-2-2"
	20,263	"1-2-3"					1	"1-2-3-2"
	303	"1-2-4"					18	"1-2-5"
	3	"1-3-1-1"					1	"1-2-6"
	795	"1-3-2"					3	"1-3-1-2"
	2	"1-3-3"					328	"1-3-3"
	57	"1-3-4"					5	"1-3-5"
	1	"1-4-2"					3	"1-4-2"
	36	"1-6"						
Total		**21,505**		**7,324**		**2,199**		**374**

3.1.4. Gross Vehicle Weight (GVW) Distribution

Each vehicle's gross vehicle weight (GVW) is calculated by the WIM system by summing the individual axle weights. Figure 3-5 shows the GVW distributions within each vehicle class. For example, the majority of Class 5 vehicles are in the 20,000-40,000 lb range. The vehicle classes that include a trailer (8 and above) tend to experience higher GVW. The "unloaded" weight of these vehicles tends to be around 30,000-lb. The peak of the "loaded" vehicles tend to be around 80,000-lb, the legal limit so that companies can maximize their payload. However, many vehicles are partially loaded or are fully loaded with material that is not heavy, which results in the observations between the loaded and unloaded values. The Class 9 vehicles dominate the higher bins since they are the most common vehicle type. This plot alone suggests that there are a significant number of overweight trucks (i.e. observations above 80,000-lb), but an analysis of the WIM weight accuracy has not been verified and the trucks that are overweight could have a valid permit or be on a CRTS route.

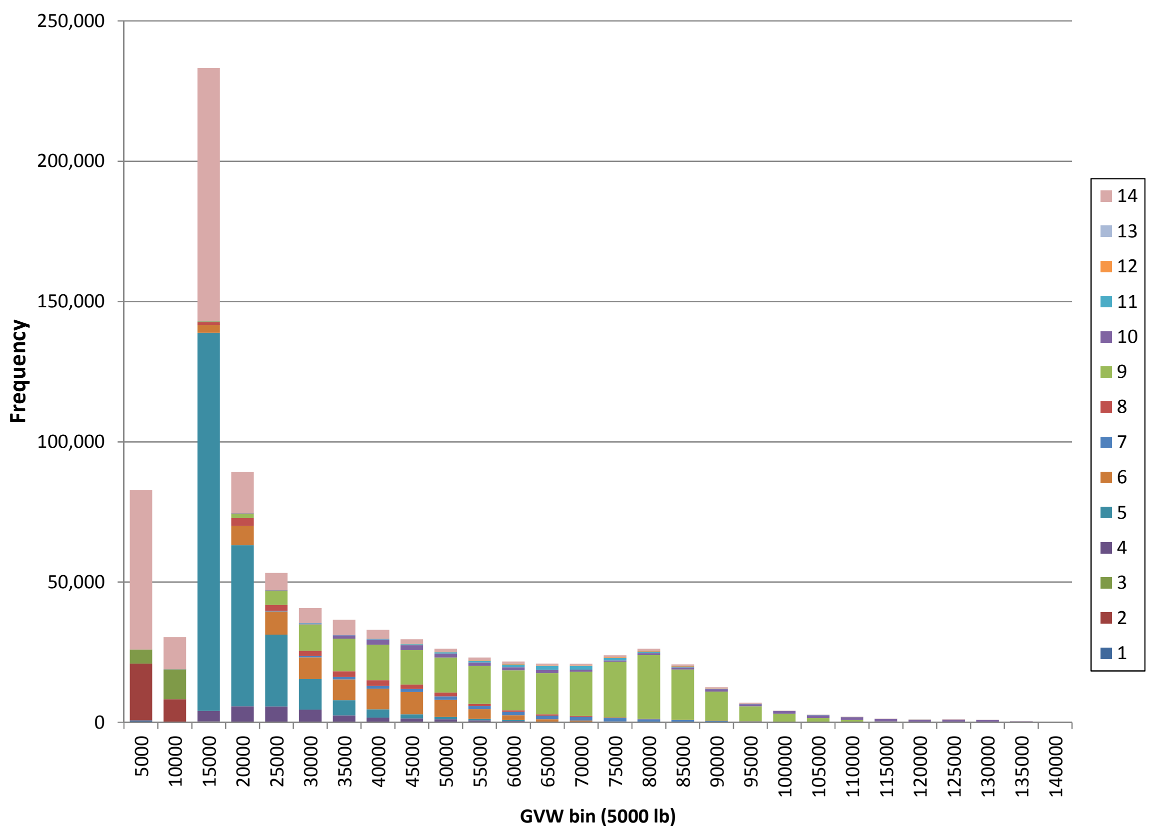


Figure 3-5 GVW Distribution by Vehicle Class

GVW distributions also vary from station to station. As depicted in Figure 3-6, various GVW group compositions were calculated and scaled to a hundred percent for vehicles in Class 9 and above, which are the most common commercial vehicle classes. Some stations reported a higher percentage of heavy vehicles while other sites reported a higher percentage of light vehicles.

It is interesting to observe that some WIM sites experience different patterns in each direction. For example Site 28 is near a coal transfer location, with vehicles bound for that destination being loaded traveling northbound and empty on the return trip southbound. In West Virginia, coal is primarily hauled with a 3-axle tractor and 3-axle trailer, which is a Class 10. The GVW distributions for all vehicles in each direction of travel at this Site are depicted in Figure 3-7. The Class 10 GVW in the northbound direction is in the range of 98,000-138,000 lb, while the GVW for Class 10 in the southbound direction is 32,000-56,000 lb. While these WIM stations could have accuracy problems, the relative difference clearly depicts the shift between loaded and unloaded for Class 10 vehicles, while the distributions for other classes is similar in each direction.

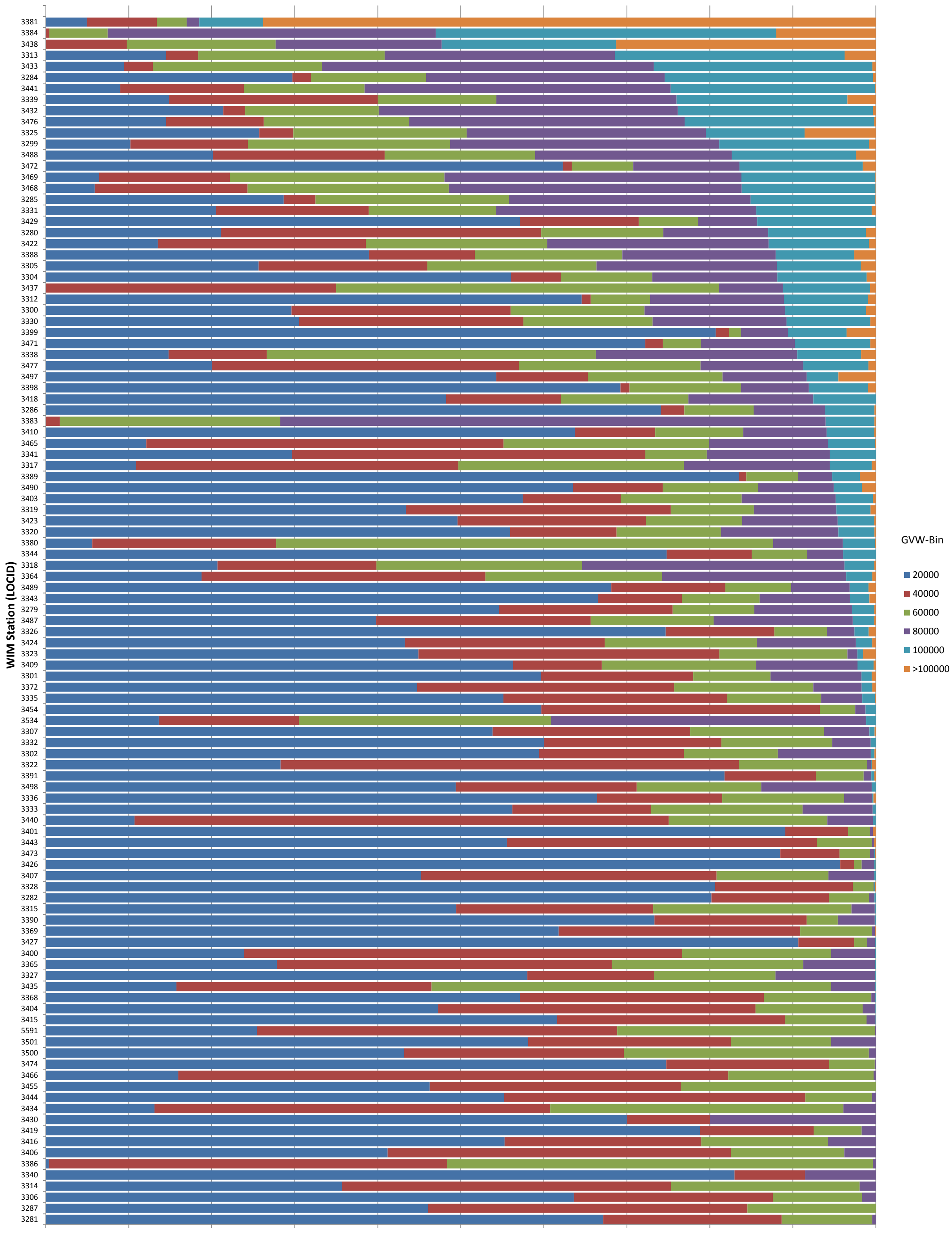
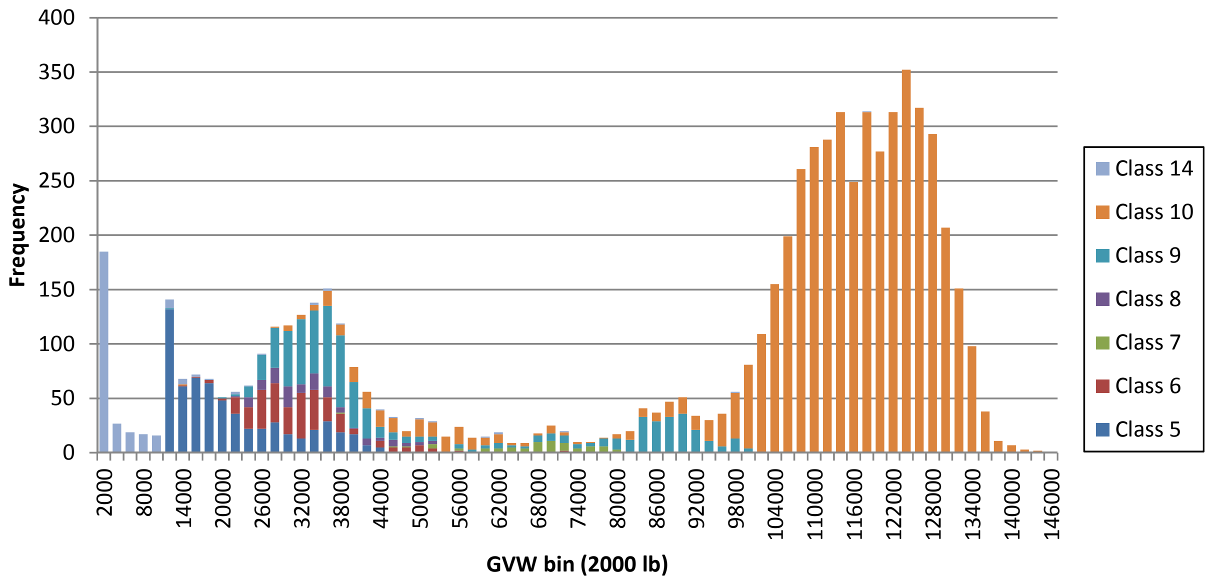
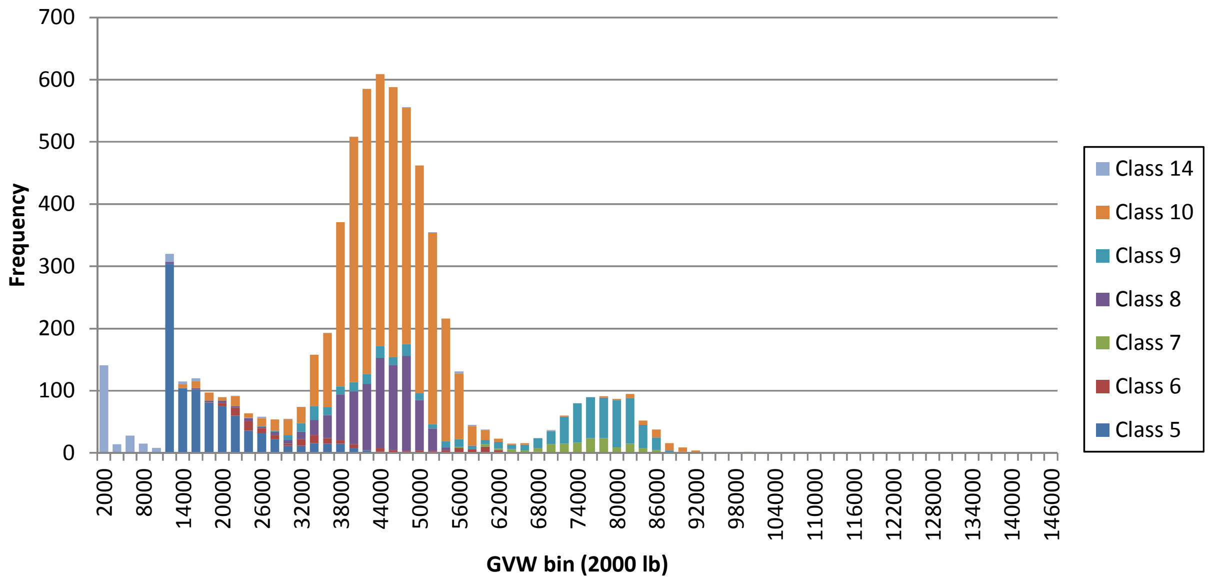


Figure 3-6 Distribution of Class 9 GVW Composition (20,000-lb bins) by Station



(a) Northbound



(b) Southbound

Figure 3-7 GVW Distributions by Direction of Travel at Site 28

3.2. <u>WV WIM Data Accuracy Assessment</u>

WIM data accuracy, particularly the weight, is always a concern due to the difficulty of weighing vehicles in motion. Weights for an individual vehicle can be affected by dynamics induced by pavement roughness, lane positioning, temperature effects on the sensor, and sensor fatigue.

Regular calibration schedules and frequent monitoring are necessary to maintain accuracy. Most monitoring can be performed by analyzing various metrics in the archived WIM data. In this section, the West Virginia WIM accuracy is assessed. The accuracy of weights from many stations appears to be suspect. Therefore, additional WIM data from a national study (*5*) were obtained to use as a basis for evaluating and tuning the West Virginia WIM data.

3.2.1. Vehicle Classification Scheme

In order to facilitate the analysis comparing the WIM data to the permit data, a vehicle classification needed to be assigned to the vehicles in the permit database based on the axle parameters entered by the applicant. A classification is already generated by the WIM system, but this is not a component of the permit system. Ideally, the WIM classification scheme and permit classification scheme would be the same. There are numerous vehicle classification schemes used by various agencies. The most recent scheme that is widely applied was developed by the Long Term Pavement Performance (LTPP) program (*6*). The LTPP scheme is superior to many schemes because it utilizes front axle weight (FAW) and gross vehicle weight (GVW), in addition to number of axles and axle spacings. It can also accommodate up to eleven axles, which is beneficial since oversize/overweight vehicles tend to have many axles. The rules for the LTPP scheme are provided in Appendix C. The WIM vendor's rules used in West Virginia only went up to eight axles with limited weight attributes. For comparison, these rules are provided in Appendix D.

In this study, a set of SQL procedures were developed to apply the LTPP rules and reclassify the WIM data. Figure 3-8 shows the distributions of vehicle classes using the WIM vendor and LTPP rules for all records included in this analysis. There are very few vehicles in Classes 1-4 in the database because the majority of the WIM sites do not archive per-vehicle records for motorcycles, passenger cars, and light-duty trucks. It is interesting that the percentage of Class 5 vehicles was higher than or equal to the Class 9 percentage. This may reflect the rural nature of many of the WIM sites that experience a lot of dump trucks, buses, and other 2-axle vehicles and not many combination trucks. Class 9 is typically the most common truck class in the United States, so it is not surprising that this class is also high.

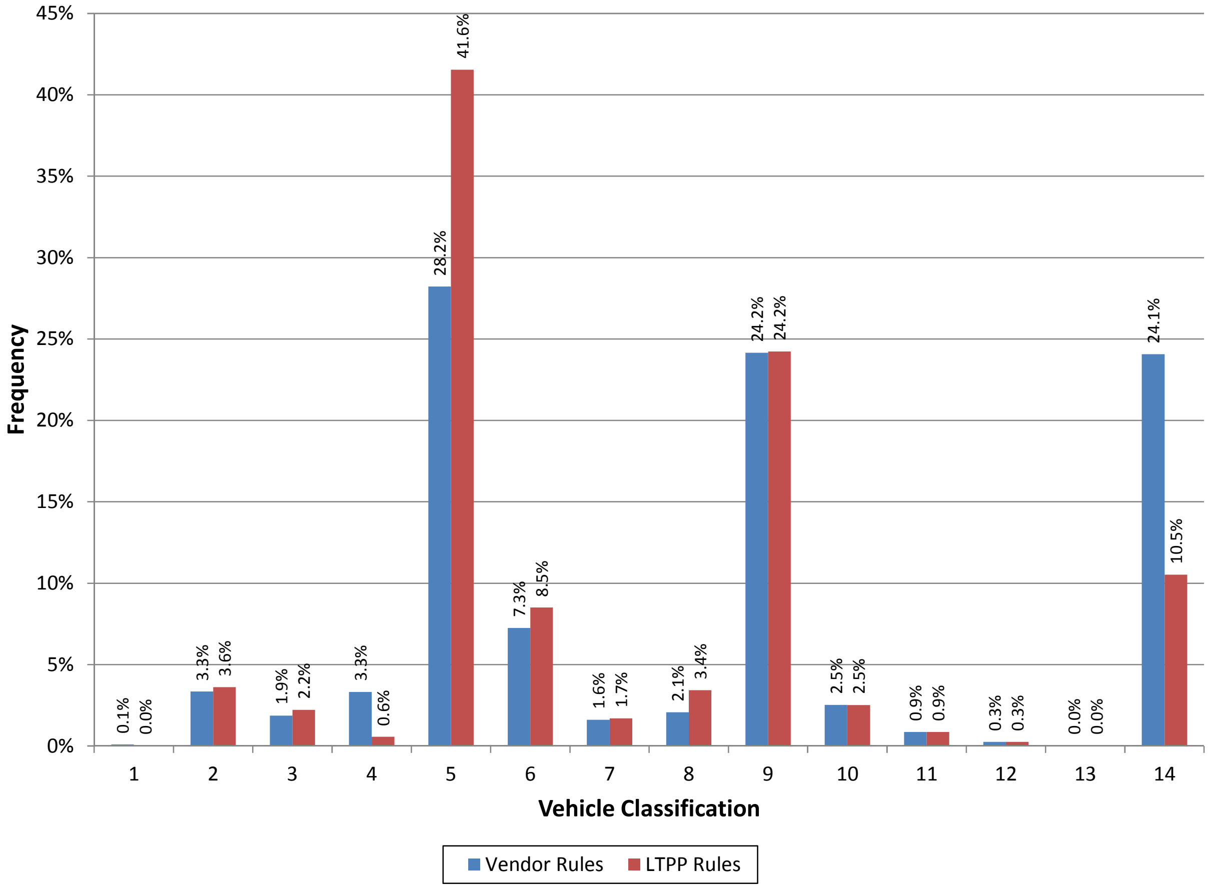
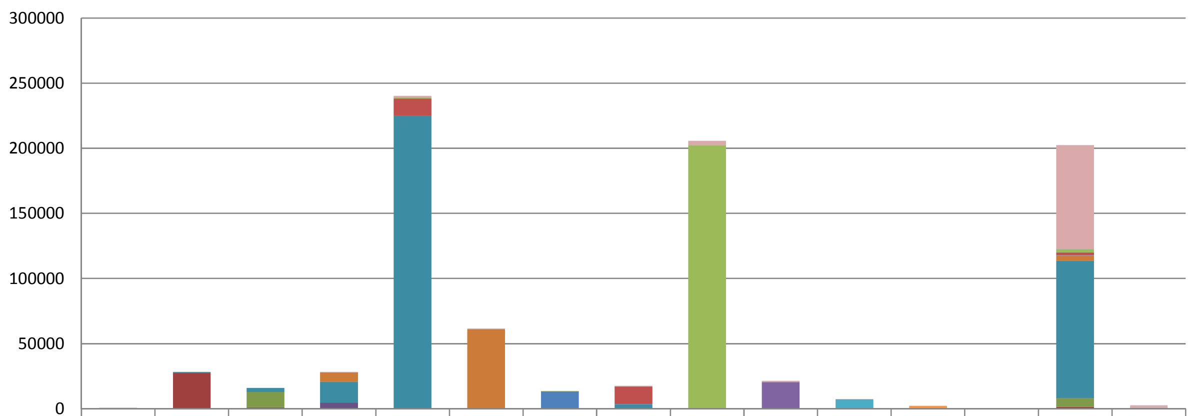


Figure 3-8 Vehicle Classification Distribution by Vendor Rules and LTPP Rules

The largest discrepancies between the two sets of rules appear in Class 5 and Class 14 (unclassified). The LTPP rules were able to classify approximately 14% more vehicles than the vendor rules. However, there were shifts occurring in all vehicle classes. Figure 3-9 provides a comparison of the vehicle classification before and after the reclassification. The x-axis in the chart and columns of the table correspond to the vendor rules before reclassification and the bar colors in the chart and rows of the table correspond to the LTPP rules after reclassification. The vendor Class 14 vehicles were reclassified into Classes 2-9 and 11, while 79,733 remained unclassified. The number of unclassified vehicles isn't necessarily alarming since many oversize and overweight loads are hauled by tractor-trailer combinations that are uncommon and do not conform to conventional axle configurations. These can also be a result of sensor accuracy problems. It is equally interesting to point out that a number of vehicles classified as 1-13 by the vendor rules were not able to be classified with the LTPP rules.

One of the largest shifts was from vendor Class 14 to LTPP Class 5, 105,530 vehicles. This is most likely attributed to the minimum threshold for the spacing between axles 1 and 2. The vendor rules have a minimum threshold of 10 feet and the LTPP rules have a minimum threshold of 6 feet, which is less restrictive.

The analysis and discussion hereafter will be based on the LTTP classification assignments.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	99
14	484	279	17	334	1243	615	243	432	3297	1039	18	42	9	79733	1519
13										37			28		235
12												2157			23
11											7306			1	
10										20429			337		555
9					763		70		202386					2458	
8					13282			13563						2254	
7							13476	119						462	271
6				7352	54	61135								3641	
5	1	504	3059	15843	224716		1	3076	4					105530	
4				4782										11	
3			11810		212			59						6785	
2	110	27655	1071				1	358						1431	
1	208														

Figure 3-9 Redistribution of Vehicle Classes from Vendor (Column) to LTPP Class (Row)

3.2.2. <u>Evaluation of Class 9 Attributes</u>

Generally, Class 9 trucks with pattern “1-2-2” and “1-2-1-1” (shown Figure 3-10) can be employed for inspecting WIM measurement accuracy since these two types of vehicle have a common non-varying tractor type, which is desirable for calibration targets that rely on population averages. Previous studies have shown that the front axle weight (FAW) and drive tandem axle spacing (Axle 2 to Axle 3) can be used to assess both weight measurement and axle spacing measurement accuracies (see *7* for a summary). The average FAW for a population of Class 9 vehicles should fall within the range of 9,000 to 11,000 lbs and the drive tandem spacing within 4.25 to 4.58 feet.

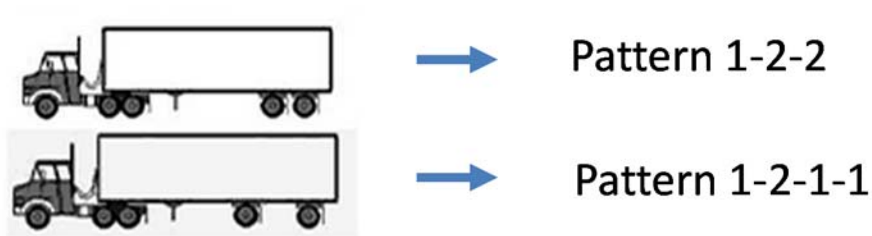


Figure 3-10 Desired Class 9 Patterns for Accuracy Assessment

Figure 3-11 and Figure 3-12 depict these distributions for each WIM station (lane) reporting data. The raw data from these figures is provided in Appendix E. Approximately 42% of the lanes had an average FAW outside the expected range and 12% had spacing measurements outside the expected range.

If the average FAW is significantly lower than 9,000 lbs or significantly higher than 12,000 lbs, this clearly indicates a sensor accuracy problem. Based on Figure 3-11, the sites that are too high include 3384 (19,594 lb), 3399 (16,280 lb), 3389 (15902 lb), 3326 (14,814 lb), 3344 (12,479 lb), 3497 (12,382 lb), 3343 (12,186 lb), and 3423 (12,170 lb). Average FAW in the 11,000-12,000-lb range warrants further investigation before assuming a sensor accuracy problem.

Sites with an average drive tandem axle spacing significantly higher or lower than the expected range most likely indicates a problem with calibration or a problem with one of the axle detection sensors. These sites include 3403 (4.79 feet), 3430 (4.04 feet), 3280 (4.02 feet), 3279 (4.02 feet), and 3282 (3.96 feet)

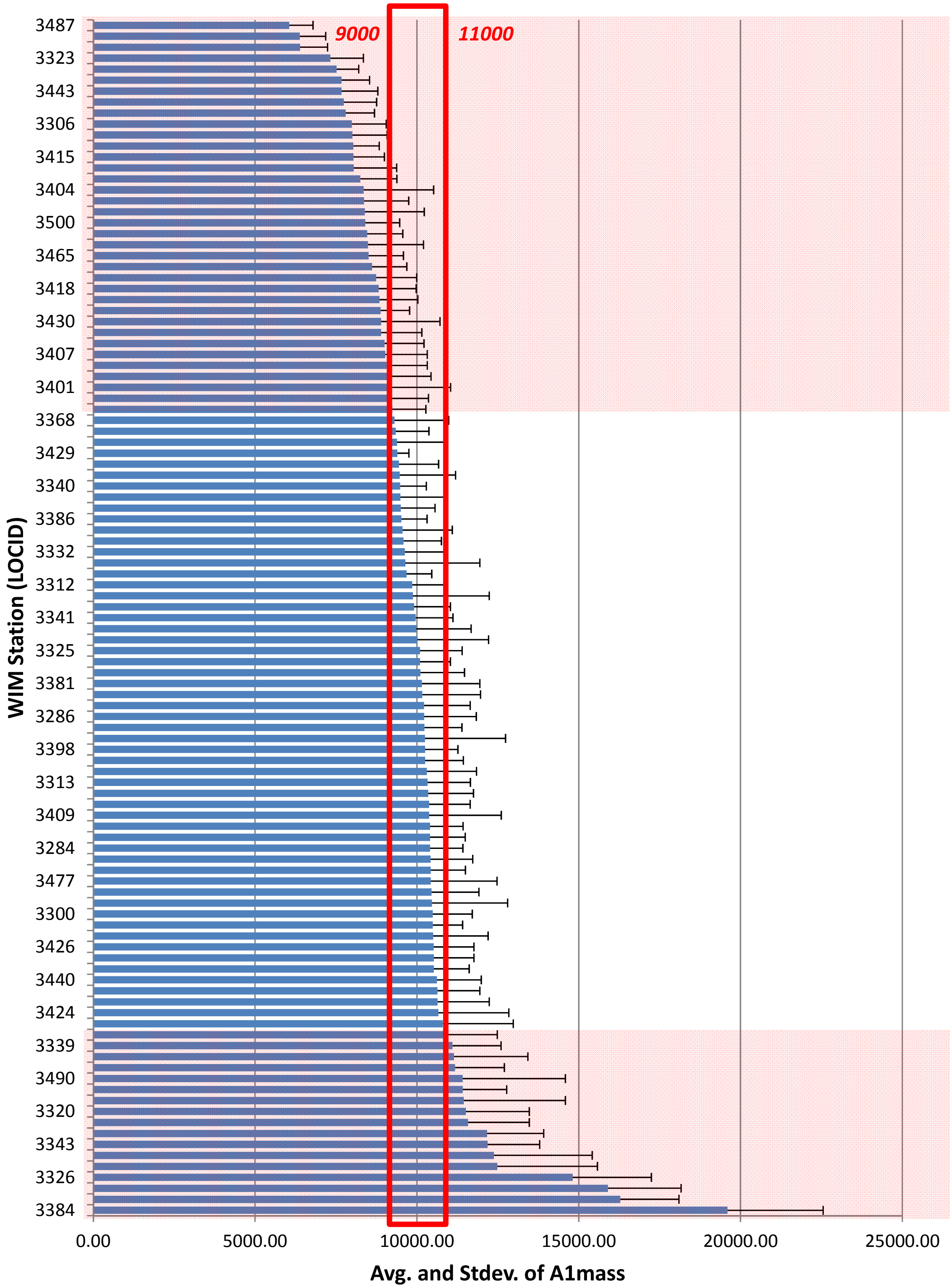


Figure 3-11 Class 9 Average Front Axle Weight (FAW) by WIM Station (WV)

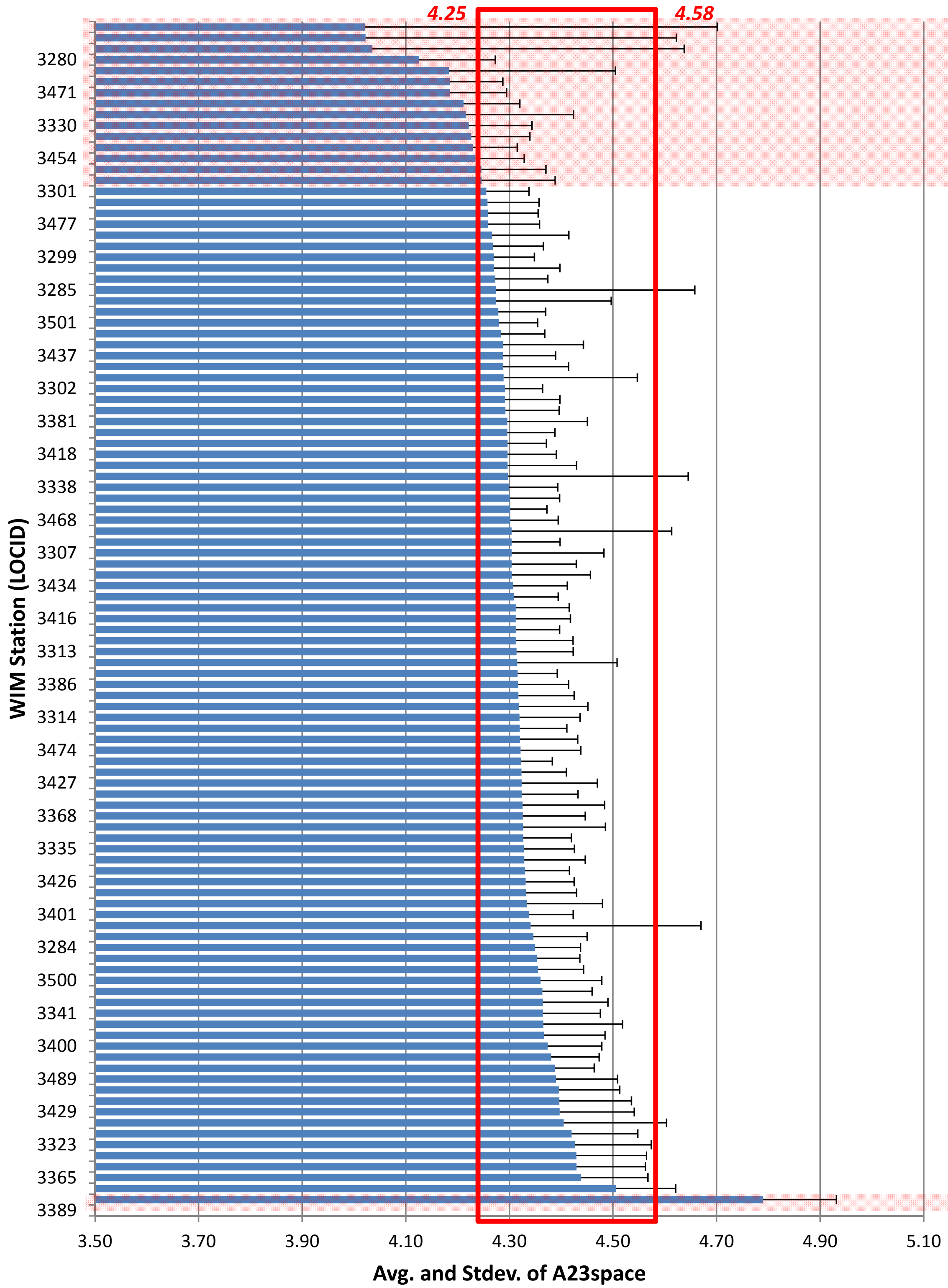


Figure 3-12 Class 9 Average Drive Tandem Spacing by WIM Station (WV)

Additionally, Southgate (*8*) further proposed a metric to inspect WIM sensor measurement accuracy. In this method, the ratio of the FAW and spacing of axles 1 and 2 are plotted against the axle 1-2 spacing for the Class 9 trucks. He applied log-log regression models in the form of $\text{Log}_{10}(y) = a + b^* \log_{10}(x)$, where y = (FAW/A12space) and x = (A12space), to fit the plots and calibrate the parameters (coefficients). He also proposed regression boundaries using tractor manufacturers' specifications for the minimum boundary and the 12,000-lb legal limit for steering axles (in most states). Observations outside these boundaries are considered to have questionable accuracy. This relationship is based on the assumption that the weight on the front axle weight will increase as the length of the tractor (as indicated by the distance between the first two axles) decreases.

In Figure 3-13, the (FAW/Axle 1-2 space) vs. (Axle 1-2 space) were plotted using the West Virginia data with the upper and lower boundaries prescribed by Southgate. Each color represents observations from different WIM stations. In the figure, there are groups of observations from at least two WIM stations that are far above the upper boundary. Further investigation shows that these two stations are associated station 3384 (blue) and station 3399 (green). These two stations also had FAW and Axle 2-3 spacing averages outside the target ranges discussed previously, and 3399 had a high frequency of Class 14 vehicles (based on vendor rules).

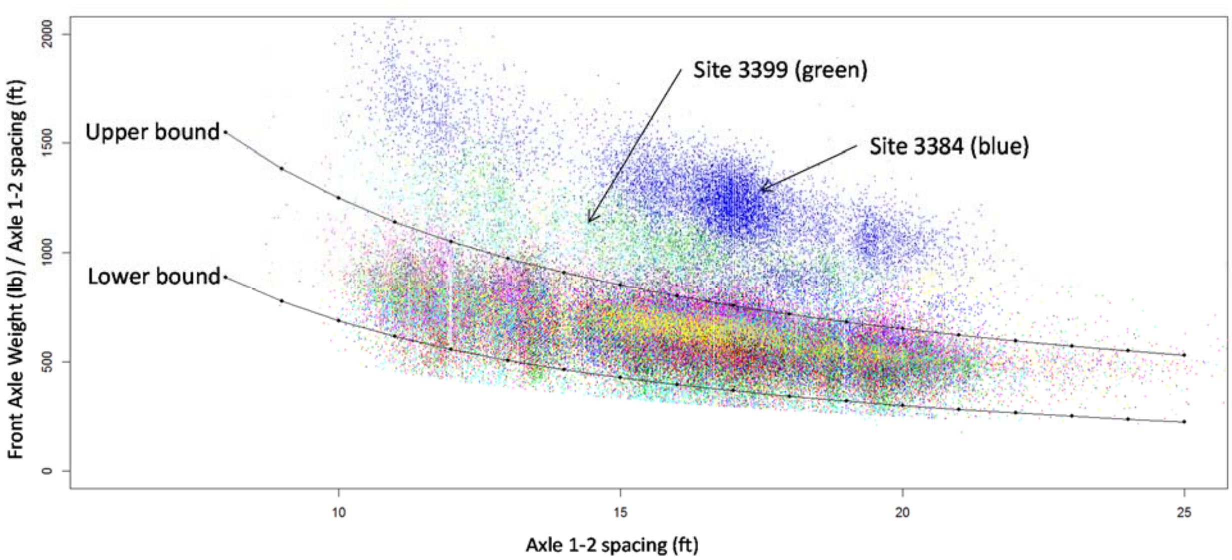


Figure 3-13 Front Axle Weight and Axle 1-2 Spacing Relationships for WV Sites

Another accuracy assessment check is based on the examination of GVW distributions at each site. Previous research has suggested that the unloaded peak for Class 9 vehicles should occur in the 28,000-32,000-lb range and the loaded peak should occur in the 70,000-80,000-lb range (*9*). Figure 3-14 illustrates the GVW distribution for all WIM stations reporting data, with each bar color corresponding to a different site. It is difficult to assess individual sites with this chart, but it provides an overall view of the distributions. However, station 3384, which had the highest average FAW, is noticeably higher than the rest of the stations, with very few observations in the unloaded range and many observations in the overweight range.

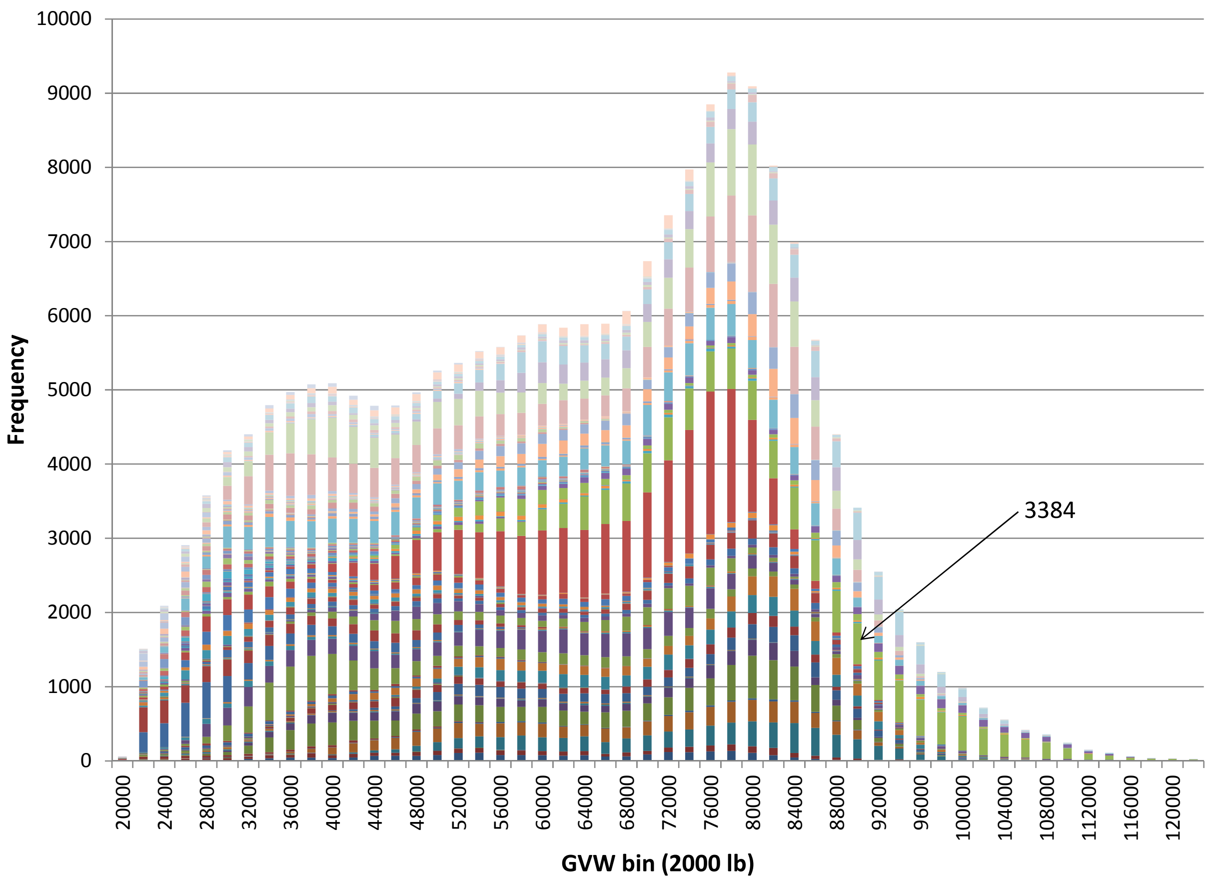


Figure 3-14 Class 9 GVW Distribution by WIM Station (WV)

3.3. National WIM Data Accuracy Assessment

In order to benchmark the accuracy of the West Virginia WIM data, data from the Long Term Pavement Performance (LTPP) program was analyzed. The specific data obtained was collected as part of a Transportation Pooled Fund (TPF) study, which was a multi-year effort to collect "research quality" WIM data at multiple locations to be utilized by the LTPP program and the development of the mechanistic-empirical pavement design guide (MEPDG). This data is considered to be of high quality because of the calibration procedures utilized and the daily monitoring to maintain accuracy. Per-vehicle records were obtained from 19 WIM sites covering 2005 to 2012.

The LTPP classification rules were already applied to the LTPP data, which allowed a direct comparison to the reclassified West Virginia data. Similar to the West Virginia data, only Class 9 trucks associated with either pattern "1-2-2" or "1-2-1-1" were analyzed. Initially, the data were analyzed by site and year. A total of 46,069,847 Class 9 truck records from 19 stations across 17 participating states were included and are subsequently referred as the "national data" (ND).

Similar accuracy metrics as described in the previous section were first inspected for the national data. Figure 3-15 lists the average FAW by site and year. Approximately 57% of the sites had a front axle weight inside the expected range of 9,000-11,000 lbs. Figure 3-16 lists the average drive tandem axle spacing by site and year. Approximately 97% of the sites had a drive tandem axle spacing inside the expected range of 4.25-4.58 feet. The raw data from these figures is provided in Appendix F.

It isn't surprising that the drive tandem axle spacing data is within the expected range, as those are based on truck characteristics that change very little over time and the actual calibration of this parameter is relatively straightforward (measuring the distance between axle detection sensors). The distribution of average FAW is a bit more interesting. The initial research that indicated the expected range of front axle weight values was completed in the early 1980s and has been verified by other studies (*9*). However, most agencies use these prescribed ranges without much question. The analysis of this LTPP data suggests that the average FAW are increasing above levels previously observed. Front axle weights for individual vehicles can be affected by aerodynamics (down force on front of vehicle due to hood design), tractor length (evidenced by axle 1-2 spacing), pavement roughness, kingpin placement (shifts more trailer load to front of the vehicle), and trailer weight. Perhaps this increase is attributed to one of these factors or a combination of factors, but it is evident that front axle weights are, on average, higher now than they were 20+ years ago.

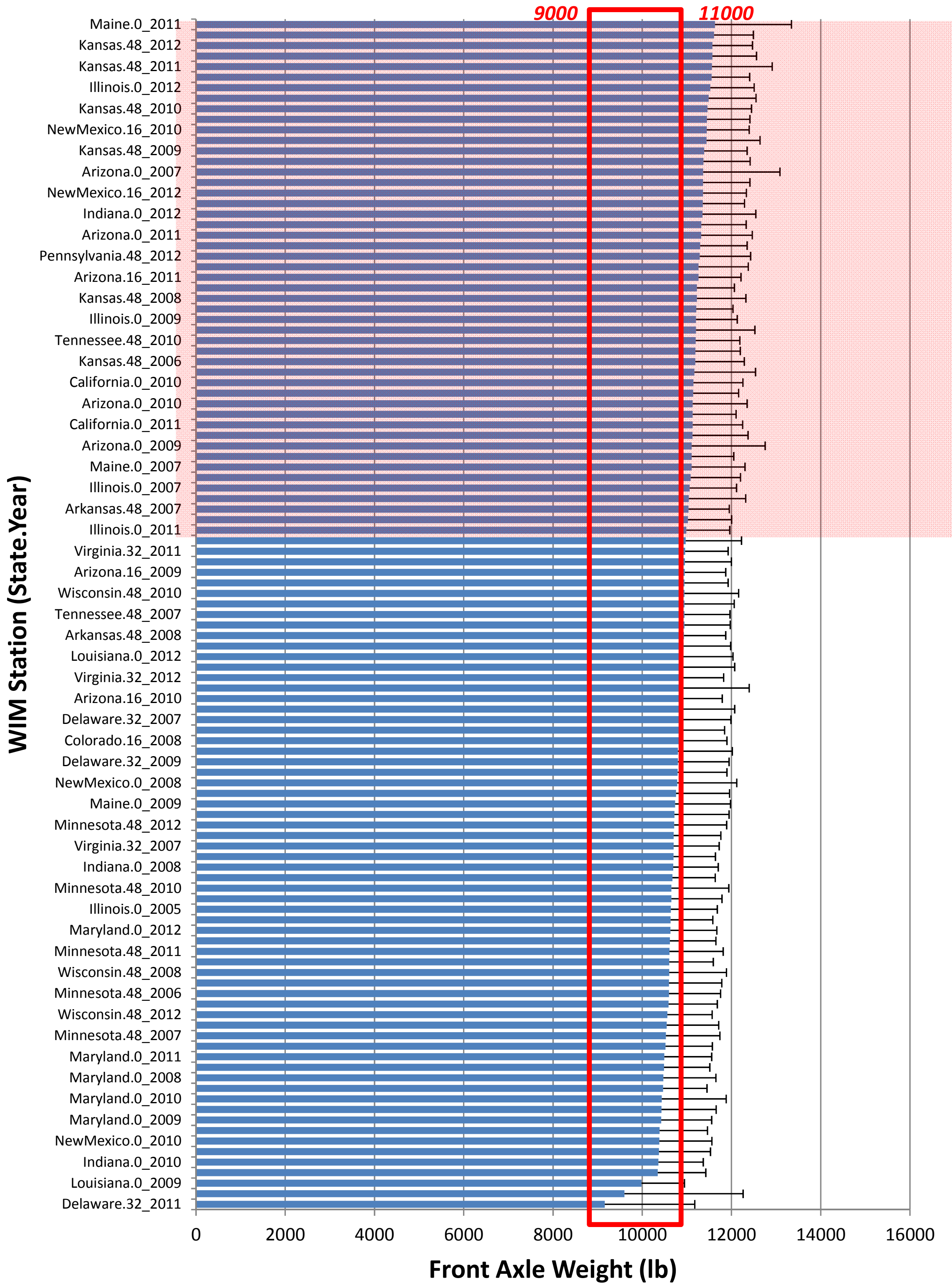


Figure 3-15 Class 9 Average Front Axle Weight (FAW) by WIM Station (National)

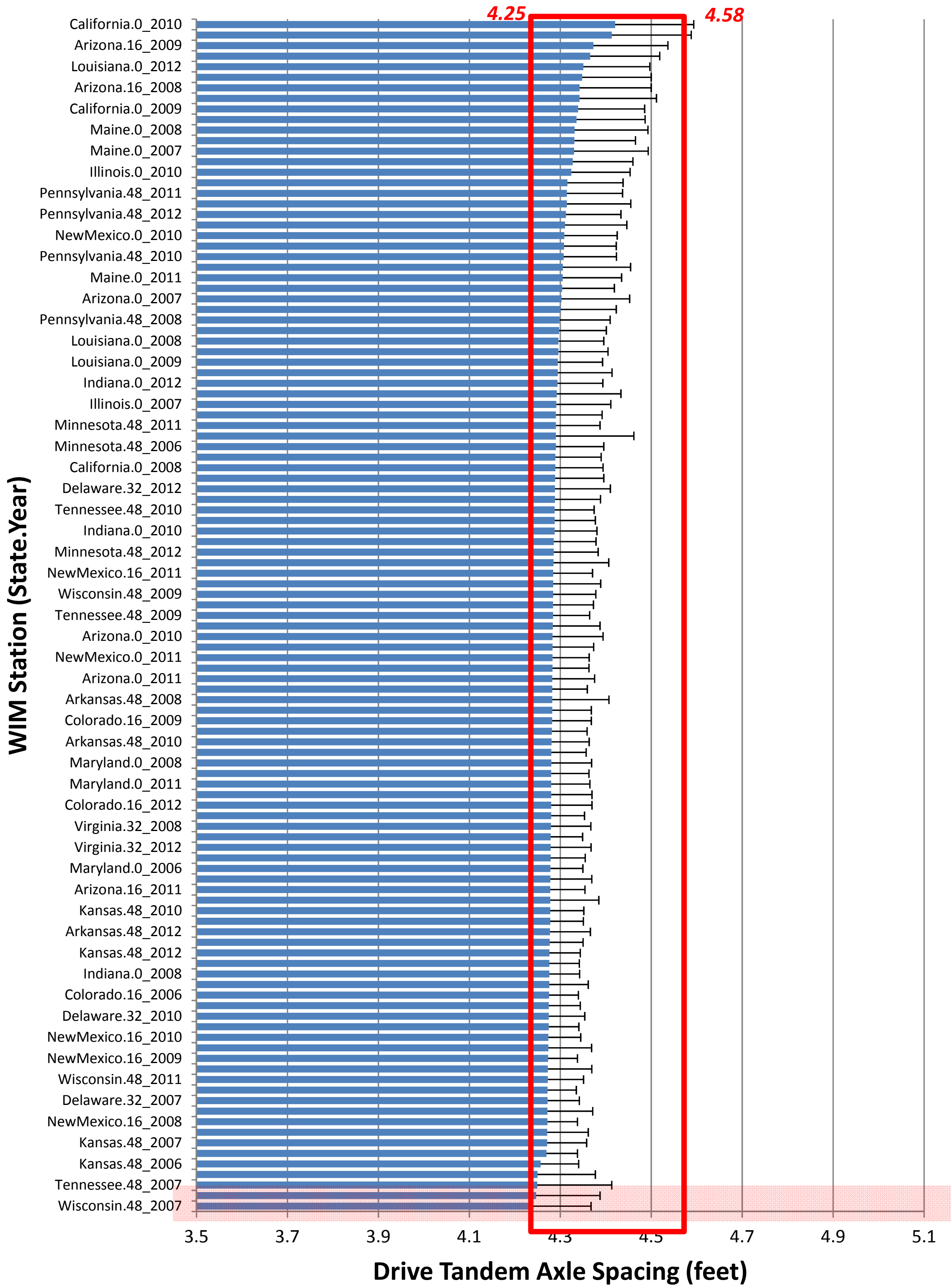


Figure 3-16 Class 9 Average Drive Tandem Spacing by WIM Station (National)

Figure 3-17 summarizes the average FAW and drive tandem axle spacing for both the West Virginia stations and the national data stations (by year). There are certainly more observations in the national data compared to the West Virginia data, which should decrease the variations. However, the average values should still be consistent for well calibrated sensors. The variation of the West Virginia data is clearly higher than the national data.

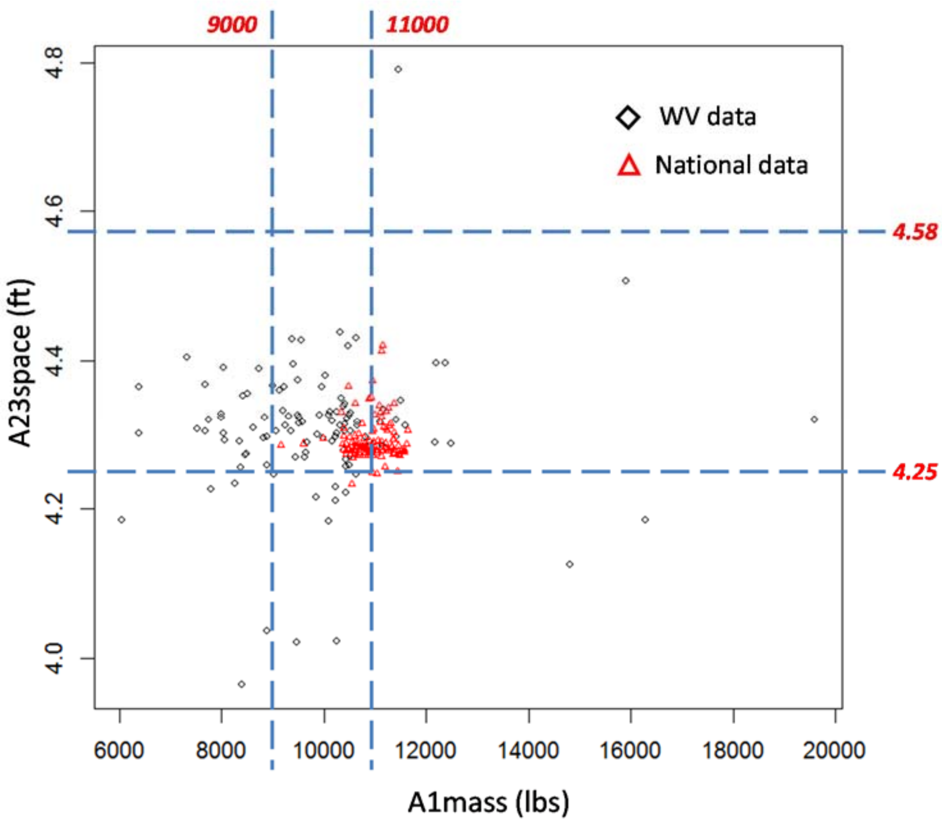
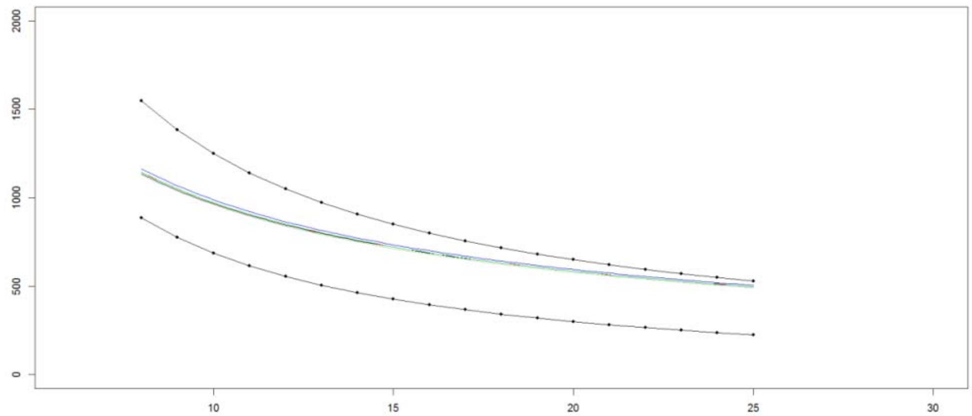
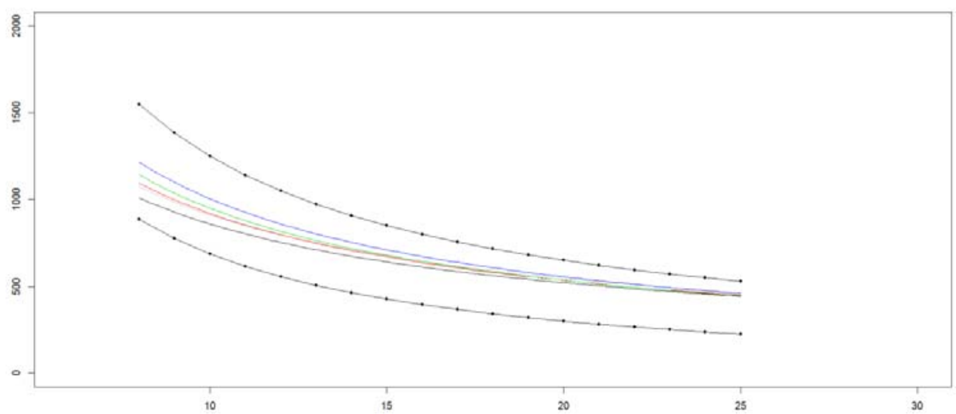


Figure 3-17 Summary of FAW and Drive Tandem Axle Spacing Values

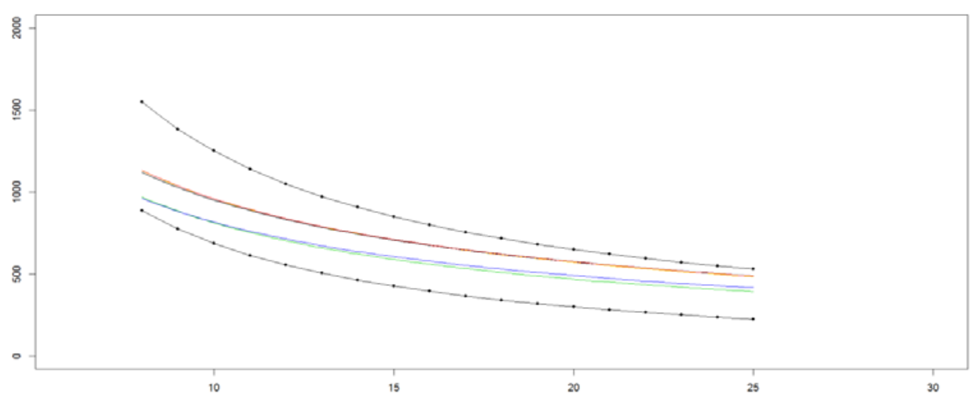
The log-log regression estimates of (FAW/A12space) vs. (A12space) were also evaluated for the national data. For this purpose, regression models for each sample (composed of observations from a state within a year) were plotted. By visual inspection, these plots can be classified into three categories as presented in Figure 3-18. The first category as shown in Figure 3-18a demonstrates a pattern where regression lines are consistent from year-to-year. Data pertaining to stations associated with California, Kansas, Virginia, Maryland and one station from New Mexico are in this category. The second category includes most stations and shows that there might be some year-to-year differences, e.g. Louisiana data in Figure 3-18b. The third category is only observed in the state of Delaware where data can be separated into two groups: (2005 to 2010) and (2011 and 2012) as seen in Figure 3-18c. Regardless of the category, the fitted regression lines are all within the upper and lower bounds.



a. California (2008-2012)



b. Louisiana (2008 - 2012)



c. Delaware (2007- 2012)

Figure 3-18 Representative Log-Log Regression Plots (National)

Figure 3-19 depicts the accuracy assessment using the log-log regression models derived from various data sources. Line A, B and C are models proposed in Southgate's study, and Line D is derived with LTPP data from 2005 to 2012.

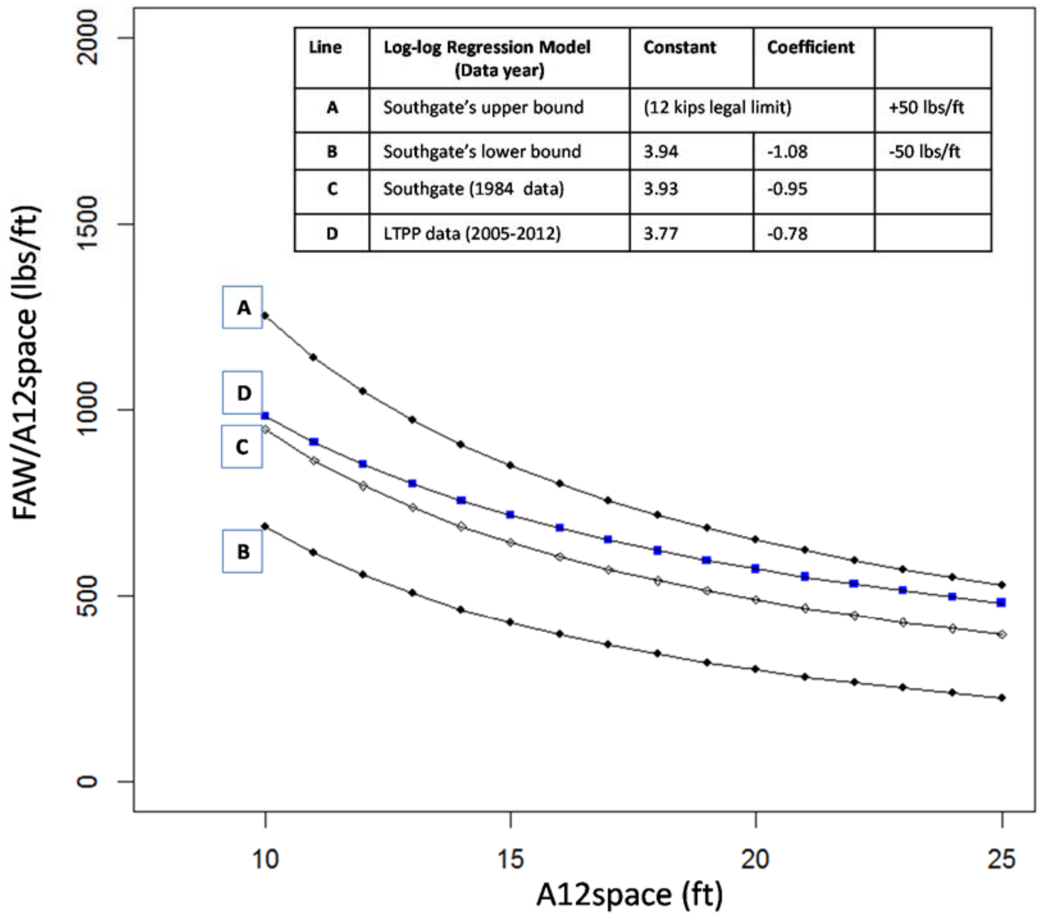


Figure 3-19 WIM Data Accuracy Assessment with Log-Log Regression Models

3.4. <u>Weight Data Tuning Procedure</u>

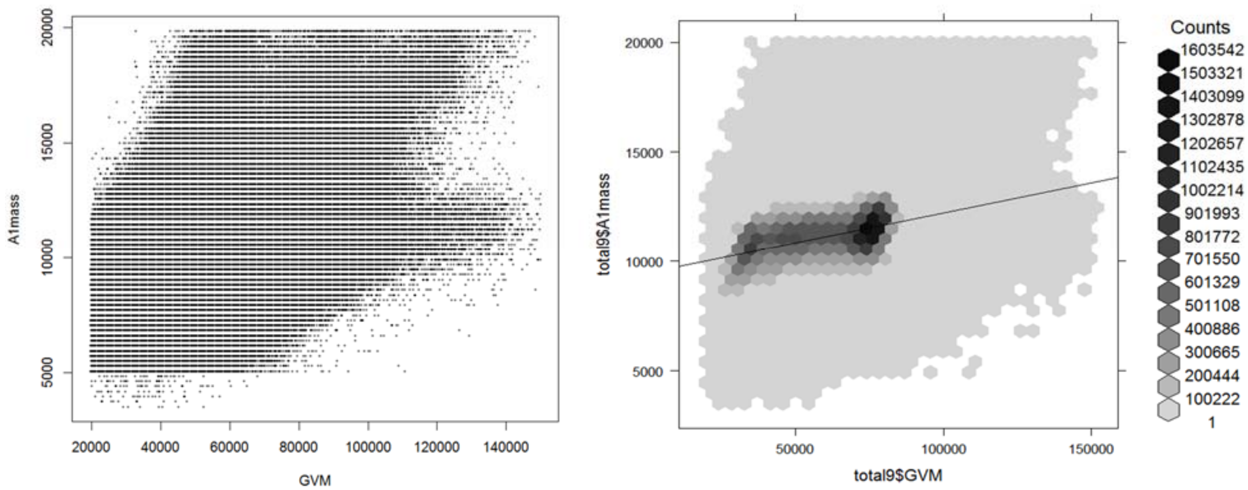
The West Virginia data exhibited poor accuracy compared to the national data. In order to draw conclusions regarding overweight trucks, the decision was made to adjust the weight data collected at many of the West Virginia WIM sites. These inaccuracies were likely caused by insufficient calibration, temperature-induced fluctuations, and/or sensor fatigue. The only documented procedure for adjusting WIM data is based on the log-log regression plot developed by Southgate from data collected in Kentucky (*8*). The difference between the baseline and observed regression models shows a drift that can be added to (or subtracted from) the observed dataset. Each observed Class 9 sample of interest is tuned according to the drift. The tuning rates can be further applied to other vehicle classes.

The brass linguini piezoelectric sensors are known to be affected by temperature, which can fluctuate significantly on a daily basis. Most WIM systems utilize an autocalibration feature that continually checks either the Class 9 FAW or Class 2 axle weights (if light truck volumes) and compares them to set target values. If those characteristics are not within a certain tolerance, then the calibration parameters are automatically updated. The WIM systems in West Virginia are calibrated to FAW of loaded Class 9 vehicles (GVW > 60,000 lbs) using a target weight of 10,600 lbs. The calibration adjustment is calculated for every three vehicles. This procedure is supposed to eliminate fluctuations in weights due to temperature, however daily fluctuations were still observed at multiple sites, which were affecting the measured weights. The Southgate tuning procedure was not able to correct this characteristic of the data, so a procedure was specifically developed to address the temperature fluctuations.

3.4.1. Gross Vehicle Weight and Front Axle Weight Relationship

The Class 9 front axle weight is commonly used as an accuracy metric because it doesn't fluctuate significantly across the population of vehicles. However, for an individual vehicle, that weight can be affected by a number of factors pertaining to the physical characteristics of the vehicle, including the length of the tractor (indicated by the spacing between Axle 1 and Axle 2) and the GVW (either through load transfer or the type of tractor required to pull the load). Southgate has a procedure to account for the length of the vehicle, but there is minimal understanding of the relationship between FAW and GVW in the literature. Since the LTPP data are considered research quality, they were further analyzed to determine the relationship between a vehicle's GVW and the FAW.

Figure 3-20a shows a plot of GVW vs. FAW for each Class 9 vehicle with pattern 1-2-2 and 1-2-1-1 in the national data. A relationship is very difficult to identify, so a tendency plot was created that utilizes shading to indicate the frequency of points in the plot area. This is shown in Figure 3-20b and indicates there is a region where a relationship appears to exist.



(a) Plot of All Points (b) Tendency Plot

Figure 3-20 Class 9 GVW vs. Front Axle Weight (National)

The next step was to aggregate vehicles at each station by GVW bin (2000 lbs in this case) and calculate the average FAW for all vehicles in that GVW range by site and year. The resulting plot is shown in Figure 3-21. The plot is divided into three sections to indicate the “Low GVW” group (> 40,000-lb), “Medium GVW” group (40,000-80,000-lb), and “High GVW” group (>80,000-lb) for discussion purposes. The line composed of blue triangles in the figure represents the average FAW for each GVW bin across all sites and years.

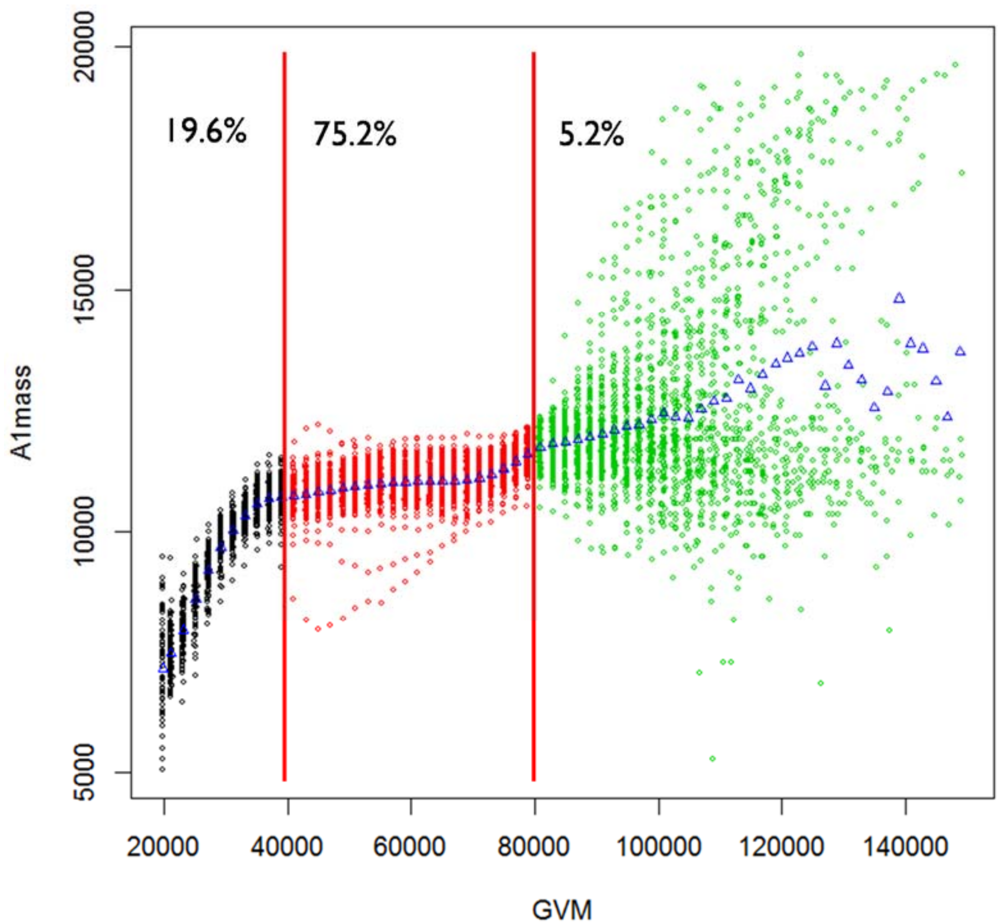


Figure 3-21 Average Class 9 GVW (2000-lb Bins) vs. Average FAW (National)

- Low GVW group: This group consists of 19.6% of the data points. In this group, there is high correlation between GVW and front axle weight and the slope of a fitted line would be +0.197. It isn't likely that Class 9 vehicles have weights lower than 8,000 lbs, so it is assumed that there are lighter vehicles being incorrectly classified as Class 9. Further analysis indicated that it could possibly be Class 5 vehicles pulling a 3-axle trailer based on the vehicle lengths and weights associated with the vehicles.
- Medium GVW group: The medium GVW group consists of 75.2% of the data. There appears to be a consistent relationship in this range across all sites and years, with a slope of +0.016. Therefore, it suggests that there is a positive, but minimal relationship between these two characteristics.

- High GVW group: This group consists of only share only about 5.2% of the data. The plot indicates a large variance. It might be due to the facts that average values tend to be dominated by extreme observations and there is no concentrated trend observed within the group. However, it is expected that the trend in this range would follow the trend of the Medium GVW group. The high variation is likely due to the limited number of observations as well as sensor calibration. Field calibration procedures do not involve the use of overweight trucks, therefore the behavior of sensors in these weight ranges are not specifically known.

Similar to the log-log regression model, the national data GVW-FAW trend can serve as an additional standard for inspecting measurement accuracy. For illustration and comparison purposes, data from the California site and West Virginia data from Site 8 (stations 3312, 3313, 3314, 3315) are illustrated along with the national data trend in Figure 3-22. It is observed that the California data is relatively close to the national trend. The West Virginia data is consistently below the national data trend. It also illustrates more variation, but that is likely attributed to the smaller sample size. The average FAW for the stations at Site 8 range from 9,488 to 10,324 lbs, so these did not seem problematic based solely on the FAW examination. However, the following analysis will support that this data has accuracy problems.

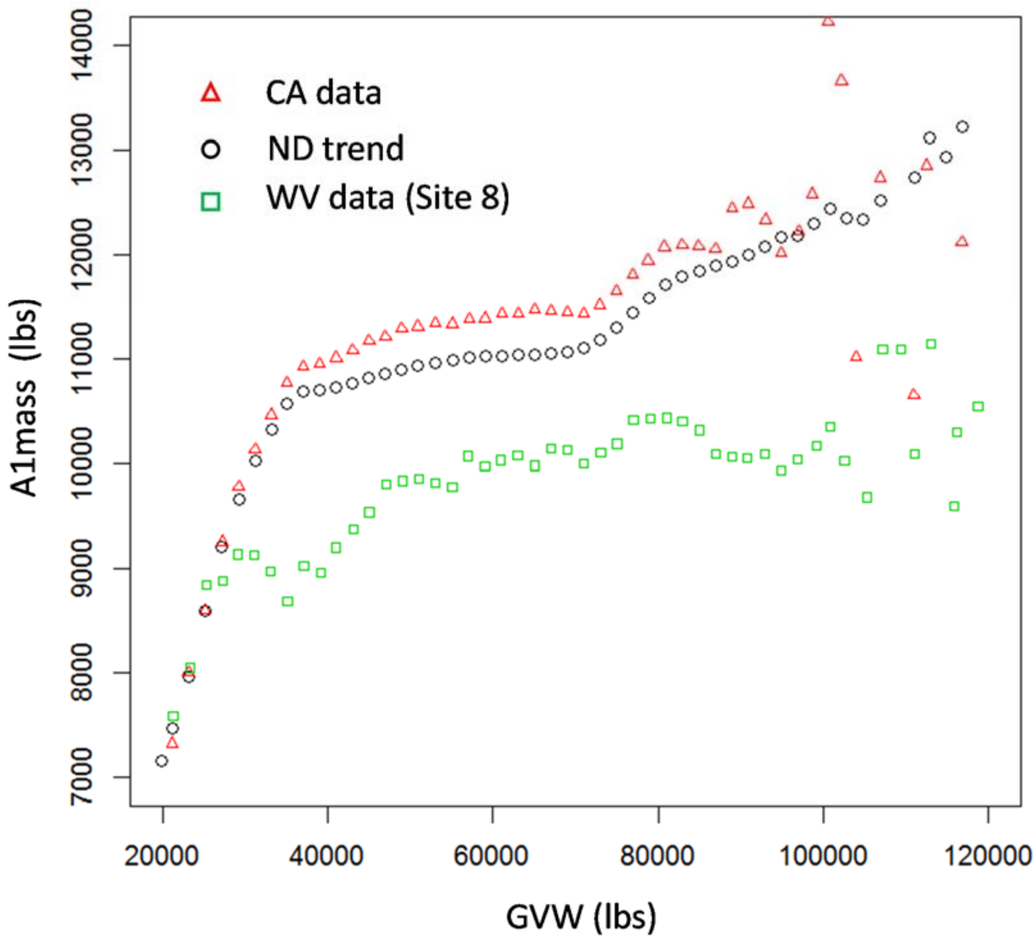


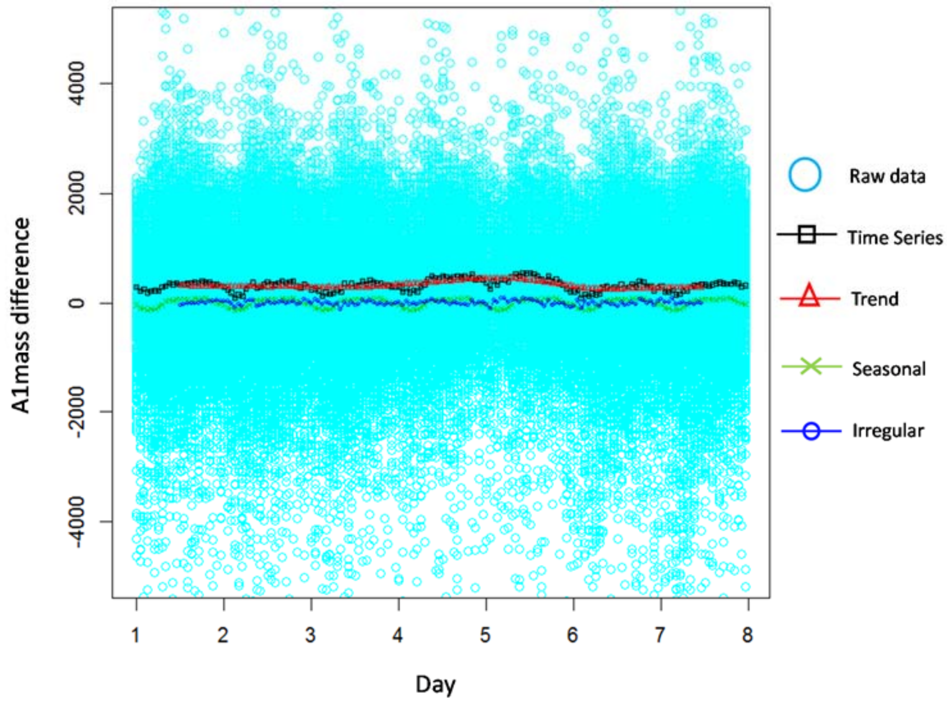
Figure 3-22 Class 9 GVW-FAW Trend Comparison

3.4.2. <u>Front Axle Weight Time Series Analysis</u>

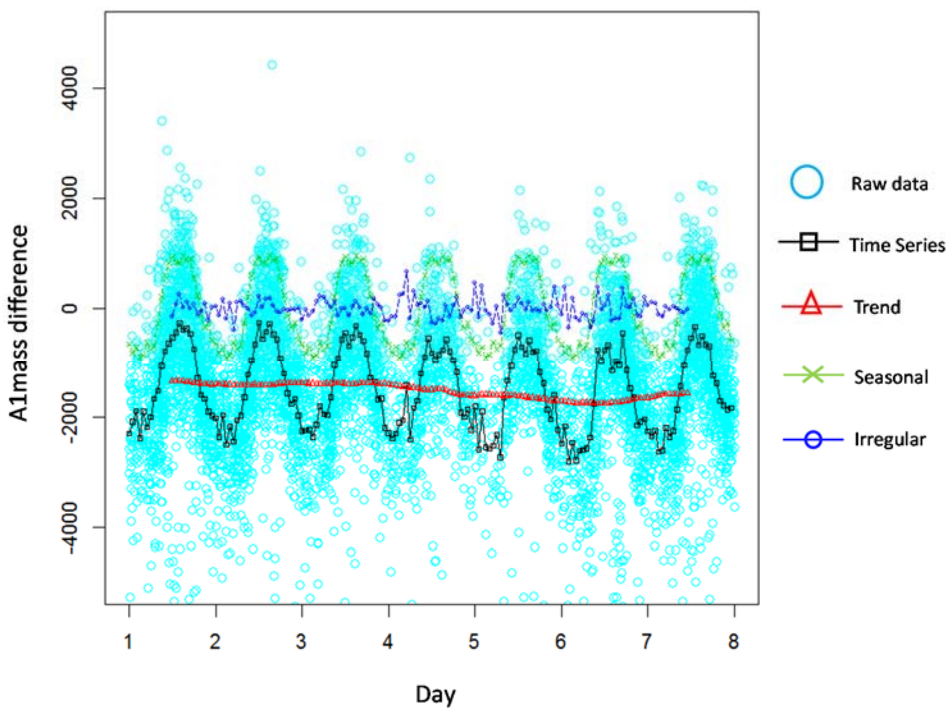
As stated previously, the brass linguini piezoelectric sensors are affected by temperature. This can result in a cyclic pattern of weight observations on a daily basis, due to the daily temperature changes. To further explore the temperature relationship, the difference between the observed FAW for each Class 9 truck and the associated average FAW based on the national data trend for its GVW bin were plotted against time in Figure 3-23 for both the California and the West Virginia Site 8 data. The time series modeling technique using statistical analysis tool R (*10*) was applied to these two datasets, which allows the results to be decomposed into “trend”, “seasonal”, and “irregular” components. The trend represents a long-term increase or decrease in the data, the seasonal component characterizes cyclic data fluctuation due to temporal impacts (e.g., by hour, day, month, year), and the irregular component is the residual portion of a time series after the former components have been removed. The results are shown in Figure 3-23a and Figure 3-23b with trend represented by red lines, seasonal represented by green, and irregular represented by blue for California and West Virginia data, respectively. Notice that the California data exhibits no observable fluctuations in the front axle weight. However, the West Virginia data exhibits a clear cyclic pattern each day, with the observed weights being higher in the middle of the day (when temperatures are highest) and lower at night (when temperatures are lowest).

The "trend" component is interpreted by the researchers as being the general calibration difference of this West Virginia site compared to the national data trend. Since this line is below the zero line, this sensor is generally weighing light. The "seasonal" component is capturing the calibration fluctuations throughout the day due to temperature changes, and repeats on a daily basis. The "irregular" component of the time series is likely capturing random effects attributed to the autocalibration algorithm, the reliability of the WIM sensor technology used in West Virginia, and other factors. Even though the same technique is applied to the California data, there is no significant variation among these three components, which is expected. The California WIM site utilizes bending plate sensors, which are not temperature dependent and are considered to be superior to brass linguini piezoelectric sensors in terms of weight accuracy and reliability. These results support the tuning of the data to remove the inaccuracies attributed to temperature drift.

This technique was applied to multiple West Virginia sites in order to estimate the adjustments that will eliminate the time series trends. These adjustments will be derived for each hour during the period of data analysis since the adjustment will vary throughout the day. These adjustments will be ultimately be applied to all axles of all vehicles at that WIM site.



(a) California Data



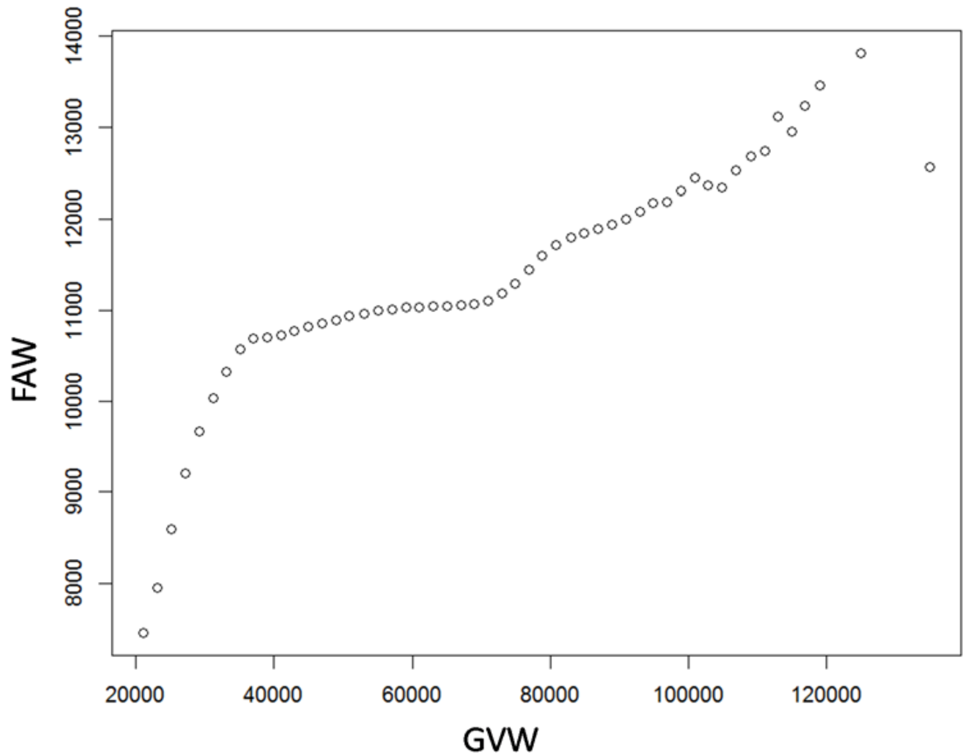
(b) West Virginia Site 8

Figure 3-23 Time Series and Decomposition Components of Front Axle Weight

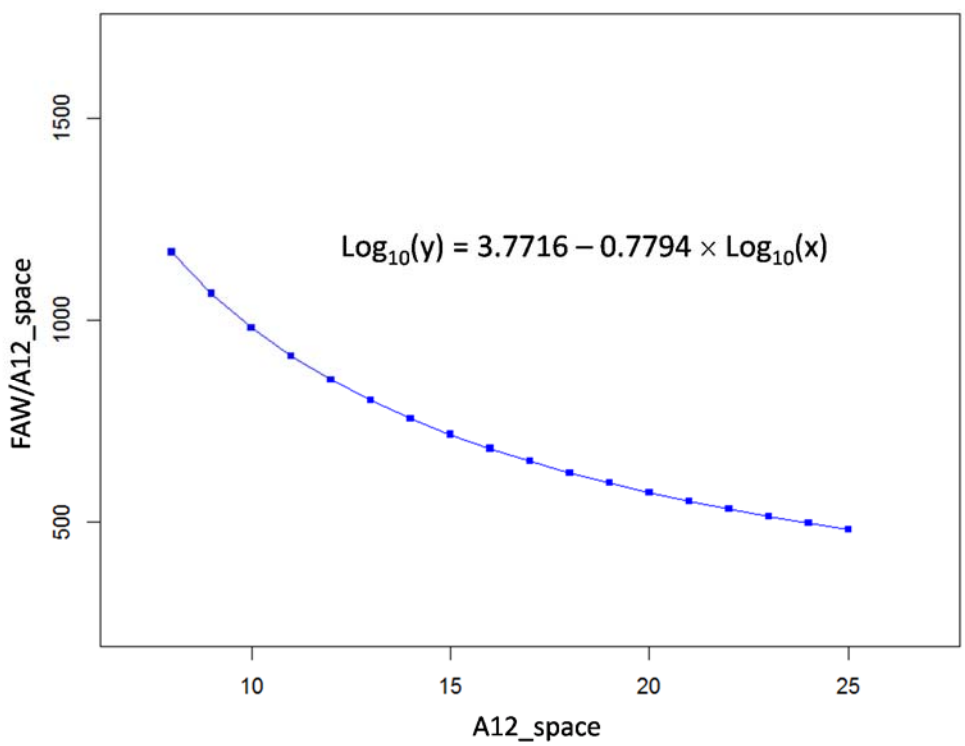
3.4.3. Tuning Procedure Overview and Application to WV Site 8

A hybrid data tuning procedure that combines the log-log regression relationship and the time-series modeling technique is proposed herein. The two relationships will use the national data as the baseline for deriving the adjustments. Data from West Virginia Site 8 is used to illustrate the output of each step. The step-by-step procedure is outlined below and the formulations of each step are provided in Appendix G.

Step 1 - Define baseline relationships. Develop the baseline GVW-FAW relationship and FAW-Axle 1-2 Spacing relationship. For this study, the national data was used for the baseline. The GVW-FAW relationship is represented in Figure 3-24a. The raw values corresponding to this relationship are provided in 0. The FAW-Axle 1-2 spacing relationship and regression coefficients are included in Figure 3-24b. Other data sources could be utilized to define these relationships. These relationships should be developed using Class 9 vehicles with pattern 1-2-2 and 1-2-1-1.



(a) FAW-GVW Baseline Relationship



(b) FAW-Axle 1-2 Spacing Baseline Relationship

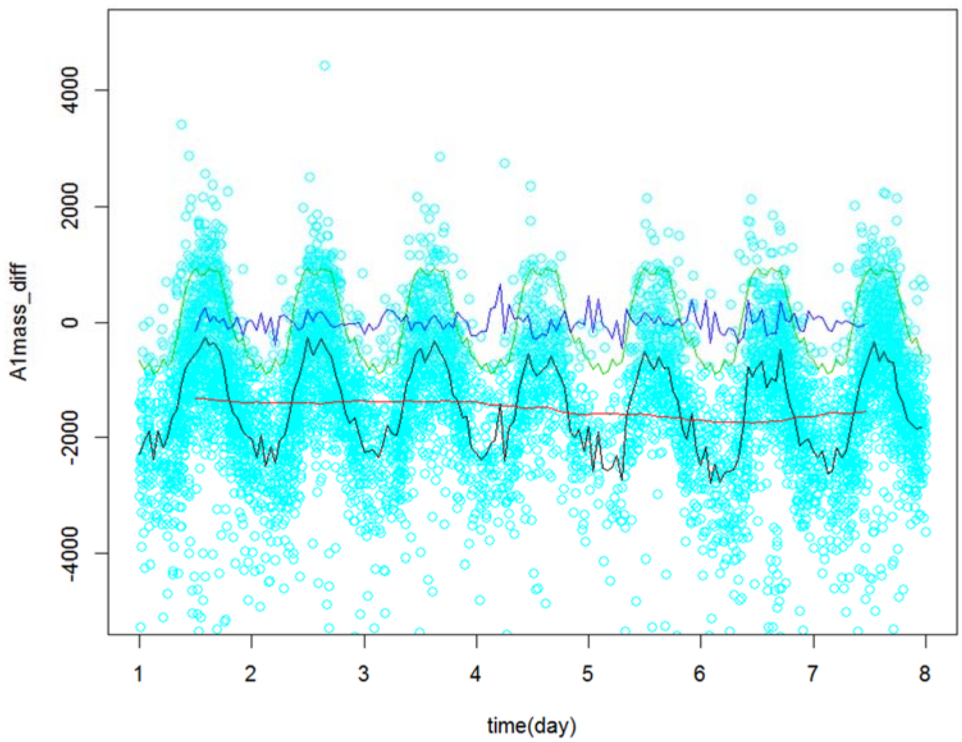
Figure 3-24 Baseline Relationships for Tuning (Step 1)

Step 2 - Calculate FAW differences. Identify the Class 9 vehicles with pattern 1-2-2 and 1-2-1-1 for the WIM station to be adjusted (observed). For each GVW bin, calculate the difference between each observation's FAW and the national data average FAW. Plot each observation's FAW difference versus time (see turquoise points in Figure 3-25a).

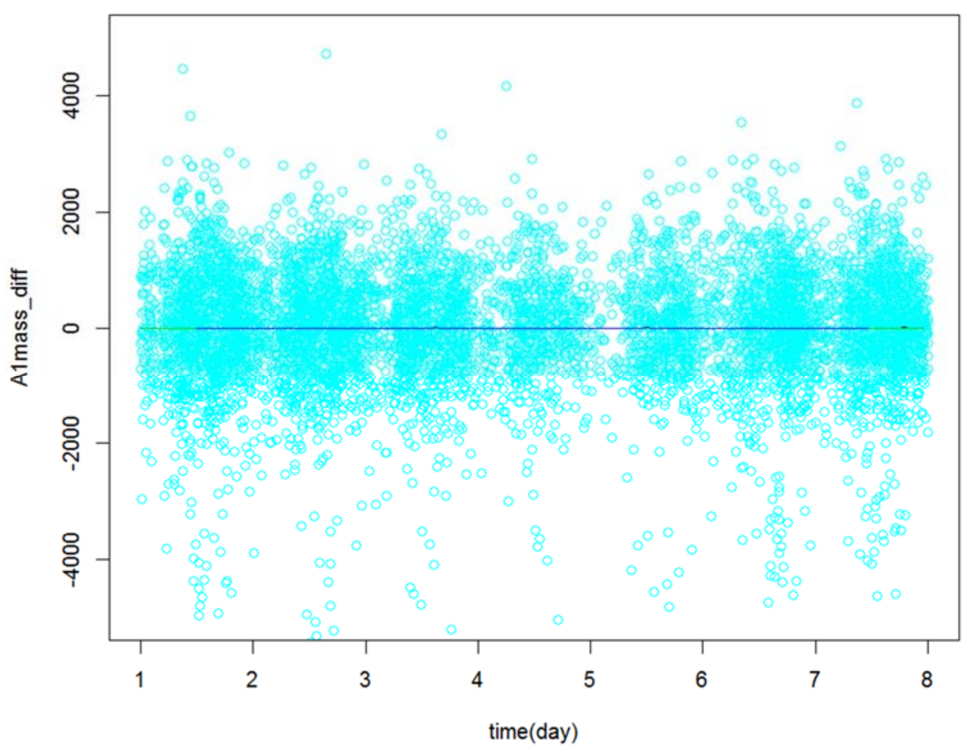
Step 3 - Generate time series line. Average the FAW differences for each hour in the analysis period so that there is one value per hour on which to base the time series analysis (see black line in Figure 3-25a).

Step 4 - Decompose time series. Apply additive time series analysis and decompose into trend, seasonal, and irregular components (see red, green, and blue lines in Figure 3-25a).

Step 5 - Calculate and apply time series adjustments. A single adjustment is calculated to raise or lower the trend, seasonal, and irregular lines to be zero (see Figure 3-25b). This difference is calculated as a fixed adjustment (rather than a percentage) for each hour. Therefore, all observations within a given hour will be adjusted by the same fixed amount. These adjustments are applied to each observed FAW for use in the remaining steps.



a. Data before Time Series Tuning (Result of Steps 2-4)



b. Removal of Time-Series Component (Step 5)

Figure 3-25 Time Series Tuning Process Applied to WV Site 8

Step 6 - Generate Log-Log regression line for tuned FAW. A log-log regression line is developed from the adjusted observed data from Step 5 covering the full analysis period (see red line in Figure 3-26).

Step 7 - Calculate Log-Log adjustments. For each observation, the difference between the baseline log-log regression (Step 1) and the tuned data log-log regression (Step 6) is calculated as a fixed value. This fixed value is applied to that tuned FAW observation from Step 5. Once all observations have been tuned and the log-log regression line regenerated, the blue line in Figure 3-26 results (which is overlapping the national data).

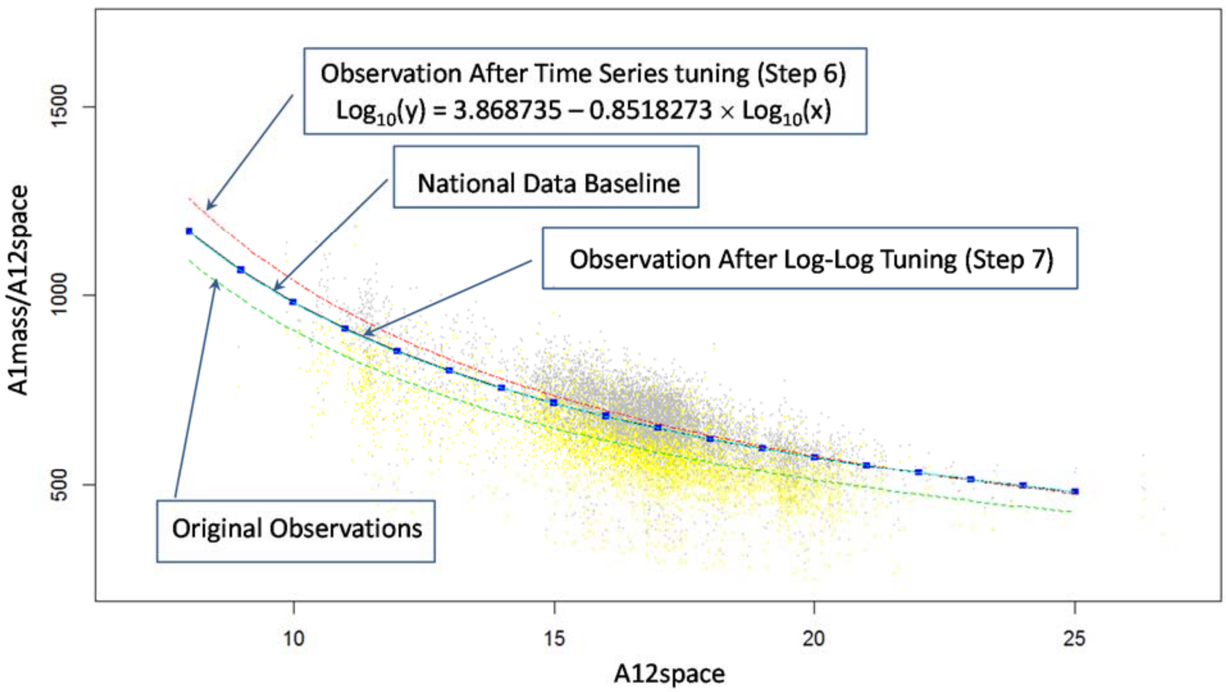


Figure 3-26 Log-Log Tuning Process Applied to WV Site 8

Step 8 - Generate percentage adjustment for each observation. Each observation's final adjusted FAW from Step 7 is used to compute a percentage adjustment based on the original FAW. The tuning percentages for each individual Class 9 vehicle at WV Site 8 are shown in Figure 3-27.

Step 9 - Generate adjustment matrix by hour. The percentage adjustments from Step 8 are aggregated into hourly bins, with all values being averaged to produce a single percentage adjustment for each hour. Figure 3-28 illustrates a contour of the aggregated adjustment factors by hour (y-axis) and by day (x-axis). These adjustments are then applied to other axles on the Class 9 vehicles as well as other vehicle classes based on the time they crossed the WIM sensors.

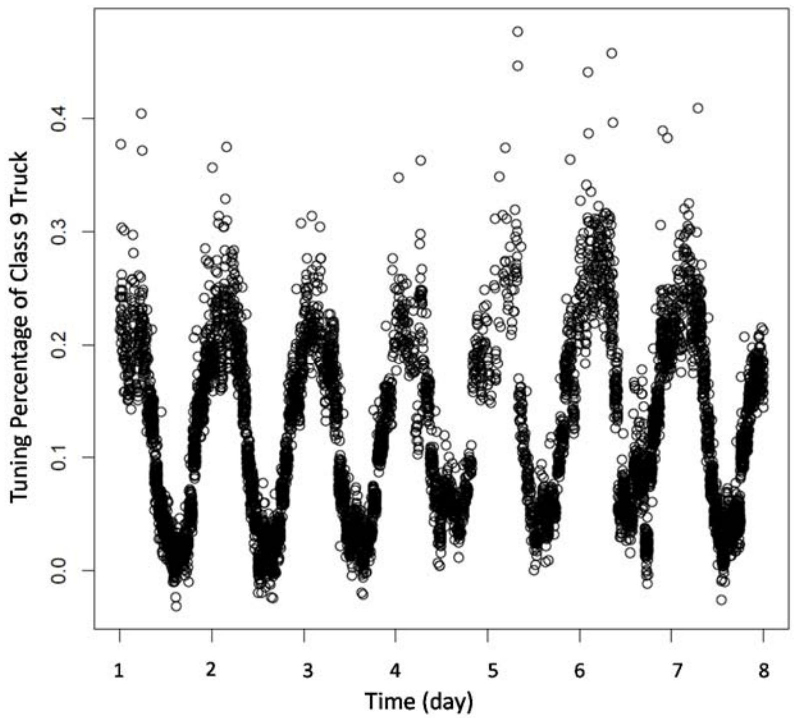


Figure 3-27 Tuning Percentages for Individual Class 9 Vehicles (Step 8)

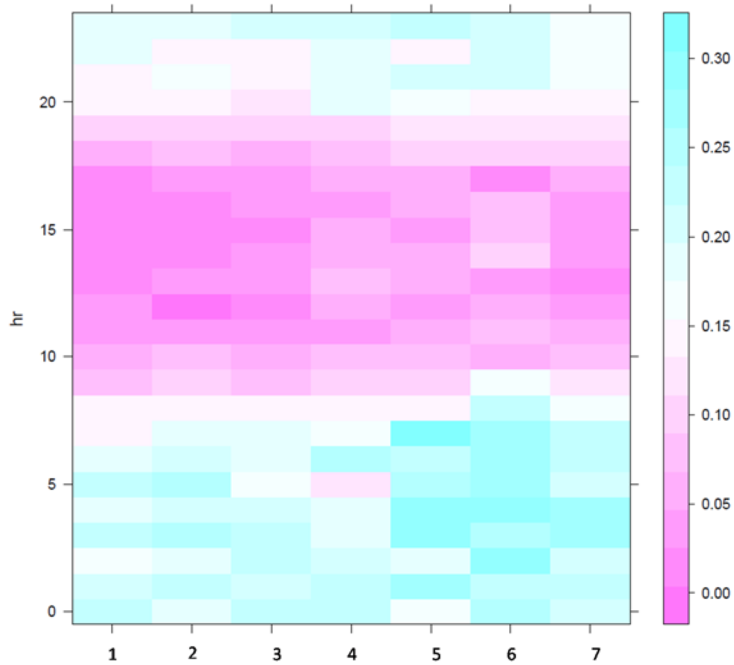


Figure 3-28 Tuning Rate Contour for Adjusting All Axle Weights (Step 9)

The WV Site 8 relationships before and after tuning are illustrated in Figure 3-26 for the log-log relationship and Figure 3-29 for the FAW-GVW relationship. In Figure 3-26, the yellow dots represent the individual data points before any tuning and the gray dots represent the final tuned data. Notice the upward shift of the data. The green line is the regression for the data before tuning, the red line is the data after time series tuning, and the turquoise line is data after all tuning. In Figure 3-29, the red triangles represent the aggregated data before tuning, green x's represent the data after time series tuning, the turquoise circles represent the data after all tuning, and the blue stars represent the national data. The data trend improved through each tuning stage and the final tuned data is very close to the national data for both relationships.

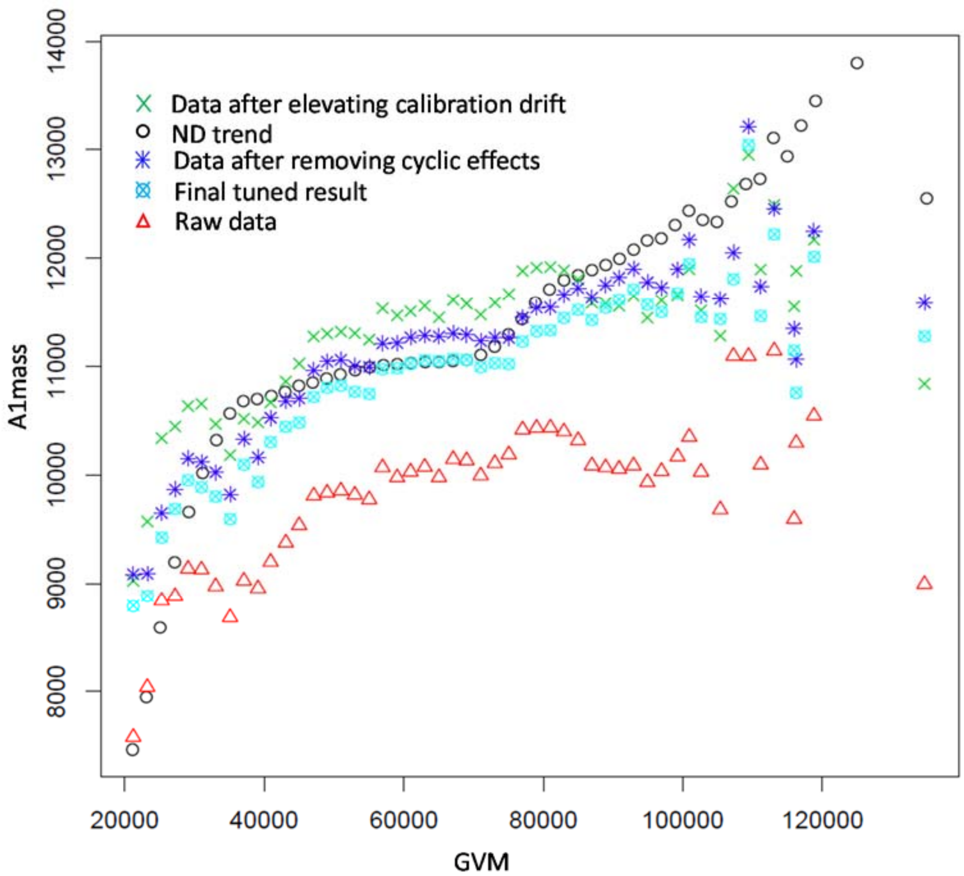


Figure 3-29 WV Site 8 GVW-FAW Relationships through the Tuning Process

Figure 3-30 illustrates the GVW distribution for WV Site 8 before and after tuning. The GVW distribution is shifted to the right due to the adjustments. Since these sensors were weighing too light during all periods of the day, particularly at night, the GVW values were being underestimated. Without the data adjustments, the overweight truck percentages at this location would have been underestimated for the purposes of this analysis.

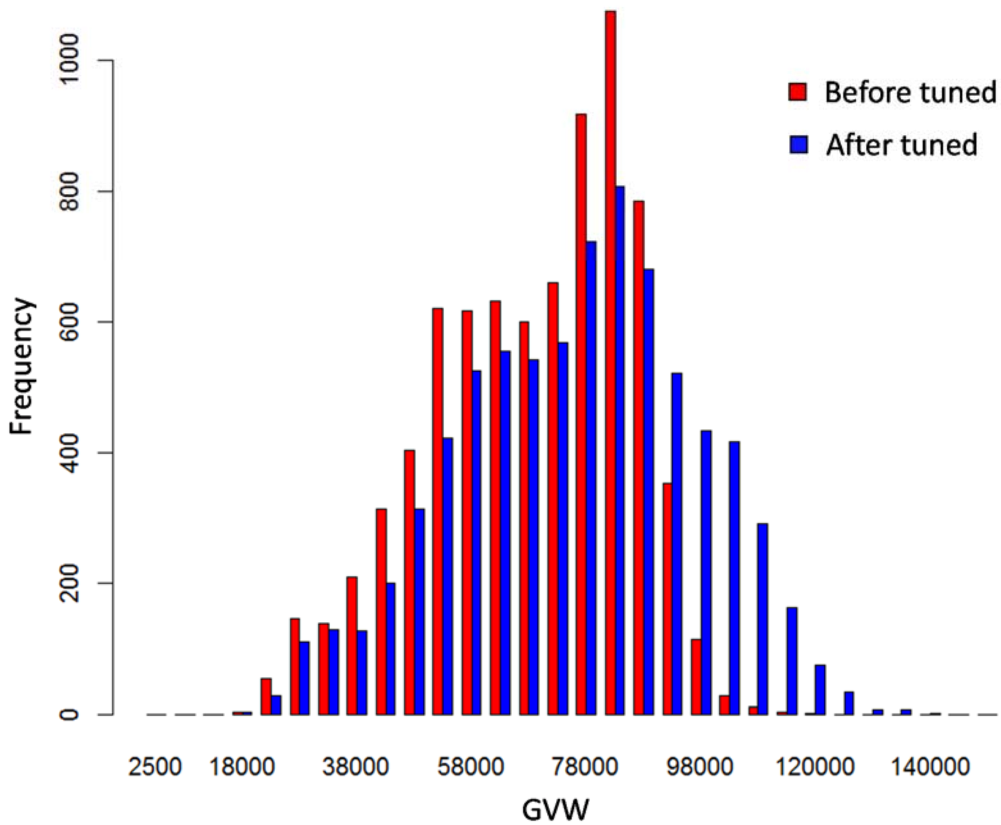
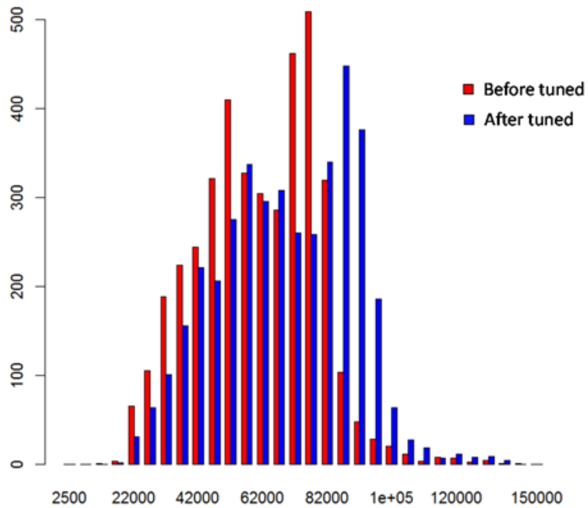


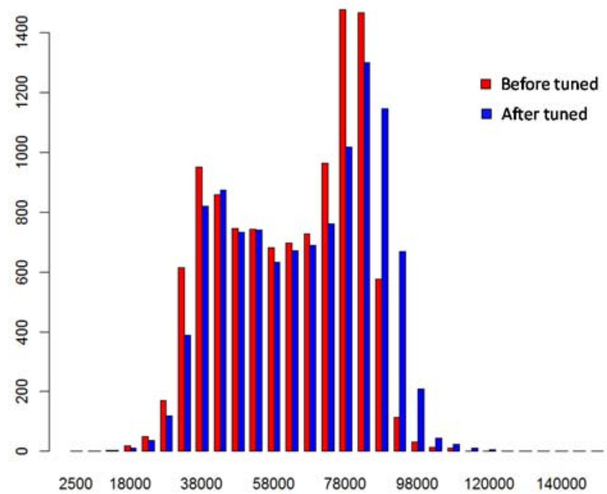
Figure 3-30 WV Site 8 GVW Distribution Before and After Tuning (Class 9 and above)

3.4.4. Application of Tuning Procedure to Four Other WV Sites

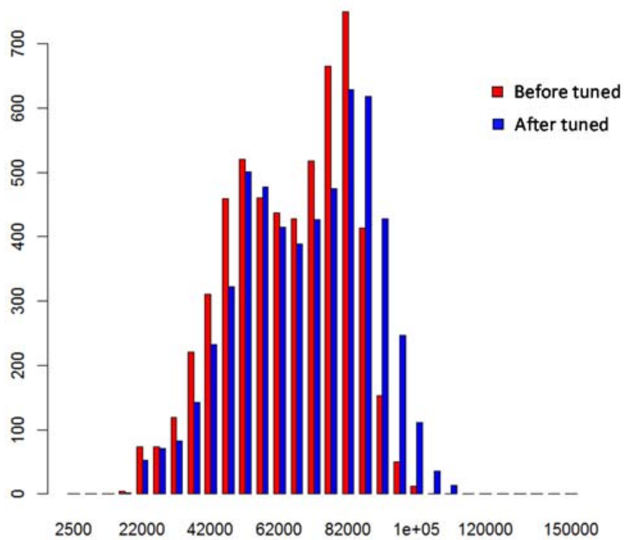
Since each WIM site will experience different calibration, drift, and temperature fluctuations, the tuning procedure was applied to each individual site to be analyzed. Based on the data availability during the study period, five sites (including Site 8) were selected to apply the tuning procedure. The resulting tuning matrices were applied to each site individually and the resulting GVW distributions were produced. Plots illustrating the tuning procedure for these four sites are provided in the Appendix I. Figure 3-31 depicts the GVW distribution before (red) and after (blue) tuning for all vehicles in Class 9 and above at the four additional sites. The tuning procedures resulted in a shift of the GVW distribution to the right for all four of these sites.



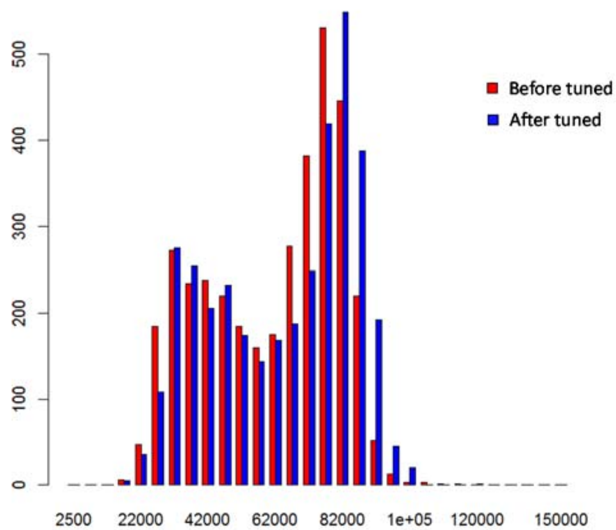
(a) Site 1



(b) Site 5



(c) Site 6



(d) Site 12

Figure 3-31 GVW Distribution Before and After Tuning (Class 9 and above)

3.5. <u>Summary</u>

This chapter reviewed the comprehensive analysis of the West Virginia WIM data from 2011 that was provided for this project. To achieve the study goal of estimating overweight trucks not holding proper permits, issues related to vehicle classification and measurement accuracy in the WIM database were addressed. The LTPP classification rules were used to reclassify the vehicles.

The WIM measurement accuracy was conducted by focusing the examination on Class 9 vehicles with specific patterns (1-2-2 and 1-2-1-1). A national WIM dataset was utilized to compare the accuracy levels of the West Virginia data. Through inspecting accuracy indicators, such as target values or data patterns, the West Virginia data illustrated inaccuracies. Therefore, a tuning procedure was developed as part of this project in order to improve the accuracy of the weight data. Both adjusted and unadjusted data from the specific sites to be analyzed will be utilized in Chapter 5 to estimate the percentage of overweight trucks without proper permits.

4. HISTORICAL PERMIT DATA ANALYSIS

4.1. Vehicle Permit System in WV

In West Virginia, the process of acquiring a permit for an oversize or overweight truck is conducted electronically through the WVDOT website (*1*). The WVDOT issues six different permit types; Blanket, Mobile Home Blanket, Seagoing, Single Trip Mobile Home, SASHTO and OS/OW/Superload. Typically, the OS/OW/Superload permits will be assigned with a specific route because their weight limits approach the limits of some bridges across the state and require that a certain route be followed. Permit applicants submit sufficient information for the WVDOT to evaluate the vehicles, including the vehicle model, dimensions, axle spacing, axle and gross weights, desired travel dates, and origin and destination (within West Virginia). With user defined origin and destination information, the online permit system will generate a recommended route that accounts for various factors, such as bridge weight limits, underpass height limits, and other general travel restrictions. In this study, the permit database was provided by WVDOT for 2011, consisting of 150,390 permit records. Important attributes associated with a permit include permit's reference number, type, status, route and time window of travel. The records were managed in an MS SQL database with the scheme provided in Appendix J.

4.2. Permit Data Analysis

4.2.1. Number of Permits Issued and Denied

The Disposition field contains values from 0 to 5 indicating the status of permit in the review process. Table 4-1 summarizes the disposition code meanings and frequencies in the database. This analysis only focused on the issued permits, Disposition 5.

Table 4-1 Distribution by Permit Status

Disposition	Status	Frequency
0	New Request	731
1	Completed Request	1,178
2	Completed Analysis - Failed	1,849
3	Completed Analysis - Passed	100
4	Completed Permit Info	197
5	Issued Permit	146,335

4.2.2. Permit Distribution by Type

Figure 4-1 lists the number of issued permits by type. More information on each permit type is provided in Appendix A. Approximately 94% of the permits are of Oversize (OS)/Overweight (OW)/Superload type, which is the focus of this study. This also provides a breakdown of how many permits included route information, which is essential for the analysis being conducted.

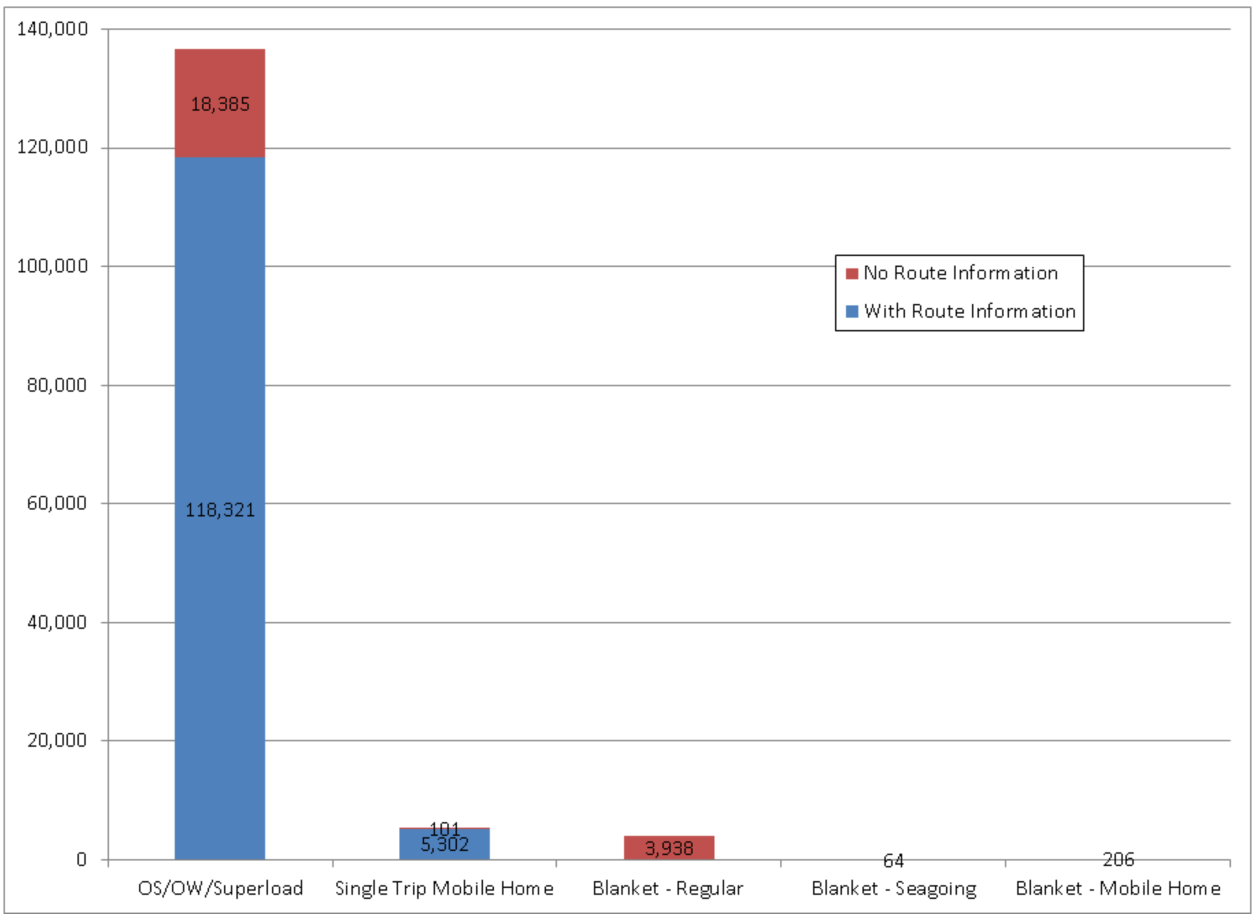


Figure 4-1 Permit Distribution by Type

4.2.1. Permit Distribution by Company State

Permit applicants indicate the state in which the company is based. Figure 4-2 lists the frequency of states by permit type. The majority of the permits are issued to companies based in Pennsylvania, followed by West Virginia, Texas, and Ohio.

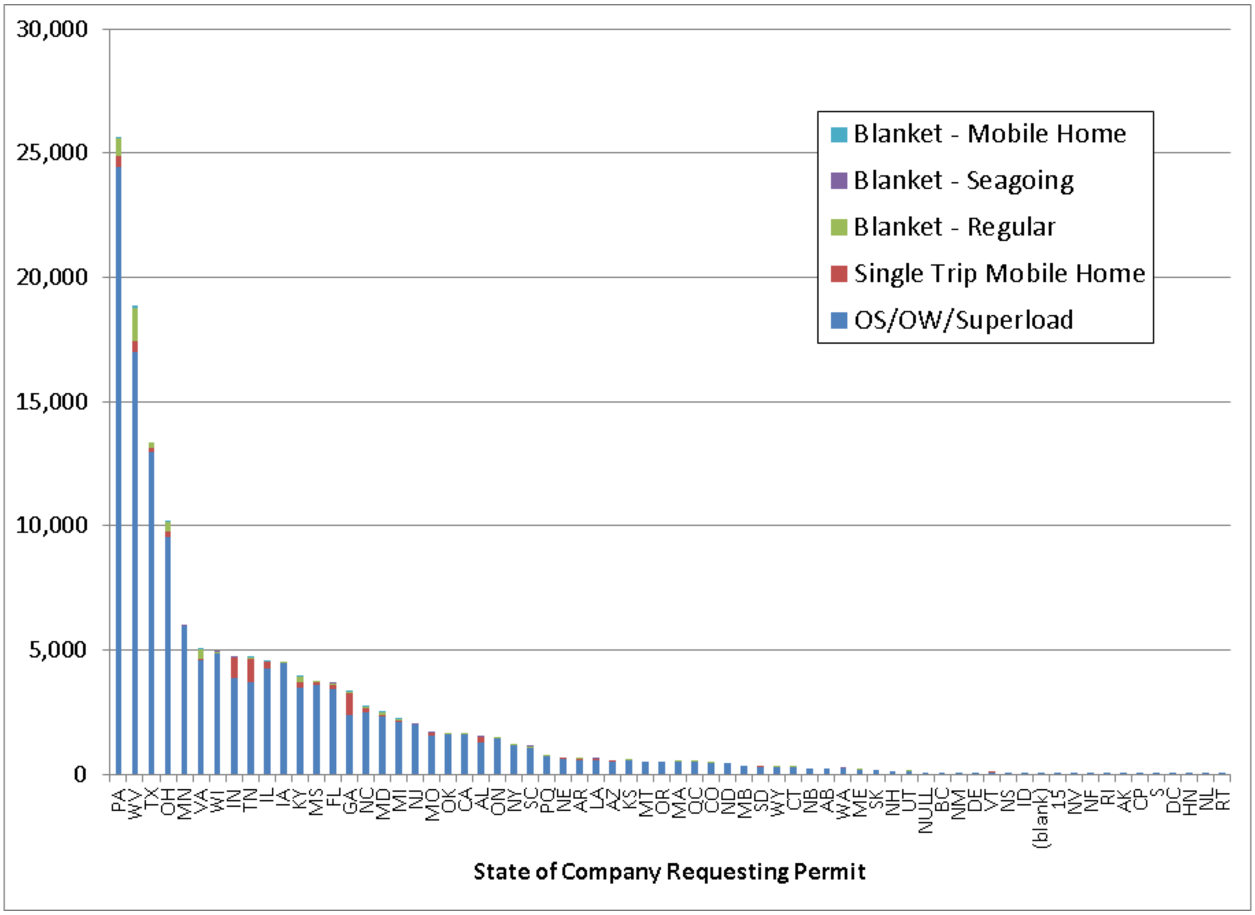


Figure 4-2 Permit Distribution by Company State

4.2.2. Permit by Duration

The non-blanket permit types are issued for a specific time window. The blanket permits typically last the entire year. Table 4-2 lists the duration by permit type. The majority of the OS/OW/Superload permits had 6-day travel windows.

Table 4-2 Permit Distribution by Duration

Permit Time Window (day)	Blanket	Mobile Home Blanket	OS/OW/Superload	SASHTO	Seagoing	Single Trip Mobile Home	Grand Total
1			2			14	16
2			14			19	33
3			2			11	13
4			38,008	3		12	38,023
5			506			8	514
6			87,346	15		2	87,363
7			5,968			5	5,973
8			2,916			6	2,922
9			1,010			19	1,029
10			16			58	74
11			789			1,131	1,920
12			122			50	172
13						2,894	2,894
14						522	522
15						185	185
16						253	253
17						26	26
18						181	181
364	557	14			14		585
365	3,381	192			50		3,623
371			4				4
other			3			7	10
Grand Total	3,938	206	136,706	18	64	5,403	146,335

4.2.3. Routing Information Availability

The applicant specifies the origin and destination of the trip and usually has the option within the electronic permit system to select a preferred route that accounts for any restrictions. This route is saved in the database in a single field, which are turn-by-turn directions. There are 123,641 permits with route information. For the OS/OW/Superload permits, 87% permits have route information while 13% are missing such information as shown in Table 4-3.

Table 4-3 Permit Route Information by Type

Permit type	No Route Information	With Route Information	Total
Blanket	3,938		3,938
Mobile Home Blanket	206		206
OS/OW/Superload	18,385	118,321	136,706
SASHTO		18	18
Seagoing	64		64
Single Trip Mobile Home	101	5,302	5,403
Total	22,694	123,641	146,335

4.3. GIS Methodology to Map Permit Routes using LRS

Important fields associated with a permit are "Permit ID" (as a unique permit identifier), "Origin", "Destination", and "Routes". Table 4-4 shows the data contained in these four fields for a sample permit. As shown in the table, the Routes field contains the permitted route as a single string of text, which is a set of segment-by-segment instructions with the keywords "START", "TO", "END", and "RETURN". This sample route is a roundtrip permit that starts on a state route (WV-25), continues on the interstate (I-64), and ends on a US route (US-35) where it intersects with a county route (C33). The information after the "RETURN" keyword indicates the route to take from the destination back to the origin. To facilitate the analysis and visualization of the permit data, the route information from each permit must be mapped in GIS.

Table 4-4 Sample Permit Database Record

Permit ID	Origin	Destination	Routes
10140093	NITRO	ST ALBANS	**START** WV-25 W MP PUTNAM 2.19 **TO** WV-25 MP PUTNAM 1.07 @ I-64 W **TO** I-64 MP PUTNAM 43.78 @ US-35 S **END** US-35 @ C33AND **RETURN** US-35 N @ C33 **TO** US-35 MP PUTNAM 2.10 @ I-64 E **TO** I-64 MP PUTNAM 44.53 @ WV-25 E **END** WV-25 MP PUTNAM 2.19

The permit system in West Virginia appears to have some linear referencing system (LRS) components as it incorporates milepost information and consistent route name information in the Routes field. This system, however, does not seem to be fully integrated with the WVDOT LRS because the route name does not follow a common route numbering structure. The format of this data is not compatible for GIS mapping purposes without additional processing. Thus, this section discusses a methodology that was used to convert this field of data into a format that is LRS compatible for GIS mapping purposes.

4.3.1. Linear Reference System (LRS)

Linear referencing is a method of specifying a location as a distance or offset measurement (e.g., milepost) along a linear feature (e.g., a roadway), from a known reference point (e.g., milepost 0.0) (*11*). An LRS is one type of location referencing system with the primary benefit of establishing intuitive reference points which are easily identified in the field. For example, transportation agencies use routes and mileposts to define the locations of assets (e.g., bridges, signs, structures) and events (e.g. road conditions, traffic counts, incidents) (*12*). The WVDOT has developed a Road Inventory Log (RIL) that uses LRS as a reference system. WVDOT RIL is a transportation network database defined and maintained in a tabular form and records transportation assets or activities on or along the route.

A key feature of an LRS is a systematic way to define route segments, (i.e., Route ID). Each agency defines its own Route ID structure as well as the number designations for each component of the Route ID. The current WVDOT structure is shown in Figure 4-3. The county code is a two digit number referring to one of the 55 counties. The road classification is a single digit from 0 to 9, where 1 is an Interstate, 2 is a US route, 3 is a State route, etc. The route number is a four digit number corresponding to the assigned route number. The sub-route number is the assigned route designation for those roadways that have a sub-route designation. Generally, primary roadways (road classification 1, 2, and 3) only have a route number and non-primary roadways (typically road classification 4 and above) will have both a route number (corresponding to its adjacent primary route) and a sub-route number. The supplemental code is a code that provides additional information about certain roadway characteristics (e.g., toll roads, entrance/exit ramps, spurs). The LRS codes for each road segment in the permit route will be automatically assigned within Step 2 of the methodology.

XX	X	XXXX	XX	XX
↑	↑	↑	↑	↑
County Code	Road Classification	Route Number	Sub-route Number	Supplemental Code

Figure 4-3 WVDOT LRS Route ID Structure (*13*)

4.3.2. Methodology Overview

Since the Routes field in the permit database contains “route” and “milepost” information, it is feasible to assign the trips to the WV LRS after the data is converted to be compatible. The methodology used in this study to convert the route information and plot it consists of a five-step process, summarized in Figure 4-4. Step 1 seeks to decompose the single string of text into specific transition points along the permit route, which would occur when the vehicle must turn onto a new route. Step 2 creates a unique Route ID for every transition point, which corresponds to the Route IDs used in the WVDOT LRS. In Step 3, all transition points in each permit are plotted on a map. These plotted points are then connected and the segments merged to form a continuous permit route in Step 4. Finally, Step 5 assigns the cardinal direction of travel on each tangent segment in the permit route, which is necessary to determine which direction the vehicle traveled past the WIM site.

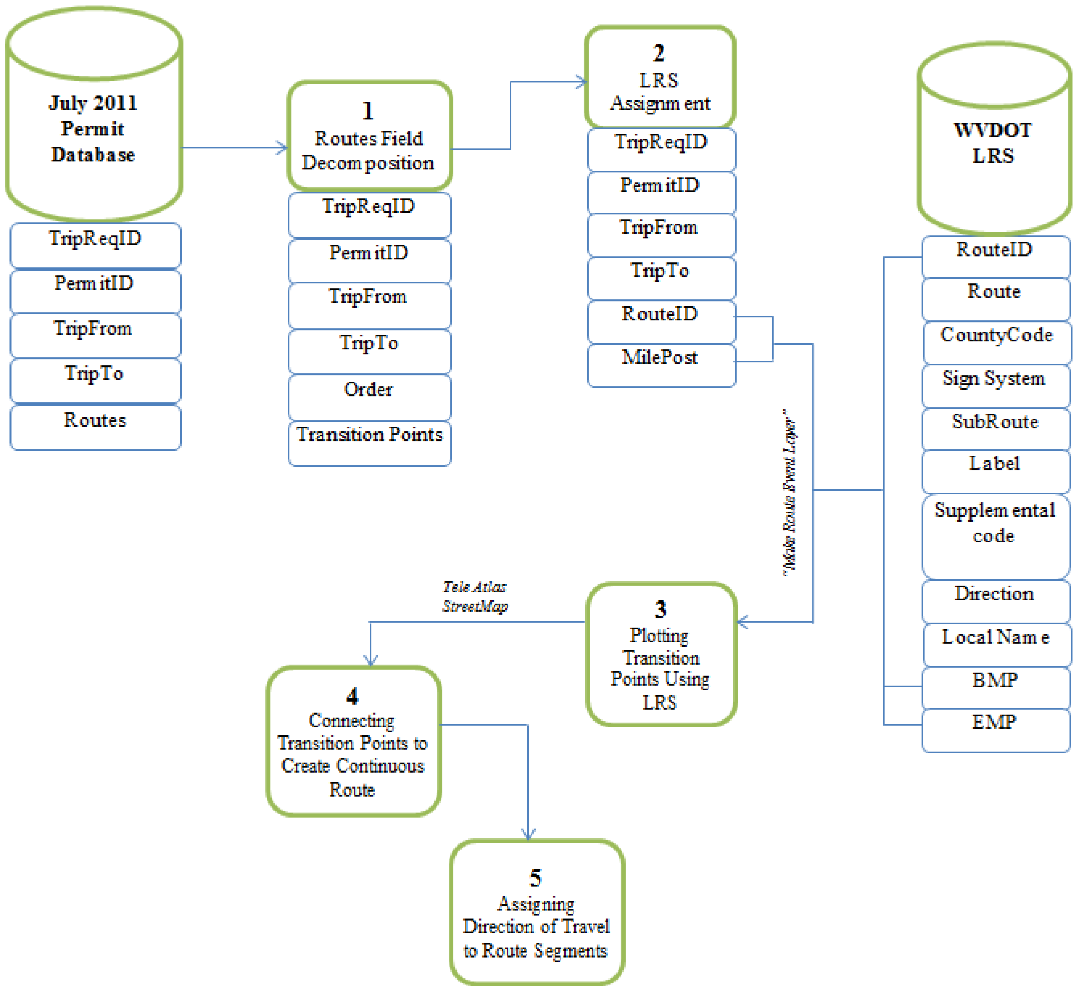


Figure 4-4 Permit Rout Mapping Methodology Flowchart

4.3.3. Step 1. Route Field Decomposition

This step decomposes the continuous text string from the Routes field into segments corresponding with a transition point in the permit trip. A Visual Basic program was written to search for key words in the route string, including START, RETURN, TO, and END, which are then used to partition the string. This exercise is continued until the end of the string to get a complete list of transition points associated with a permit.

The transition points of each permit are also identified with the order in which the transition points occurred, which is important in Step 4 when the continuous route is constructed. The program generates a new field called "order" and assigns the sequence value for each transition point. This process served as the initial stage for LRS assignment and GIS transition point plotting and permit mapping.

4.3.4. Step 2. LRS Assignment

For each transition point in the route, the text content is further evaluated to assign an 11-digit Route ID that corresponds to the WVDOT LRS format. The text in each transition point field was processed automatically using a Visual Basic script that utilized lookup tables and logic statements to determine each individual component of the Route ID. Each component had a separate lookup table that contained all possible values from the WVDOT LRS. The individual components were then concatenated to form the overall Route ID, which is shown in Table 4-5.

Table 4-5 LRS Route ID Generation for Sample Permit ID 10140093

General Road Name	County	Road Classification	Route Number	Sub Route	Supplemental Code	Concatenated 11-digit Route II
I-64	40 (Putnam)	1 (Interstate)	0064 (64)	00 (none)	00 (n/a)	40100640000
US 35	40 (Putnam)	2 (US Route)	0035 (35)	00 (none)	00 (n/a)	40200350000
WV 25	40 (Putnam)	3 (State Route)	0025 (25)	00 (none)	00 (n/a)	40300250000

The results of Steps 1 and 2 are a new data table similar to the one in Table 4-6, which lists the order, Route ID and milepost for the decomposed text of Permit ID 10140093, all necessary components for LRS/GIS plotting.

Table 4-6 LRS Compatible Transition Points for Permit ID 10140093

Transition Point	Order	Route ID	Milepost
WV-25 W MP PUTNAM 2.19	1	40300250000	2.19
WV-25 MP PUTNAM 1.07 @ I-64 W	2	40300250000	1.07
I-64 MP PUTNAM 43.78 @ US-35 S	3	40100640000	43.78
US-35 MP PUTNAM 0.00 @ C33	4	40200350000	0
US-35 N MP PUTNAM 0.00 @ C33	5	40200350000	0
US-35 MP PUTNAM 1.59 @ I-64 E	6	40200350000	1.59
I-64 MP PUTNAM 44.53 @ WV-25 E	7	40100640000	44.53
WV-25 MP PUTNAM 2.19	8	40300250000	2.19

Table 4-7 summarizes the records that were processed in Steps 1 and 2. The scripts automatically processed 12,178 of the 13,325 records that contained route information. There were 1,147 records that could not be automatically processed and required manual inspection. Problems with these records included missing key words (i.e. START, RETURN, TO, END), missing transition point information or milepost in route description, or inconsistent descriptive structure (e.g., missing the @ indicator for an intersection). Of these 1,147 records, 905 were successfully coded manually and 242 had insufficient information to generate a Route ID or milepost and could not be processed or included for further analysis. The resulting permit database of 13,083 unique records was utilized for Steps 3 and 4.

Table 4-7 Summary of Record Processing Statistics after Steps 1 and 2

Description	Frequency
Total Records for July 2011 with Route Information	13,325
Successfully Processed with Automated Procedure in Step 1 and Step 2	12,178 (91.4%)
Required Manual Processing	1,147 (8.6%)
Manual Route ID Generation Successful	905
Insufficient Route or Milepost Information and Excluded	242

4.3.5. Step 3. Plotting Transition Points Using LRS

The plotting of transition points from the permits was possible using the "make route event layer" in the LRS tools in ArcGIS. This tool uses a reference network, in this case the WVDOT LRS, to locate events or points along the network, using the Route ID field and the milepost information for each transition point as a reference. The WVDOT network already includes the Route ID field for proper matching as well as the calculated measurements, referred to as M values, along each of the routes. This allows the identification of specific routes and the location of transition points along such routes, providing alternative location determination to records or features without the use of longitude or latitude information. This layer was needed for the route generation and automated mapping process carried out in Step 4. The plotted points for the sample permit are shown in Figure 4-5.

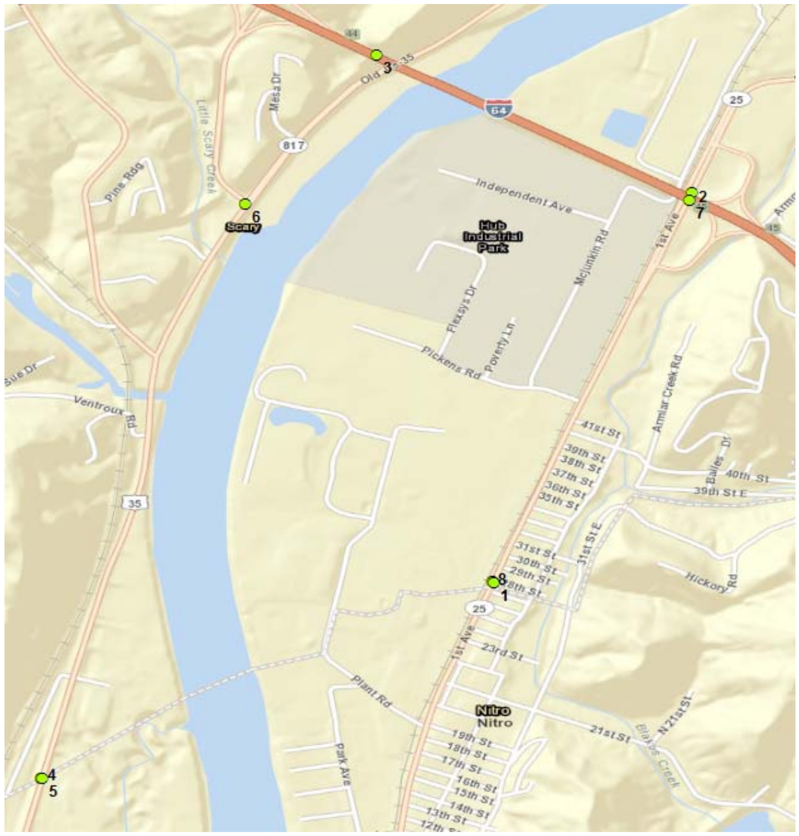


Figure 4-5 Permit 10140093 Transition Point Plot in GIS in Step 3

The GIS process generated a point feature class for all successfully located transition points as well as an error field flagging transition points that could not be automatically located on the LRS due to a problem with the Route ID or with the milepost. Two types of errors were generated in the LRS plotting process, “Route Not Found” and “Route Measure Not Found”. The Route Not Found error generally indicates a segment where the 11-digit Route ID generated in Step 2 does not correspond to an actual Route ID in the WVDOT LRS. This is most likely caused by a clerical error in the reference WVDOT network. The Route Measure Not Found error indicates that the milepost in the transition point is outside the milepost limits in the WVDOT LRS. This generally occurs near the end of a route (at the maximum milepost or county line) or if the milepost information assigned by the permit system is invalid. Example for this error type is presented in Figure 4-6. In this example, a transition point within a permit was assigned the milepost 7.45, however, the route only goes up to milepost 6.95 which yields an LRS plotting error. All errors were manually inspected and resolved in an iterative process until all permit records were properly matched with the route network.

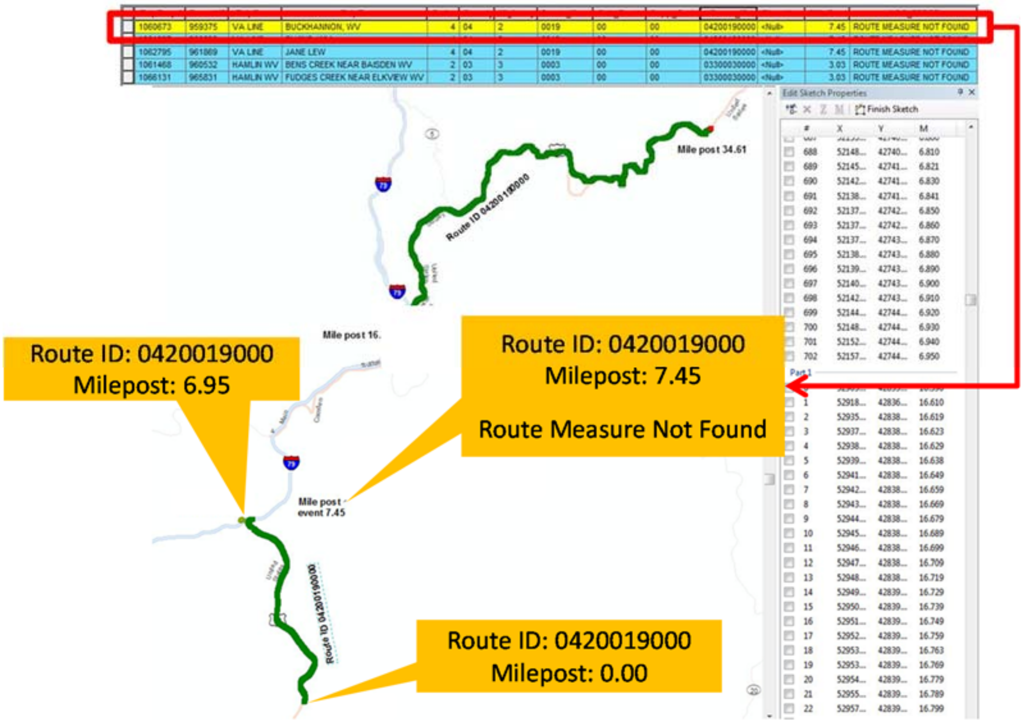


Figure 4-6 Example for LRS Error "Route Measure Not Found"

4.3.6. <u>Step 4. Connecting Transition Points to Create Continuous Route</u>

After the transition points are plotted along the road network, a continuous permit route is created by connecting these points along the mapped roadway, as opposed to a straight line connecting the points. A batch process was developed within ESRI ArcGIS Model Builder and utilized Network Analyst and Tele Atlas Premium StreetMap North America to automatically construct the continuous routes (*14*, *15*). The batch process is illustrated in Figure 4-7. Model elements include an iterator to process all permits in the database and their transition points. The model integrated "MakeRouteLayer", "AddLoactions", and "Solve" tools from the Network Analyst extension in ArcGIS. The first tool creates a route analysis layer, namely "outputRoute", for determining the optimized routes between a set of transition points. The output is carried over to the next tool, AddLocations, which adds the transition points (RouteStops in Figure 4-5) to the network created by the first tool. All transition points are sorted by the order value assigned in Step 1 for a hierarchical assignment. Both the outputs for the AddLocations and MakeRouteLayer tools are analyzed to solve the network analysis layer. The "Solve" tool determines the optimal route by identifying the barriers and constraints within the network transition points, and accounting for their hierarchical order by which their connectivity is determined. The final output, "NetworkAnalystLayerSolved" captures the actual traveled route for each permit within the database, accounting for all transition points.

Figure 4-8 shows Permit 101400093 plotted in GIS after connecting the transition points in Step 4. Notice that the plotted route follows the mapped roadways rather than the straight line distance, which would have missed the ramps connecting I-64 to US 35.

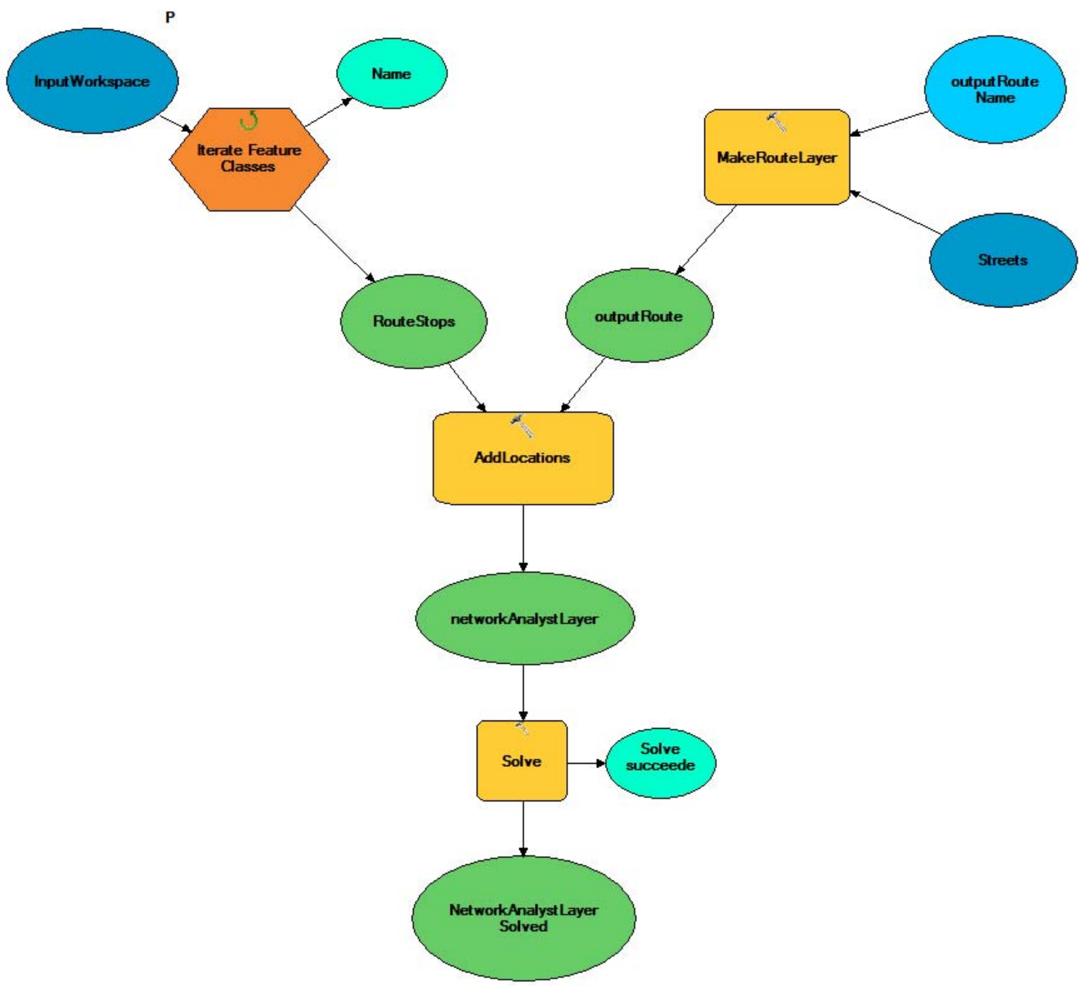


Figure 4-7 GIS Batch Routing Model for Step 4

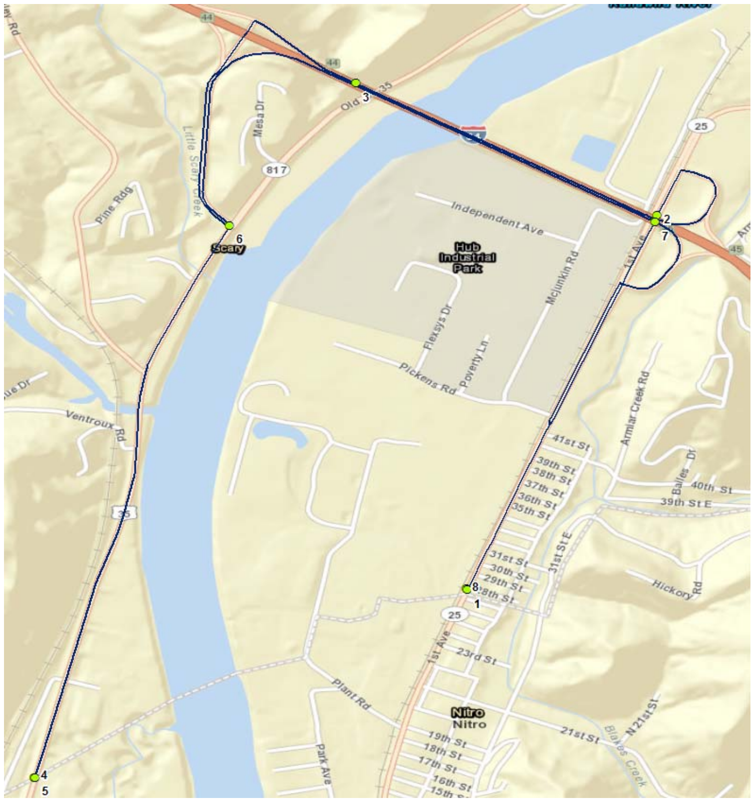


Figure 4-8 Permit 10140093 GIS Plot in Step 4

4.3.7. Step 5. Assigning Direction of Travel to Route Segments

It was desirable to assign the direction of travel to certain segments of the permit route in order to facilitate the assignment of permits to WIM stations. In order to derive the directional information of a route at any specific location, the permit was segmented in order to identify tangent sections. Once the straight segments were identified, the Linear Directional Mean (LDM) was calculated using the corresponding ESRI ArcGIS Spatial Statistics tool. The LDM computes the azimuth for a line, referenced from north (0 degrees) in a clockwise direction. A Python script was used to convert the azimuth to one of the four primary directions – North, South, East, West. Figure 4-9 illustrates the azimuths assigned to each travel direction of the segment of I-64 in Permit 10140093.

Figure 4-9 Assigned Azimuth for I-64 Segment from Permit 10140093

4.4. Sample Applications

4.4.1. Matching Permits to WIM Stations

This methodology can assist estimating the percentage of overweight trucks on certain roads/locations. For example, in West Virginia, truck weight data is collected at 73 weigh-in-motion (WIM) stations. The physical location of the WIM stations was known, so by plotting their location in GIS and identifying the permits that should have crossed the corresponding tangent roadway section, the permit data and the WIM data could be directly compared. Figure 4-10 shows the frequency of unique permits that crossed each WIM station during July 2011. It is easy to see that the WIM sites located along interstates and other primary routes experienced more permitted overweight activity. By comparing the quantity of permits crossing the WIM with the actual overweight truck counts crossing the WIM, compliance rates can be estimated. This information is useful for overweight enforcement purposes and will be discussed in Chapter 5.

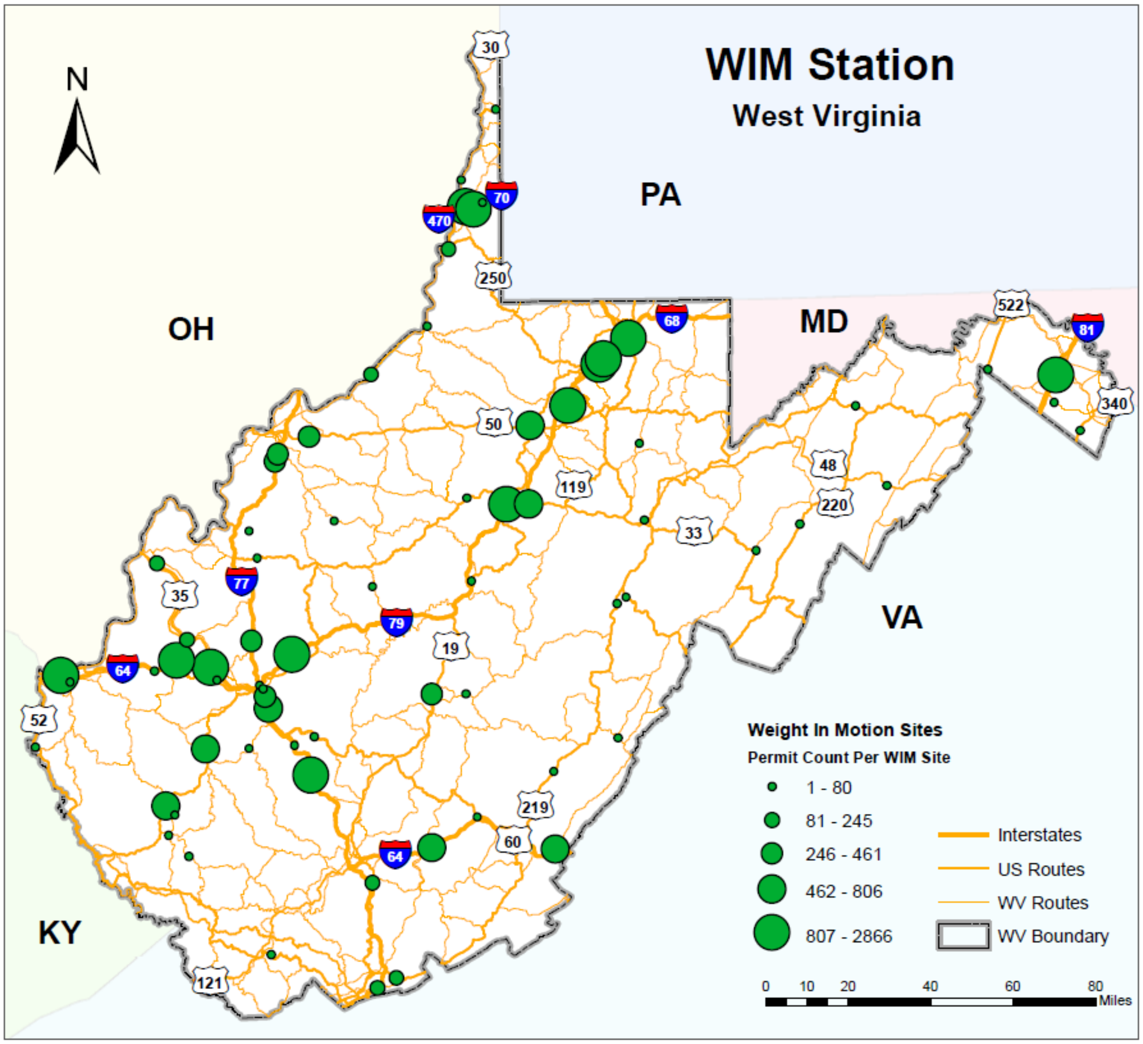


Figure 4-10 Frequency of Permits Crossing WIM Sites (July 2011)

4.4.2. Statewide Roadway Permit Frequency

To protect the highway infrastructure and prioritize maintenance activities, a map illustrating the routes that overweight trucks are taking is useful. Figure 4-11 illustrates the mapped results from the 13,083 permits that were processed for July 2011. The roadway segments with the highest frequency of permitted loads can easily be identified, which tend to be the interstate system. I-79 between Morgantown, WV and the Pennsylvania border showed the highest number of truck permit loads in the range of 1,241 to 2,485 permits during the study period. Heavy truck loaded roadway segments warrant frequent inspections to protect the safety of the infrastructure. Additionally, this information might assist the authorities in selecting segments for permit compliance enforcement.

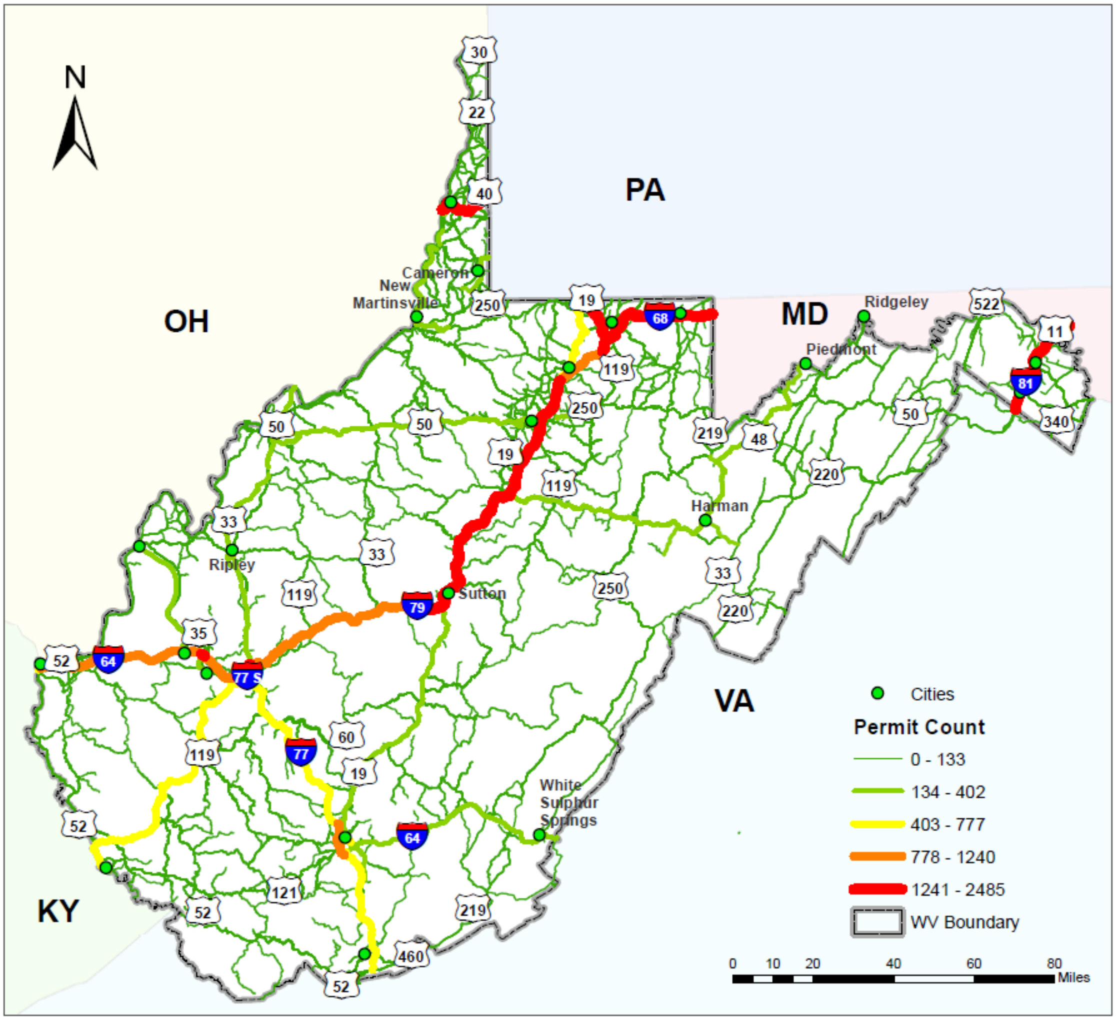


Figure 4-11 Statewide Frequency of Permits on Roadway Network (July 2011)

4.4.3. Origin-Destination Analysis

An origin-destination (OD) matrix can be created to map all OD pairs, which can be used to identify frequently used travel paths, useful in planning new facilities or upgrading existing ones. As an example, all permits with an origin in the vicinity of Nitro, WV were plotted, both as Euclidean Distance (Figure 4-12) and the permitted routes (Figure 4-13). The data in Figure 4-12 could have been plotted without the data processing described in this study since it does not utilize the route information. Figure 4-13 can only be derived after processing the route data, using the procedure discussed here.

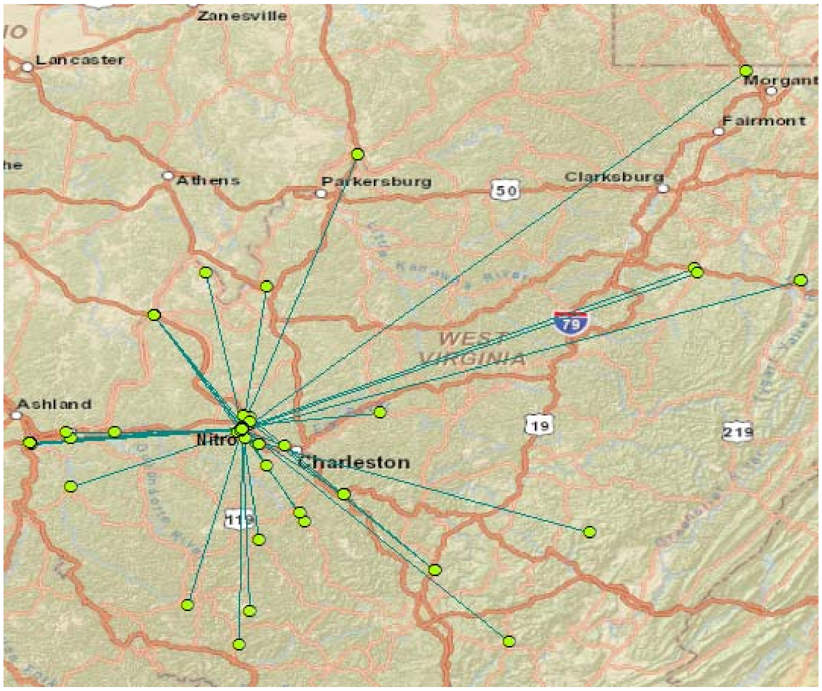


Figure 4-12 Euclidean Distribution of Permit OD Pairs Leaving Nitro, WV (July 2011)

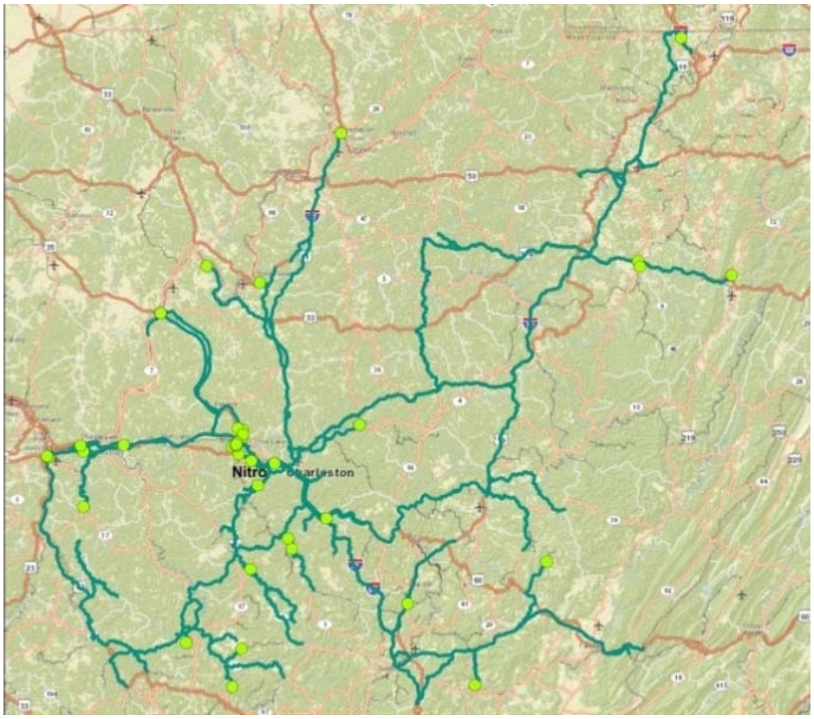


Figure 4-13 Actual Route Distribution of Permit OD Pairs Leaving Nitro,WV (July 2011)

4.5. Summary

This Chapter summarized the permit distribution and presented a methodology to convert oversize/overweight permit data into a format compatible with a LRS for GIS mapping purposes. Overall, the methodology resulted in successful mapping of 91.4% of the permits that contained route information during July 2011 in West Virginia. This methodology could be applied by other states, as most state transportation agencies manage their assets with a LRS and have network established.

With this analysis, the actual route that is assigned to each permit as can be determined. This information along with the travel window will be used in the next chapter to estimate the percentage of overweight trucks without permits based on the unadjusted and adjusted WIM weights during the travel window.

5. COMPARISON OF WIM AND PERMIT DATA

Indications are that many overloaded vehicles travelling our highways are not obtaining the proper permits in West Virginia. This can lead to accelerated damage to the transportation infrastructure. This chapter will combine the historical WIM data with the permit data to in order to estimate the percentages of overweight trucks that have likely not acquired proper permits to travel at that time and/or location. To achieve this goal, three databases pertaining to historical WIM data, WIM station location, and historical oversize/overweight permits are analyzed. These databases were fused and analyzed with a methodology proposed in this Chapter.

5.1. Data Preparation

5.1.1. WIM Station Database

The WIM station database archives location attributes of the 73 WIM sites in West Virginia. Each lane of a WIM site has its own set of sensors and is considered an independent "station". This database also contains latitude and longitude for each site, which will be used for co-locating the WIM with the permits that likely crossed it.

5.1.2. WIM (Per-Vehicle) Database

The WIM per-vehicle database was provided by the WVDOT through their archived data management website (*3*). This database archives vehicles' attributes when they pass through a station on a per-vehicle basis. During 2011, about one month data was archived to this database and provided for this study. It composed a total of 848,925 records (i.e. vehicles) from 109 WIM stations at 40 sites. This data forms the basis of the analysis for this study. The original unadjusted weight data as well as the adjusted weight data will be utilized.

5.1.3. Permit Database

A full year of permit data during 2011 was provided by WV DOT for this study. The database comprised a total of 146,335 issued permits. The data in this database was originally entered manually by system users via the web interface. Therefore, there is a certain amount of error expected in the data entry methods, resulting in the reported vehicle attributes likely not matching the actual vehicle.

Fields from each database are applied in different steps in the data fusion methodology. Table 5-1 summarizes each field's name, description and the database in which it exists.

Table 5-1 Data Fields Employed in the Fusion Process

Field name	Field description	WIM DB	WIM Station DB	Permit DB
Station ID	Four digits number representing a WIM station or site (a site might have multiple WIM stations)	X	X	
Vehicle ID	A unique number to identify a vehicle record in the database	X		
Axle Pattern	combination of numbers showing vehicle layout with axle group (e.g. "1-2-2," "1-2-1-1" for truck Class 9)	X		
Number of axles	Total axle numbers associated with a vehicle	X		X
Gross vehicle weight	Total vehicle weight by adding all individual axle loads of a vehicle • WIM DB using Metric unit (Metric ton) • Permit DB using English unit (lbs)	X		X
Axle loading	Load(mass) associated with individual axle • WIM DB records up to 10 axles with metric unit (metric ton) • Permit DB records up to 21 axles with English unit (lbs)	X		X
Axle spacing	Axle-to-axle space measures • WIM DB records up to 10 axles with metric unit (meter) • Permit DB records up to 21 axles with English unit (feet and inch)	X		X
Vehicle Class	Vehicle class number based on FHWA classification scheme	X		
Date	Date information when a vehicle is detected	X		
Time	Time information when a vehicle is detected	X		
Permit start date	The start day of a valid permit			X
Permit end date	The end day of a valid permit			X
Latitude	Latitude of the WIM site		X	
Longitude	Longitude of the WIM site		X	
Permit ID	A unique number for identifying a permit in the database			X
Routes	A string showing the origin, intersections, and destination of allowed routes for travelling			X

5.2. <u>Data Fusion Methodology</u>

The data fusion methodology is summarized in Figure 5-1. It illustrates that data fusion can be grouped into six major steps that involve the three databases. In Step 1, data in the Permit database is reformatted to facilitate later analysis. Attributes associated with a vehicle in the WIM database and with a permit in the Permit database are processed to obtain a common vehicle classification in Step 2. In Step 3, the data accuracy of WIM and Permit databases is inspected through multiple metrics. Step 4 processes the Permit database route data to facilitate GIS analysis and mapping of the routes. These results feed to Step 5a and 5b for matching the spatial and temporal attributes, respectively, between WIM and Permit databases, which will facilitate vehicle matching and comparisons. After selecting a station for analysis, an analysis is conducted to estimate the percentages in Step 6. In the next section, data preparation of the three databases are discussed. It is followed by presenting each step in the data fusion methodology in sequence from one to six.

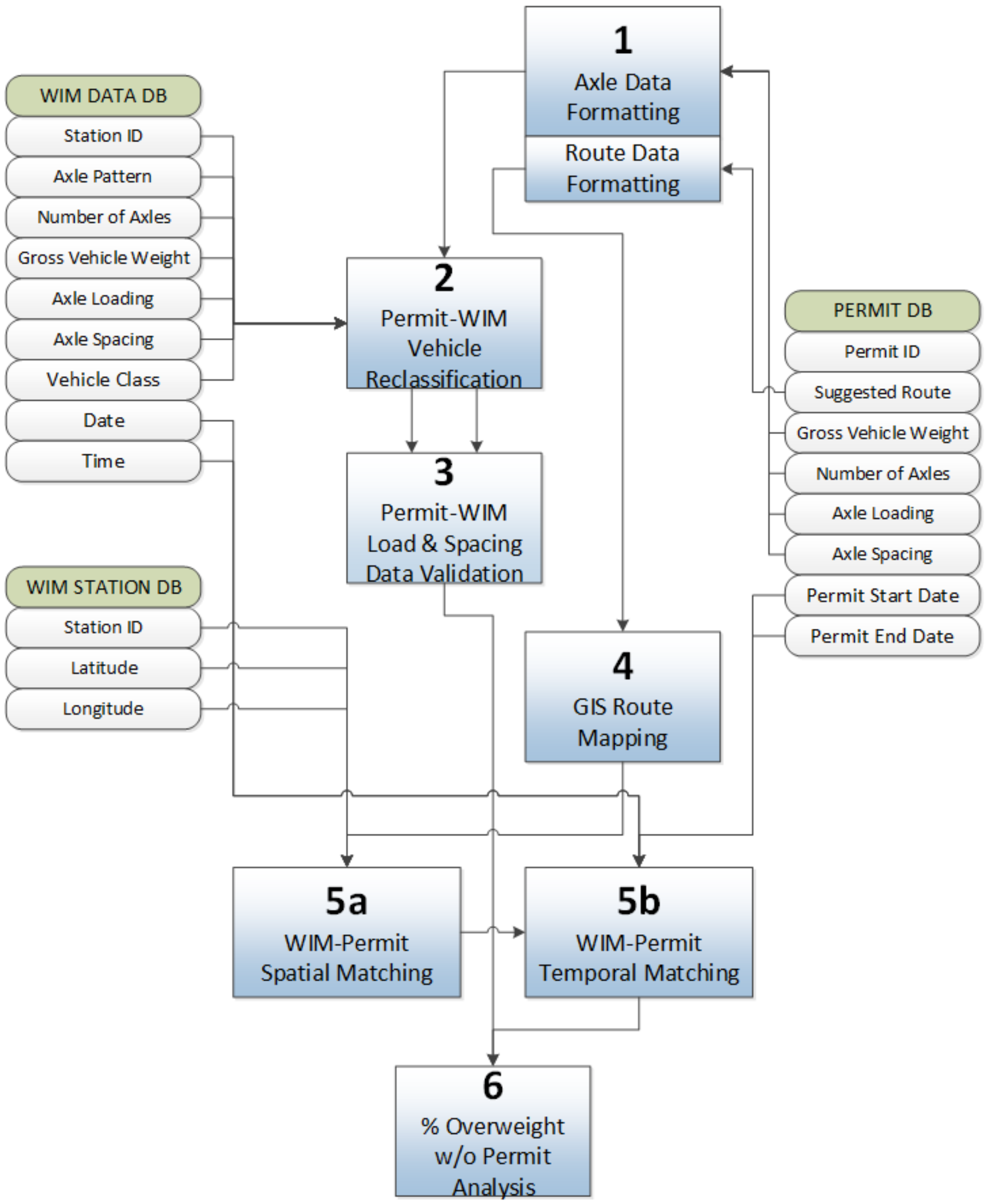
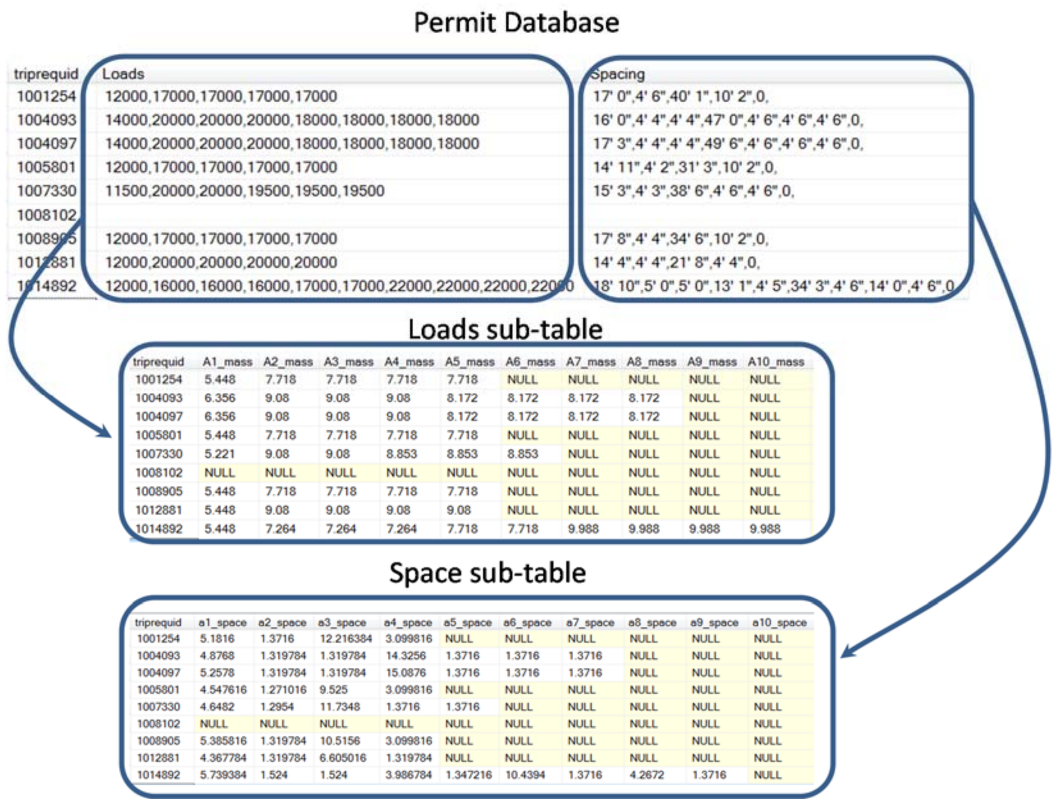


Figure 5-1 WIM and Permit Data Fusion Methodology

5.2.1 Step 1. Permit Data Formatting and Preparation

In the Permit database, attributes associated with axle "loads" and axle "spacing" were archived in a text string format, with inconsistent characters (to denote feet and inches) and character spacing. To utilize these logs for analysis in the data fusion process, they had to be reformatted as numbers. Thus, two sub-tables were generated for the loads and spacing logs through a string partition process that is based on the number of axles. The sub-tables contain the load and space values in numeric format with proper measurement units for analysis. This data was already in English units, but both the Permit data and WIM data need to be in the same units for analysis, so any units conversion for the Permit data occurred during this step. Figure 5-2 shows examples of data logs pertaining to nine permits in the Permit database and the sub-tables after reformatting. The updated sub-tables were populated back into the primary database for analysis purposes.



Permit Database

tripreqid	Loads	Spacing
1001254	12000,17000,17000,17000,17000	17' 0",4' 6",40' 1",10' 2",0,
1004093	14000,20000,20000,20000,18000,18000,18000,18000	16' 0",4' 4",4' 4",47' 0",4' 6",4' 6",4' 6",0,
1004097	14000,20000,20000,20000,18000,18000,18000,18000	17' 3",4' 4",4' 4",49' 6",4' 6",4' 6",4' 6",0,
1005801	12000,17000,17000,17000,17000	14' 11",4' 2",31' 3",10' 2",0,
1007330	11500,20000,20000,19500,19500,19500	15' 3",4' 3",38' 6",4' 6",4' 6",0,
1008102		
1008905	12000,17000,17000,17000,17000	17' 8",4' 4",34' 6",10' 2",0,
1012881	12000,20000,20000,20000,20000	14' 4",4' 4",21' 8",4' 4",0,
1014892	12000,16000,16000,16000,17000,17000,22000,22000,22000,22000	18' 10",5' 0",5' 0",13' 1",4' 5",34' 3",4' 6",14' 0",4' 6",0

Loads sub-table

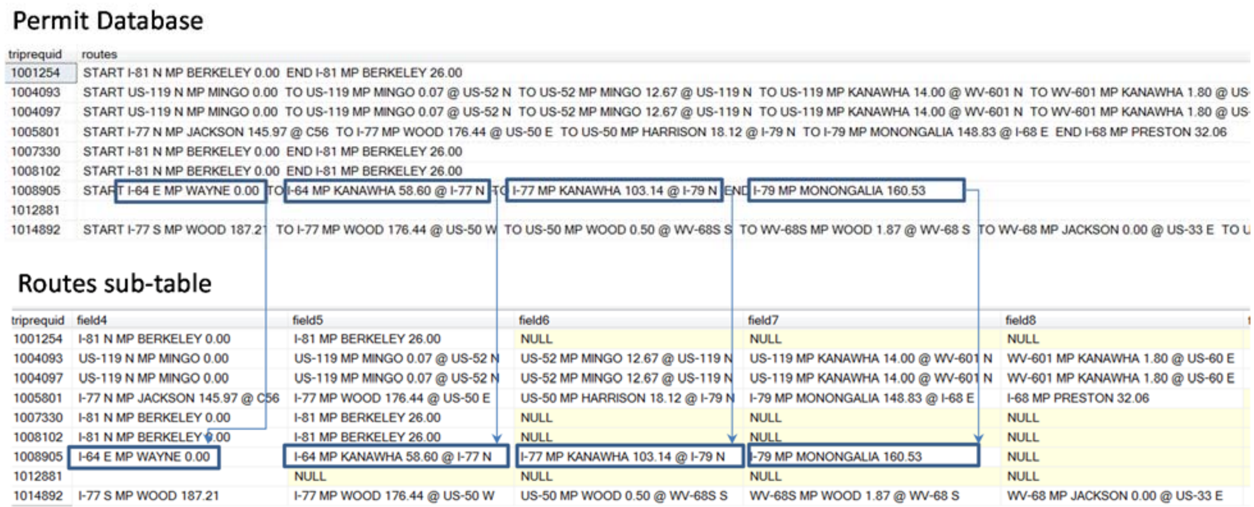
tripreqid	A1_mass	A2_mass	A3_mass	A4_mass	A5_mass	A6_mass	A7_mass	A8_mass	A9_mass	A10_mass
1001254	5.448	7.718	7.718	7.718	7.718	NULL	NULL	NULL	NULL	NULL
1004093	6.356	9.08	9.08	9.08	8.172	8.172	8.172	8.172	NULL	NULL
1004097	6.356	9.08	9.08	9.08	8.172	8.172	8.172	8.172	NULL	NULL
1005801	5.448	7.718	7.718	7.718	7.718	NULL	NULL	NULL	NULL	NULL
1007330	5.221	9.08	9.08	8.853	8.853	8.853	NULL	NULL	NULL	NULL
1008102	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1008905	5.448	7.718	7.718	7.718	7.718	NULL	NULL	NULL	NULL	NULL
1012881	5.448	9.08	9.08	9.08	9.08	NULL	NULL	NULL	NULL	NULL
1014892	5.448	7.264	7.264	7.264	7.718	7.718	9.988	9.988	9.988	9.988

Space sub-table

tripreqid	a1_space	a2_space	a3_space	a4_space	a5_space	a6_space	a7_space	a8_space	a9_space	a10_space
1001254	5.1816	1.3716	12.216384	3.099816	NULL	NULL	NULL	NULL	NULL	NULL
1004093	4.8768	1.319784	1.319784	14.3256	1.3716	1.3716	1.3716	NULL	NULL	NULL
1004097	5.2578	1.319784	1.319784	15.0876	1.3716	1.3716	1.3716	NULL	NULL	NULL
1005801	4.547616	1.271016	9.525	3.099816	NULL	NULL	NULL	NULL	NULL	NULL
1007330	4.6482	1.2954	11.7348	1.3716	1.3716	NULL	NULL	NULL	NULL	NULL
1008102	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1008905	5.385816	1.319784	10.5156	3.099816	NULL	NULL	NULL	NULL	NULL	NULL
1012881	4.367784	1.319784	6.605016	1.319784	NULL	NULL	NULL	NULL	NULL	NULL
1014892	5.739384	1.524	1.524	3.986784	1.347216	10.4394	1.3716	4.2672	1.3716	NULL

Figure 5-2 Reformatting Load and Spacing Fields in Permit Database

The "Routes" field in the Permit database contains the recommended route for the vehicle to take, which accounts for known restrictions, as automatically generated by the Permit system. In the database provided for this project, that field contains a single text string that contains all of the turn-by-turn instructions, regardless of the number of segments in the trip. The string uses intersection name or route mile marker to denote the start/origin, end/destination, and transition points of routes that are assigned to a permit. In order to facilitate processing this data in GIS, this single text string was partitioned based on key words in a string showing origin (i.e. START), transitions(i.e. TO) and destination (i.e. END) of a route so that each point was in a separate field. A sample of the sub-table that was generated in the database based on the route field is shown in Figure 5-3. This procedure is discussed in more detail in Chapter 4.



Permit Database

tripequid	routes
1001254	START I-81 N MP BERKELEY 0.00 END I-81 MP BERKELEY 26.00
1004093	START US-119 N MP MINGO 0.00 TO US-119 MP MINGO 0.07 @ US-52 N TO US-52 MP MINGO 12.67 @ US-119 N TO US-119 MP KANAWHA 14.00 @ WV-601 N TO WV-601 MP KANAWHA 1.80 @ US-
1004097	START US-119 N MP MINGO 0.00 TO US-119 MP MINGO 0.07 @ US-52 N TO US-52 MP MINGO 12.67 @ US-119 N TO US-119 MP KANAWHA 14.00 @ WV-601 N TO WV-601 MP KANAWHA 1.80 @ US-
1005801	START I-77 N MP JACKSON 145.97 @ C56 TO I-77 MP WOOD 176.44 @ US-50 E TO US-50 MP HARRISON 18.12 @ I-79 N TO I-79 MP MONONGALIA 148.83 @ I-68 E END I-68 MP PRESTON 32.06
1007330	START I-81 N MP BERKELEY 0.00 END I-81 MP BERKELEY 26.00
1008102	START I-81 N MP BERKELEY 0.00 END I-81 MP BERKELEY 26.00
1008905	START I-64 E MP WAYNE 0.00 TO I-64 MP KANAWHA 58.60 @ I-77 N TO I-77 MP KANAWHA 103.14 @ I-79 N END I-79 MP MONONGALIA 160.53
1012881	
1014892	START I-77 S MP WOOD 187.21 TO I-77 MP WOOD 176.44 @ US-50 W TO US-50 MP WOOD 0.50 @ WV-68S S TO WV-68S MP WOOD 1.87 @ WV-68 S TO WV-68 MP JACKSON 0.00 @ US-33 E TO U

Routes sub-table

tripequid	field4	field5	field6	field7	field8
1001254	I-81 N MP BERKELEY 0.00	I-81 MP BERKELEY 26.00	NULL	NULL	NULL
1004093	US-119 N MP MINGO 0.00	US-119 MP MINGO 0.07 @ US-52 N	US-52 MP MINGO 12.67 @ US-119 N	US-119 MP KANAWHA 14.00 @ WV-601 N	WV-601 MP KANAWHA 1.80 @ US-60 E
1004097	US-119 N MP MINGO 0.00	US-119 MP MINGO 0.07 @ US-52 N	US-52 MP MINGO 12.67 @ US-119 N	US-119 MP KANAWHA 14.00 @ WV-601 N	WV-601 MP KANAWHA 1.80 @ US-60 E
1005801	I-77 N MP JACKSON 145.97 @ C56	I-77 MP WOOD 176.44 @ US-50 E	US-50 MP HARRISON 18.12 @ I-79 N	I-79 MP MONONGALIA 148.83 @ I-68 E	I-68 MP PRESTON 32.06
1007330	I-81 N MP BERKELEY 0.00	I-81 MP BERKELEY 26.00	NULL	NULL	NULL
1008102	I-81 N MP BERKELEY 0.00	I-81 MP BERKELEY 26.00	NULL	NULL	NULL
1008905	I-64 E MP WAYNE 0.00	I-64 MP KANAWHA 58.60 @ I-77 N	I-77 MP KANAWHA 103.14 @ I-79 N	I-79 MP MONONGALIA 160.53	NULL
1012881		NULL	NULL	NULL	NULL
1014892	I-77 S MP WOOD 187.21	I-77 MP WOOD 176.44 @ US-50 W	US-50 MP WOOD 0.50 @ WV-68S S	WV-68S MP WOOD 1.87 @ WV-68 S	WV-68 MP JACKSON 0.00 @ US-33 E

Figure 5-3 Reformatting Routes Field in Permit Database

<u>5.2.2 Step 2: Vehicle Classification for WIM and Permit Data</u>

It was decided that the LTPP scheme (*6*) would be applied to both the WIM and permit datasets in order to have a common classification scheme for drawing comparisons and analysis. The actual scheme utilized is not as important as having a common scheme between the two databases, however some consideration should be given to choose a scheme that can accommodate a high number of axles, since oversize/overweight vehicles tend to have many axles. One benefit of the LTPP rules are that vehicles with up to 11 axles can be classified based on axle spacing, steering axle weight, and gross vehicle weight, whereas the West Virginia vendor's rules only went up to eight axles with limited weight attributes.

After the reformatting task in Step 1 for the Permit database, the attributes associated with the FAW, GVW, axle-to-axle spacing, and number of axles are processed to classify permits for their vehicle classification using LTPP rules. Thus each permit is associated with one vehicle class number. The percentage distribution of vehicle classification in the Permit database, as well as the WIM database classification distribution, is shown in Figure 5-4.

As expected, the majority of the permits are in the truck classes 9, 10, and 14. Classes 9 and 10 are conventional tractor-trailer combinations, with the only difference being that the Class 10 trailer has a tridem set of axles instead of a tandem set of axles. It is surprising to see a much higher percentage of Class 10 permits compared to the percentage of Class 10 vehicles in the WIM database. The Class 14 vehicles are the unusual vehicle types that do not meet the criteria for any other class. These are all of the unusual truck configurations that have many axles and are commonly used to haul oversize and overweight loads.

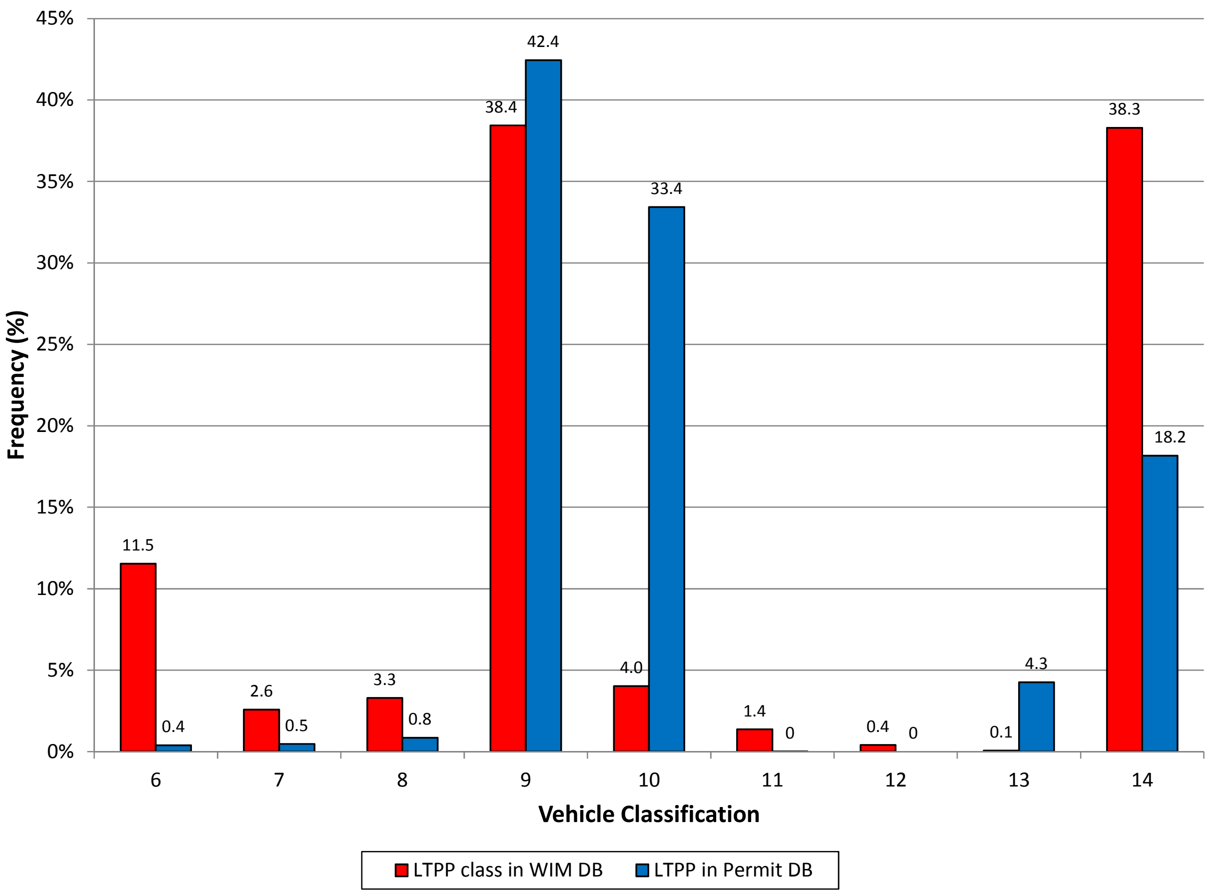


Figure 5-4 Vehicle Classification in WIM and Permit Databases (Classes 6-14)

5.2.3 Step 3. Data Accuracy Validation

A WIM site with accurate sensor data is preferred for this study since the number of overweight trucks will be needed in order to calculate a percentage of overweight trucks with permits. If the weights that these percentages are based on are inaccurate, then the percentages will be inaccurate. Two known metrics for evaluating the weight and axle spacing measurement accuracy were employed. Specifically, the average drive tandem axle spacing (i.e. axle space 2-3) and the steering axle weight of Class 9 trucks typically fall within the range 4.25 to 4.58 feet and 9,000 to 11,000 lbs, respectively (*7*). The distributions associated with these attributes were applied to check the data accuracy of the WIM stations. Similar distributions can also be reviewed for the Permit data to check the reasonableness of the data for the Class 9 vehicles, keeping in mind that these measurements are manually entered by users and may not closely match the actual vehicle characteristics. Furthermore, as expected, most of the vehicles detected by a WIM sensor should be able to be classified by the FHWA classification scheme, with the exception of the few anomalous vehicles with uncommon axle configurations. Thus, the distribution of unclassified vehicles also assists in selecting a WIM site with better data quality. Details of the WIM data review and necessary adjustments are included in Chapter 3.

Unlike the WIM vehicle records that are measured by sensors, the vehicle loads and spacing attributes in the Permit database are manually input by applicants who apply for permits. Thus, the accuracy of the data might not be as reliable as the WIM data. In addition, there is no Pattern field in the Permit database, and the Class 9 vehicles might include other truck types (e.g. type "1-1-3"). Figure 5-5 provides the GVW distribution by vehicle classification for all permits in 2011. It is interesting to note the majority of the permits in the 80,000-lb bin are exactly 80,000 lbs, the legal limit. One possible explanation for this is that a number of the permits are for oversize loads (e.g., height or width) that do not exceed the legal limit, and therefore the applicants simply selected weights that were the maximum of the legal limit. Unfortunately, it is not possible to tell from the database whether the permit is for oversize dimensions only and not overweight loads. In the summary analysis, the permit GVW will be based on GVW higher than GVW to exclude the vehicles that are likely oversize and not overweight.

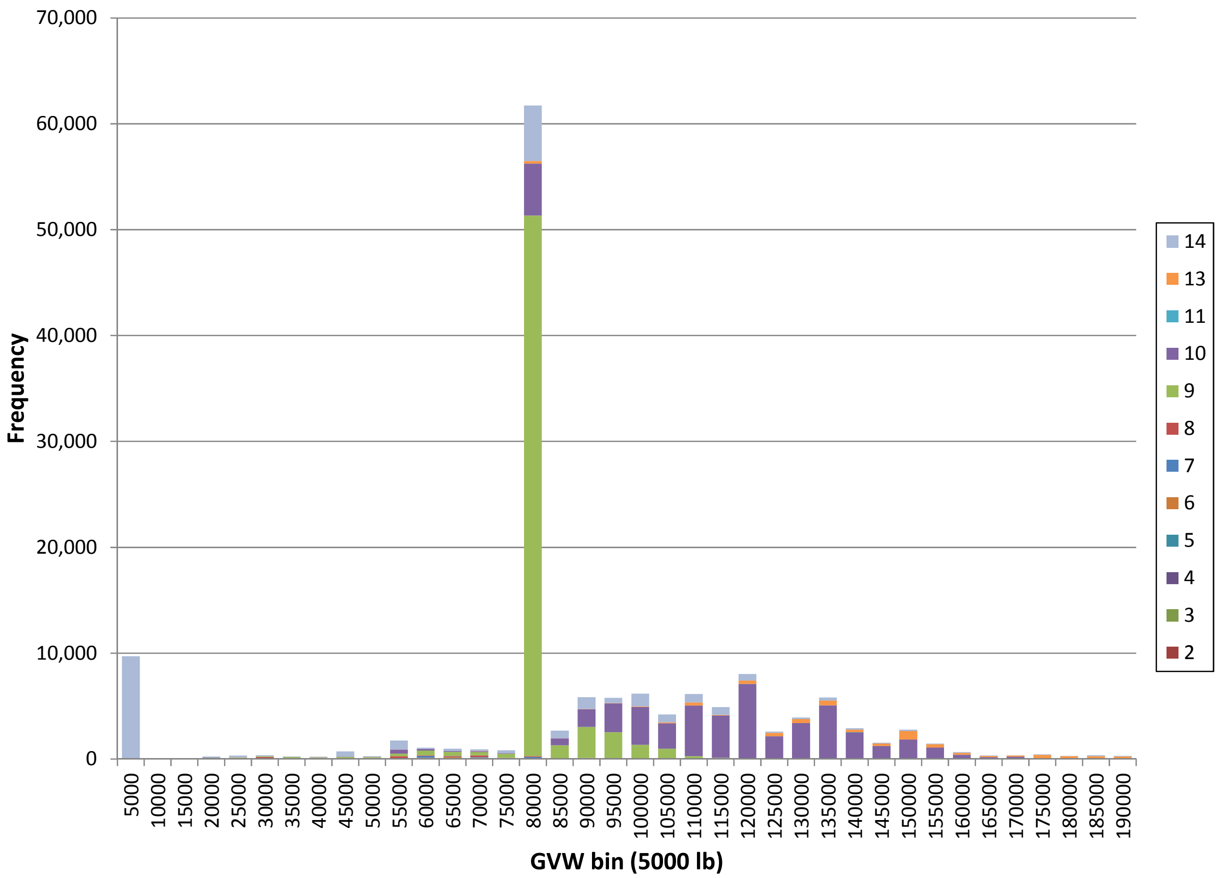


Figure 5-5 GVW Distribution for All Permits by Classification

5.2.4 Step 4. Permit Data Mapped in GIS

Since the detail of permits associated with certain WIM site is not direct information in the Permit database, such information is retrieved through GIS route mapping process. This process is designed for listing permits that are crossing a particular WIM site and involved the process as discussed thoroughly in Chapter 4. It is summarized as following:

- *Formatting intersections:* Results from the route sub-table in Step 1 were converted to the WVDOT LRS format, where roads are referenced with a standard format using milepost (MP) and 11 digit route ID, showing county, sign, route, sub route and other supplemental information.
- *Creating GIS network*: Points were created on the WVDOT LRS road network based on the converted route ID and MP by utilizing Linear Referencing (*16*) and Dynamic

Segmentation (*17*), which is a process of computing a location on a spatial data set comprised of linear features based on a linear measurement.

- *Routing:* A traversal permit route was created which connects points made up of the origin, intersection, and destination. ESRI ArcGIS Desktop software (*18*) and Tele Atlas Premium StreetMap (*19*) were used for the routing process.

5.2.5 Step 5: Spatial and Temporal Matching of WIM and Permit Records by Site

This step in the process is to merge the route information from the GIS analysis (Step 4) with the locations from the WIM Stations database to identify those permits that should have crossed each WIM station. Specifically, WIM sites were located on the GIS road network based on their latitude and longitude and spatially joined with the traversing permit routes. The IDs of the permits associated with each WIM site/station were compiled. Based on the data availability and data accuracy reviewed in the previous steps, Sites 1, 5, 6, 8, and 12 were selected for detailed analysis. Site 8 will be used to illustrate the details of this analysis. Site 8 is located on US 19 in Nicholas County. There are two lanes in each direction and four stations are deployed on this site (3312, 3313, 3314, 3315). In 2011, there were 28,197 WIM records for this site during the analysis period.

The next step is to temporally match the permits with the WIM data to define the search window for the analysis. Unlike the WIM database that vehicles are assigned a timestamp when passing through the WIM station, each permit contains a start date and end date to allow some travel flexibility. The WIM database only covers data from July 26 to August 3 in 2011 for Site 8. Thus the permits that had a window that fell on any of these dates were included in order to be conservative. After the spatial and temporal considerations, 123 permits from the Permit database are identified for subsequent analysis.

5.2.6 Step 6. Estimate Percentage of Overweight Trucks without Permits

This step estimates the percentage of overweight trucks without a permit by comparing the number of permits that should have crossed the WIM with the number of overweight trucks observed at the WIM during the same time period.

The legal limit for GVW is 80,000 lbs, but a 10% tolerance is allowed when enforcing the weight limits, so 88,000 lbs is used as the threshold for identifying an overweight vehicle in the data. Furthermore, vehicles with a GVW of exactly 80,000 lbs in the permit database were not considered since these were most likely oversize trucks and not overweight trucks. But all vehicles in the permit database with GVW greater than 80,000 lbs are counted, in order to be conservative. The analysis of Site 8 resulted in the following counts in each overweight group for both the WIM and permit databases. The overweight WIM count is provided for both the unadjusted and adjusted data. The breakdown of these overweight groups by vehicle class is illustrated in Figure 5-6.

- WIM Site 8 unadjusted weights with 10% weight tolerance (1,076 records with GVW > 88,000 lbs),
- WIM Site 8 adjusted weights with 10% weight tolerance (2,611 records with GVW > 88,000 lbs),
- Permits crossing Site 8 above 80,000 lbs (53 permits with GVW > 80,000 lbs).

The estimated percentage of overweight trucks with proper permits is calculated by taking the number of permitted vehicles divided by the total number of overweight trucks. In this case, the percentages would be 5% for the unadjusted weight data and 2% for the adjusted weight data. The distributions by vehicle class suggest that the Class 14 vehicles are more likely to obtain a permit than a Class 9 vehicle. Since Class 9 vehicles can use an enclosed trailer or covered wagon to hide the contents, it is less likely for them to be caught or singled out by enforcement personnel. Whereas, Class 14 vehicles will most likely have an unusual axle configuration due to the size of the load and are more likely to get targeted for enforcement.

It is important to note that Site 8 is on a CRTS route. Coal trucks traveling these routes are primarily Class 10 vehicles. Note in Figure 5-6 that the number of overweight trucks in Class 10 is relatively unaffected by the WIM adjustment, most likely because their GVW was already so high that they were well above the 88,000-lb threshold even with the sensors weighing them light. Even if the 253 unadjusted (268 adjusted) Class 10 trucks were removed, the percentage of trucks in compliance is still very low for this site.

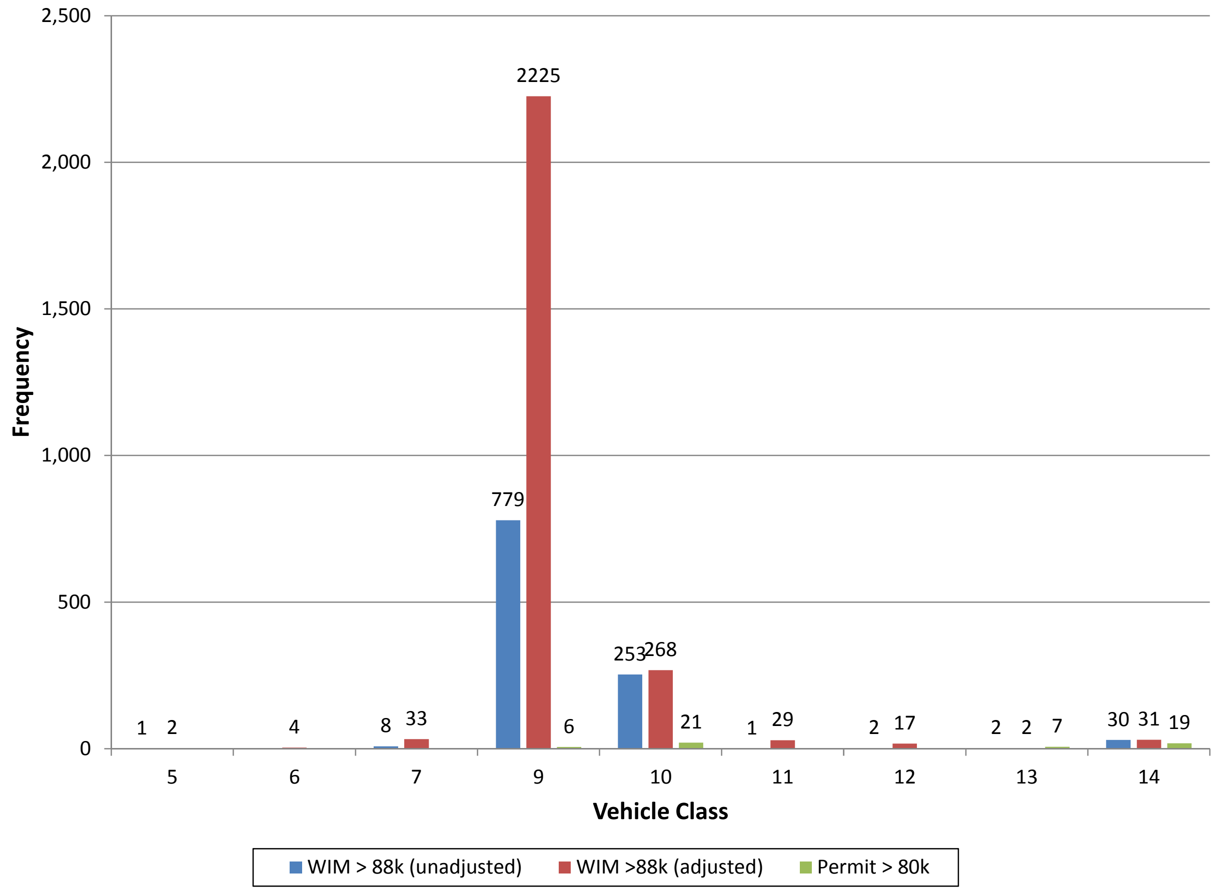


Figure 5-6 Overweight Vehicles in WIM and Permit Databases by Class (Site 8)

5.3. Application of Overweight Truck Analysis to Five Sites

This methodology was applied to a total of five WIM sites for estimating the percentage of overweight trucks with proper permits. The site selection considered data availability and quality and the analysis period was limited to July 28 to August 2, 2011 in order to allow a valid comparison between sites. The sites chosen are Site 1, 5, 6, 8, and 12.

- Site 1 is on I-64 in Summers County with 4 stations
- Site 5 is on I-79 in Lewis County with 4 stations
- Site 6 is on I-79 in Kanawha County with 4 stations
- Site 8 is on US 19 in Nicholas County with 4 stations
- Site 12 is on US 460 in Mercer County with 4 stations

Table 5-2 summarizes the number of overweight trucks (GVW exceeding 88,000 lbs to account for 10% tolerance) measured by the WIM system during this timeframe using both adjusted and unadjusted weight data, the number of permits that should have crossed the WIM system during this timeframe, and the estimated percentages of overweight trucks holding proper permits. The results show that a significant difference exists between the permits issued and the overweight vehicles observed in the field at these selected sites, even without the WIM data being adjusted. The percentage of "compliance" ranges from 2% to 46% using the adjusted WIM data. Considering the volume of vehicles and the fact this is only a 6-day period, these results suggest that compliance is not very good.

The two northbound sites on I-79 illustrate higher compliance rates and a higher number of permits than the other sites. This could be attributed to the presence of a weigh station on I-79 near Morgantown. The results for Site 6 northbound support the decision to adjust the weight data. Based on the unadjusted WIM data, there were more permits than overweight trucks, which would be highly unlikely to occur.

Table 5-2 Estimate of Percentage of Overweight Trucks Holding Proper Permits

Site (Route)	Direction of Travel	Total Permits	Permits > 80k	Total WIM Records	WIM > 88k (unadjusted)		WIM > 88k (adjusted)	
					Count	%	Count	%
Site 1 (I-64)	Eastbound	100	45	20,320	64	70%	597	8%
	Westbound	80	33	13,225	689	5%	1,248	3%
Site 5 (I-79)	Northbound	362	240	16,172	293	82%	662	36%
	Southbound	240	115	12,970	331	35%	1,096	10%
Site 6 (I-79)	Northbound	303	222	10,257	199	112%	486	46%
	Southbound	190	95	17,430	410	23%	875	11%
Site 8 (US 19)	Northbound	60	19	19,426	466	4%	1,195	2%
	Southbound	63	34	8,771	610	6%	1,416	2%
Site 12 (US 460)	Eastbound	20	8	6,075	110	7%	274	3%
	Westbound	22	12	5,387	93	13%	231	5%

5.4. Summary

In this chapter, a data fusion methodology was utilized to combine the WIM data and the permit data in order to estimate the percentage of overweight trucks with proper permits. The methodology was applied to data from five sites selected based on data availability and accuracy.

The results were derived from both the original weight data and data adjusted to account for accuracy concerns. The results indicate that a significant difference exists between the permits that should be crossing the WIM sites and the observed overweight trucks. This information is useful to decision makers regarding the enforcement of overweight truck activity and permitting.

6. SUMMARY

The objective of this study was to estimate the percentage of overweight trucks on West Virginia's roads that have the proper permits. This percentage was derived by analyzing permit data from the WVDOT oversize/overweight permit system archive and WIM data collected at sites across West Virginia for the year 2011.

The permit records contain route information that was mapped using GIS to identify the specific permits that should have crossed each WIM station. A procedure was developed within this project that enabled the archived permit route information to be formatted in a way that facilitated the mapping. The results of this permit mapping could be useful to WVDOT for planning and enforcement purposes beyond the scope of this project. The permit data contained user entered truck characteristics, which included axle spacings and gross vehicle weights. The axle spacing information was used to assign a vehicle classification for comparison purposes.

The WIM data was analyzed to verify the accuracy of the data using traditional metrics. The weight data at many of the sites was considered to be inaccurate, so WIM data from other states that was collected as part of a Transportation Pooled Fund study were obtained and utilized to both evaluate the West Virginia data and form the basis of a tuning procedure used to adjust the WIM data. The poor accuracy is likely attributed to the use of a sensor that is temperature dependent and the related use of autocalibration, lack of routine maintenance and calibration, and lack of continuous monitoring. The West Virginia WIM data was reclassified using a set of rules developed for the Long Term Pavement Performance (LTPP) project, which are considered to be more reliable than the rules used by the WIM systems in West Virginia. This resulted in more vehicles being classified.

Five WIM sites were selected for in-depth analysis based on the availability and quality of the WIM data. The weight data for these sites was adjusted using the procedure developed within this project. The tuning procedure generally increased the weights at these five sites. These sites were:

- Site 1 is on I-64 in Summers County with 4 lanes,

- Site 5 is on I-79 in Lewis County with 4 lanes,
- Site 6 is on I-79 in Kanawha County with 4 lanes,
- Site 8 is on US 19 in Nicholas County with 4 lanes, and
- Site 12 is on US 460 in Mercer County with 4 lanes.

Once the permits with GVW exceeding 80,000 lbs were assigned to each WIM station, the number of overweight trucks exceeding 88,000 lbs (legal limit plus 10% tolerance) was computed for both the unadjusted and adjusted WIM data. This allowed the calculation of the percentage of overweight trucks with proper permits for each site. These values ranged from 2% at Site 8 up to 46% at Site 6 based on the adjusted WIM data. The values ranged from 4% at Site 8 up to 112% at Site 6 based on the unadjusted WIM data.

It was not feasible to determine if the overweight vehicles measured by the WIM were the exact same vehicle that applied for the permit, but this analysis is deemed sufficient for estimating an overall percentage. At the outset of the project, it was anticipated that the permit records and WIM records could be matched based on the axle spacing and axle weight data, but the permit vehicle attributes were too inconsistent since they were estimated values entered by the applicant and not true measured values.

Based on this sample of WIM sites, there seems to be a low percentage of vehicles complying with overweight limits in West Virginia. The sites with the highest compliance rates were located on I-79, which has weigh stations in the northern part of the state near Morgantown. The compliance rate among unclassified vehicles also tended to be higher than the more common Class 9 vehicles. The unclassified vehicles tend to be unique axle configurations that are necessary for oversize and overweight loads, so it isn't surprising that they are more likely to apply for a permit compared to a common truck type that can conceal its load in a trailer or covered wagon.

In order to better estimate the overweight truck problem, it is feasible to conduct a field investigation at specific locations where overweight truck activity is suspected. The archived WIM data can be used to an extent to help identify these locations. Utilizing a location with existing WIM stations would be ideal, as long as the accuracy of the sensors was monitored throughout the project. It may also be useful to conduct the study in the vicinity of a weigh station, on both the mainline and possible bypass routes, to document the effect of the weigh station operations on overweight truck activity. The scales at the weigh station would also provide a mechanism for validating the WIM data using unique vehicles crossing both sensors.

Other recommendations that resulted from this study are summarized below.

- Modify the permit database system to record route information compatible with the WVDOT Linear Reference System. This will facilitate future analysis of this data for planning and enforcement purposes.
- Modify the permit database system so that numeric fields are not free-form. The field formatting should be set to feet and inches for distances and pounds for weights so that the applicant only enters numbers and not text. This will greatly facilitate future analysis of this data.
- Initiate a program to review the WIM system accuracy on a daily or weekly basis in order to identify sensor and calibration problems as soon as possible. These stations should also be calibrated on an annual basis, at a minimum.
- Investigate the autocalibration settings being used at all weigh stations and determine the impact it has on the reported weights.

7. REFERENCES

1. "Hauling Permits," Website, West Virginia Department of Transportation, accessed June, 2013, http://www.transportation.wv.gov/highways/maintenance/hauling_permits/Pages/default
2 Coal Resource Transportation System Roads. http://www.transportation.wv.gov/highways/programplanning/preliminary_engineering/Pages/CRTS.aspx
3. WV DOH Traffic Server. http://trafficserver.transmetric.com/wvdoh. Accessed January, 2012.
4. FHWA Website http://onlinemanuals.txdot.gov/txdotmanuals/tri/vehicle_classification_using_fhwa_13category_scheme.htm
5. LTPP Project website. accessed Oct. 2013. http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/pavements/ltpp/
6. Washington State Transportation Center, & Applied Research Associates. *Verification, refinement and applicability of LTPP classification scheme*. Olympia, WA: Washington State Transportation Center. June, 2010.
7. Nichols P.A., and Bullock, M.D. Quality Control Procedures for Weight-in-Motion Data. Research Report: C-36-17 MMM. December 2004.
8. Southgate, "Quality Assurance of Weigh-In-Motion Data," 2001.
9 Dahlin, C., Proposed Method for Calibrating Weigh-in-Motion Systems and for Monitoring That Calibration Over Time, *Journal of Transportation Research Record* 1364, pp. 161-168, Washington, D.C., 1992.
10. R manual. http://cran.r-project.org/manuals.html
11. Federal Highway Administration, "Federal Highway Administration Linear Referencing Practitioners Guidebook," GIS/Trans Ltd, 1999.
12. Curtin, K.M. "Linear Referencing," The Encyclopedia of Geographic Information Science, pp. 261-264. K. Kemp ed. Sage Publications, 2008.
13. "Geospatial Transportation Information," Website, West Virginia Department of Transportation, accessed June, 2013, http://www.transportation.wv.gov/highways/programplanning/gti/Pages/default.aspx
14. "ESRI 2011. ArcGIS Desktop: Release 10.1.," Redlands, CA: Environmental Systems Research Institute, 2011.
15. "ESRI ArcPad 10 StreetMap Premium Tele ATLAS North America," Redlands, CA: Environmental Systems Research Institute. 2010.
16. Highway Research Board, and National Academy of Engineering. 1974. Highway Location Reference Methods, National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice 21. Washington, D.C.: Highway Research Board, National Academy of Sciences.
17. Cadkin, J. Understanding dynamic segmentation. ArcUser magazine, October-December issue, 40-43. 2002.
18. Environmental Systems Research Institute. ArcGIS desktop 10 help.
19. ESRI ArcPad 10 StreetMap Premium Tele Atlas North America. Redlands, CA: Environmental Systems Research Institute. 2010.

8. APPENDIX

APPENDIX A. WEST VIRGINIA WEIGHT AND PERMIT INFORMATION

Revised 8-1-2013

WEST VIRGINIA

CONTACT INFORMATION:

Department of Transportation
State Capitol Complex
Building 5, Room 356
Charleston, WV 25305

Hours: 7:30am – 4:00pm, Monday - Friday
Phone: (304)558-0384

Website to Motor Vehicle Laws : http://www.legis.state.wv.us
Select WV Code. Browse to Chapter 17C, Article 17-1 through 18-1
Website to Legislative Rules: www.wvsos.com/csrdocs/wordDocs/157-05.doc
Websites to Apply On Line: http://wv.gotpermits.com (for West Virginia permits only – no convenience fee) or www.gotpermits.com (multi-state site – convenience fee added). Website for More West Virginia Hauling and Permit Information: www.transportation.wv.gov - Use Permits link, then Hauling Permits Link.

LEGAL LIMITS

Interstate Highways

GVW	80,000
0 (steer)	20,000
0 (single)	20,000
00 (tandem)	34,000

-Federal Bridge Formula applies to all other combinations
TOLERANCE: None

US and WV Routes

GVW	80,000
Axle Limit	20,000
Single Unit Tandem (3 axles total)	60,000
Single Unit Tridem (4 axles total)	70,000
Single Unit Quadrum (5 axles total)	73,000
Tractor-Semi Trailer (5 axles total)	80,000
Tractor-Semi Trailer (6 axles total)	80,000
Combination Tandem w/2 axles Trailer (5 axles total)	80,000
Combination Tridem w/2 axles Trailer (6 axles total)	80,000

TOLERANCE: 10%

Local Service Routes

GVW	65,000
0 (steer)	20,000
0 (single)	20,000
00 (tandem)	34,000

TOLERANCE: 10%

WIDTH	8'	Local Service routes with lanes under 10' wide			unlimited overall length on Interstates and National Network Highways
	8'6"	Interstate, US and WV routes, also local service routes with lane 10' or greater		45'	motor home (exclusive of front and rear bumper)
HEIGHT	13'6"			65'	combination travel trailer and tow vehicles (exclusive of front and rear bumper)
LENGTH		Interstate, US and WV Routes			
	40'	single unit (inclusive of front and rear bumper)			
	53'	semitrailer (measurement from tractor rear axle to trailer first axle cannot exceed 37')		97'	Driveway Saddle Mount Vehicles
			OVERHANG	3'	front (all loads)
				6'	rear (all loads)
	28'	doubles, triple trailers not allowed			
	70'	overall length on US and WV Routes			
	55'	overall length on county routes			

TYPES OF PERMITS

Single Trip – Issued for oversize and overweight. Vehicle and route specific.

Superload – Issued for size and/or weight exceeding single trip limits. Vehicle and route specific.

Blanket:
Regular – Annual permit issued for moderately oversize and/or overweight. Not vehicle or route specific.
Seagoing - Annual permit for moderately overweight seagoing containerized cargo. Not vehicle or route specific.
Mobile Home Blanket – Annual permits for mobile homes 14' wide or less. Not vehicle or route specific.

Mobile Home Single Trip – Vehicle and route specific.

All permits issued through either one of the "gotpermits" sites or through the Central Permit Office in Charleston. Both https://wv.gotpermits.com and www.gotpermits.com are self-issue sites; you are required to select routes and run an analysis. If it passes, you may print your permit and travel; if it does not, you must forward it for Central Permit Office review.

PERMIT LIMITS

SINGLE TRIP

WEIGHT			
0 (single)	28,000	WIDTH:	16'
00 (tandem)	45,000	HEIGHT:	No limit if routes can accommodate
000 (tri)	50,000	LENGTH:	No limit if routes can accommodate
0000 (quad)	55,000		
Gross	120,000		

SUPERLOAD PERMIT

Weights or dimensions exceeding any of the limits for single trip permits are superloads.
No limit on weight but all loads must pass a bridge analysis.
No limit on dimensions (except for overhang – see below) but overall size must be suitable for the route.

BLANKET PERMIT – REGULAR

Annual permit for oversize and/or overweight.

May be used for modular homes and most other nondivisible loads excluding mobile homes.

Size and weight limits are listed below:

Interstate & Other Divided Routes	US and Selected Routes	All Other Routes	Axle Limits All Routes	
14' 6" high	14' 0" high	13' 6" high	28,000 pounds single	For OW Permit
14' 0" wide	12' 0" wide	12' 0" wide	45,000 pounds tandem	For OW Permit
95' 0" long	75' 0" long	75' 0" long	50,000 pounds tri	For OW Permit
15' 0" overhang	10' 0" overhang	10' 0" overhang	20,000 pounds single	For OS Permit
110,000 pounds	90,000 pounds	Legal Weight	34,000 pounds tandem	For OS Permit

BLANKET PERMIT – SEAGOING
Annual permit for overweight seagoing containerized cargo.

Travel is allowed on most major highways. Some restrictions apply.

Maximum gross weight allowed is 90,000 pounds with a single axle limit of 28,000 pounds, tandem axle limit of 45,000 pounds, and tridem axle limit of 50,000 pounds.

BLANKET PERMIT – Mobile Home
Annual permit for mobile homes 14' wide or less. Except for width, Single Trip limits listed below apply.

SINGLE TRIP MOBILE HOME PERMIT

Combination Length	110'
Mobile Home Length	80'
Width	16'
Height	15' 6"

ALL PERMITS
OVERHANG: 15' front 30' rear

FEES

Single Trip - $20.00 for overweight or overdimensional plus $.04 per ton mile for overweight.
Superload – Same fee as for single trip.
Blanket (Regular) - $200 for each oversize permit or $500 for each oversize and overweight permit.
Blanket (Seagoing) - $150 for 1-15 permits, $15 for each additional permit.
Blanket (Mobile Home) - $200 for each permit.
Single Trip Mobile Home - $20.00 per trip.
Low Impact Monitors - $150 for the first bridge, $100 for the second bridge, and $50 for each additional bridge up to a maximum of $750. Permit monitors may be assigned in certain situations, with their fees determined on a case-by-case basis.

Payment for permits can be made by major credit card or escrow account (through Bentley Services) or through a wire service company.

GENERAL PERMIT RESTRICTIONS

Single Trip and Superload permits are good for (5) five days. Single Trip Mobile Home permits are good for ten (10) days. No travel is permitted on holidays. Divisible load permits are not available. School bus hour or other curfew may be applied.

Travel for oversize vehicles which are 14' 0" or less wide and any length, height, or weight (except for loads approved at low impact) is allowed on all routes except the West Virginia Turnpike* (when requested) from sunrise to sunset, seven days a week.

*The West Virginia Turnpike allows weekend travel for loads no more than 95' long and/or with no more than 15' combined overhang, and/or no more than 14'6" high and/or with a gross vehicle weight of no more than 110,000 lbs.

Oversize vehicles exceeding these dimensions up to and including 16' 0" wide can travel from sunrise to sunset, Monday through Friday on all routes. Travel for vehicles exceeding 16' 0" wide is allowed only on Sunday mornings.

Travel for vehicles that are overweight up to and including 110,000 pounds but not oversize is allowed (when requested) 24 hours a day, seven days a week.

Routes which cannot safely accommodate the above dimensions or weights may be rerouted or denied or have more restrictive travel times.

Mobile homes up to and including 14' wide can move from sunrise to sunset, Monday through Friday and sunrise until noon on Saturday. Mobile homes greater than 14' wide up to and including 16' can move sunrise to sunset, Monday through Thursday and sunrise until 3:00 pm on Friday. Mobile homes greater than 16' wide are not allowed.

Weekend travel, when allowed, is given upon request. Haulers should note on their application if they desire weekend travel.

Bulldozers may be hauled with the blades on, so long as the blade is angled away from oncoming traffic and the total width of the load is not more than 14'. If the load is more than 14' wide, the blade must be taken off and hauled on a separate trailer (if the load is also overweight).

INSURANCE

Not required to be on file with the permit office (except mobile home). Operators must obtain a minimum of $350,000 coverage.

PERMIT INFORMATION REQUIRED

Single Trip and Superload – Tractor and trailer information; load (make and model) information; overall dimensions; load weight and gross weight; axle spacings; axle weights; origin and destination; effective dates; routes to be traveled. Revision for dates of travel, tractor and trailer license numbers.

Blanket – Company name, address and phone number

Mobile Home Blanket – Company name, address, phone number, and insurance information.

Single Trip Mobile Home – Company name and address, Driver's name, insurance information, origin and destination, travel dates, license number, make and year of tow truck, mobile home make, serial number, license number and size.

ESCORTS AND SIGNS

ESCORT REQUIREMENTS – Overwidth and/or Loads
Escort vehicles must be in compliance with WV Administration Regulation Section 3, Title 157-05.

Highway Lanes	Escort Requirements	Days of Travel
	Overall width 10' 6" to 12' Escort vehicle with Oversize Load sign required:	
2 lane	At front	Seven days
4 lane	None	Seven days
	Overall width 12' 1" to 14' Escort vehicle with Oversize Load sign required:	
2 lane	At front and rear	Seven days
4 lane	At rear	Seven days

	Overall width 14' 1" to 15' * Escort vehicle with Oversize Load sign required:	
2 lane	At front and rear	Mon. thru Fri. **
4 lane	At front and rear	Mon. thru Fri.
	Overall width 15' 1" to 16' Escort vehicle with Oversize Load sign required:	
2 lane	Two front and one rear ***	Mon. thru Fri. and
4 lane	One front and two rear	
	Overall width 16' 1" and above Escort vehicle with Oversize Load sign required:	
2 lane and 4 lane	As required by permit	Sunday

* Districts and Parkway may require additional escort or time restrictions

** West Virginia Parkway Authority: Loads greater than 16' wide must be able to clear 2'9" high concrete barriers.

*** Loads more than 16' wide may move only on Sunday morning until noon.

ESCORT REQUIREMENTS – Overlength Vehicles and/or Loads

Escort vehicles must be in compliance with WV Administration Regulation Section 3, Title 157-05

Highway Lanes	Escort Requirements	Days of Travel
	Length 75' to 95' *	
	Escort vehicle required with Oversize Load sign:	
2 lane	At rear	Mon. thru Fri.
4 lane	None	Seven Days
	Length 95' 1" to 100' *	
	Escort vehicle required with Oversize Load sign:	
2 lane	At front and rear	Mon. thru Fri.
4 lane	At rear	Mon. thru Fri.
	Length 100' 1"	
	Escort vehicle required with Oversize Load sign:	
2 lane	At front and rear	Mon. thru Fri.
4 lane	At front and rear	Mon. thru Fri.
	OVERHANG	
	Front overhang Exceeds 10' **	

	Escort vehicle required with Oversize Load sign:	
2 lane	At front	Mon. thru Fri.
4 lane	At front	Mon. thru Fri.
	Rear Overhang Exceeds 10' **	
	Escort vehicle required with Oversize Load sign:	
2 lane	At rear	Mon. thru Fri.
4 lane	At rear	Mon. thru Fri.

Pole or extendable trailer can legally carry a load of 80' in length (without permit) providing load is not overweight. Escorts are not required but are encouraged for safety.

* Districts and Parkway Authority may require additional escorts.
** No escort required until overhang exceeds 10' front or rear.

ESCORT REQUIREMENTS - Overheight Vehicles and/or Loads

Escort vehicles must be in compliance with WV Administration Regulation Section 3, Title 157-05.

Highway Lanes	Escort Requirements	Days of Travel
	Height Exceeds 15'	
	Escort vehicle required with Oversize Load sign:	
2 lane	Front pole car required	Mon. thru Fri.
4 lane	In addition to any other escort	Mon thru Fri.

Escort requirements must be stated within the permit. These requirements are the policy of the WV Division of Highways. Districts and Parkway Authority may require additional escort or movement requirements, but never less than those listed above.

* Parkway (I-77/64 maximum height Yeager Bridge 15' 10". 16' in center of bridge.)

VEHICLE REQUIREMENTS

The escort vehicles must weigh more than 2,000 pounds and have manufacturer's gross weight rating less than 26,000 pounds and must be properly licensed. Identification signs or placards showing the name of the company or the owner or driver of the escort vehicle shall be displayed on the escort vehicle in a conspicuous place on both the right and left side. The signs shall be at least 8" by 12" and shall contain the telephone number of the owner or driver plainly legible to the motoring public.

All escort vehicles must be equipped with the following equipment:

A rotating or strobe amber yellow plastic, acrylic or glass covered flashing light which is visible from at least 500 feet and has a horizontal placement which is visible from all directions 360 degrees.

Shall display bumper mounted or roof mounted yellow 5' x 12" signs reading "Oversize Load" with black letters 10 inches high, 1-1/2 inch wide brush stroke, which must be visible from front or rear.

Two flags, red or safety orange, a minimum of 18" square in size, shall be mounted at a 40 to 70 degree angle on the escort vehicle's roof rack or flags may be mounted on all four corners of the vehicle.

All for-hire escort vehicles shall contain the following miscellaneous equipment:

A CB radio, or any other two way communication device with the permitted load; two 5 lb. Fire extinguishers (type a-b-c); a slow sign with a handle with the word "STOP" on one side and "SLOW" on the other of not less than 18" in diameter with 6" letters suitable for directing traffic; a safety orange vest, shirt or jacket; a red hand held sign 18" in size; 2 oversize load banners, yellow with black lettering; three reflecting triangles or 18" traffic cones.

FINES

OVERDIMENSION ONLY: Maximum $100 for first offense, up to $200 for second offense in the same year, and up to $500 for more than two offenses in the same year.

OVERWIGHT FINES:

1 to 4,000 lbs. overweight	$	20
4,001 to 5,000 lbs. overweight	$	25
5,001 to 6,000 lbs. overweight	$	60
6,001 to 7,000 lbs. overweight	$	70
7,001 to 8,000 lbs. overweight	$	80
8,001 to 9,000 lbs. overweight	$	90
9,001 to 10,000 lbs. overweight	$	100
10,001 to 11,000 lbs. overweight	$	165
11,001 to 12,000 lbs. overweight	$	180
12,001 to 13,000 lbs. overweight	$	195
13,001 to 14,000 lbs. overweight	$	210
14,001 to 15,000 lbs. overweight	$	225
15,001 to 16,000 lbs. overweight	$	320
16,001 to 17,000 lbs. overweight	$	340
17,001 to 18,000 lbs. overweight	$	360
18,001 to 19,000 lbs. overweight	$	380
19,001 to 20,000 lbs. overweight	$	400
20,001 to 21,000 lbs. overweight	$	525
21,001 to 22,000 lbs. overweight	$	550
22,001 to 23,000 lbs. overweight	$	575
23,001 to 24,000 lbs. overweight	$	600
24,001 to 25,000 lbs. overweight	$	625
25,001 to 26,000 lbs. overweight	$	780
26,001 to 27,000 lbs. overweight	$	810
27,001 to 28,000 lbs. overweight	$	840
28,001 to 29,000 lbs. overweight	$	870
29,001 to 30,000 lbs. overweight	$	900
30,001 to 40,000 lbs. overweight	$	1,200
40,001 to 50,000 lbs. overweight	$	1,400
50,001 and over	$	1,600

Fines are calculated beginning at legal weight. Operators may be fined for either over axle or over gross, whichever produces the greater fine. Drivers may be given time to shift load to avoid an over axle citation.

APPENDIX B. WIM DATABASE SCHEME

Field	Type	Units	Meaning	Comments
LOCID	integer		Location Id	
LANE	integer		Lane of data	
VEHID	integer		Vehicle Id	
DATE	date	dd/MM/yyyy	Date of vehicle	
TIME	time	HH:mm:ss. SSS	Time of vehicle	
SPEED	float	kph	Speed	
NAXLES	integer		Number of axles	
NGRPS	integer		Number of axle groups	
PATTERN	string		Vehicle axle group pattern	A pattern of '1-2-3' indicates a vehicle with a steering axle, a tandem drive group and a tri-axle trailer group
VEHCLASS	integer		Vehicle classification	This value is normally produced by the WIM equipment
GVM	float	tonnes	Gross Vehicle Weight	**1 tonne = 1000 kg = 2200 lbs**
TARE	float	tonnes	Vehicle Tare weight	The weight of an empty vehicle of this class
FREIGHT	float	tonnes	Vehicle freight	Freight is sometimes referred to as 'cargo'
ESA	float		Equivalent Standard Axle Load	
LEGAL	float	tonnes	Legal weight	The weight of this vehicle if it was loaded to its maximum legal carrying capacity, or zero if no value was calculated
LEGALCODE	char		Legal code	A region-specific code indicating whether the vehicle is overloaded or not. This may contain nothing.
LENGTH	float	meters	Length of vehicle	This is normally the measured bumper-to-bumper length, or its 'magnetic' length
VEHCLASS2	integer		Secondary vehicle classification	Usually based on vehicle length
TAG	integer		Transmetric tag	This may have been assigned by the operator to flag vehicles for further analysis
CODE	integer		Vendor code	A value assigned by the WIM equipment. This value may indicate an error.
AXLE_OVERFLOW	integer		Axle overflow	Whether the vehicle has more axles than can fit in this table
GROUP_OVERFLOW	integer		Group overflow	Whether the vehicle has more axle groups than can fit in this table
STATION_ID	string		Station Identifer	See Term: Station
TIMEFILTERS	string		Timefilter	Name of any time filters. If present, it normally indicates the operator has flagged this data for QC reasons
A1_MASS	float	tonnes	Weight of Axle 1	
A1_SPACE	float	meters	Spacing Axle 1-2	**1 meter = 39.37 inches**
etc ...	...	...	...	
G1_MASS	float	tonnes	Weight of Axle Group 1	
G1_TYPE	integer		Axle group code	See Code: Axle group type codes
etc ...	...	...	...	

APPENDIX C. LTPP VEHICLE CLASSIFICATION RULES

Class	Vehicle Type	No. Axles	Spacing 1	Spacing 2	Spacing 3	Spacing 4	Spacing 5	Spacing 6	Spacing 7	Spacing 8	Spacing 9	Spacing 10	Spacing 11	Gross Weight Min-Max	Axle 1 Weight Min *
1	Motorcycle	2	1.00-5.99											0.10-3.00	
2	Passenger Car	2	6.00-10.10											1.00-7.99	
2	Car w/ 1 Axle Trailer	3	6.00-10.10	6.00-25.00										1.00-11.99	
2	Car w/ 2 Axle Trailer	4	6.00-10.10	6.00-30.00	1.00-11.99									1.00-11.99	
3	Other (Pickup/Van)	2	10.11-23.09											1.00-7.99	
3	Other w/ 1 Axle Trailer	3	10.11-23.09	6.00-25.00										1.00-11.99	
3	Other w/ 2 Axle Trailer	4	10.11-23.09	6.00-30.00	1.00-11.99									1.00-11.99	
3	Other w/ 3 Axle Trailer	5	10.11-23.09	6.00-25.00	1.00-11.99	1.00-11.99								1.00-11.99	
4	Bus	2	23.10-40.00											12.00 >	
4	Bus	3	23.10-40.00	3.00-7.00										20.00 >	
5	2D Single Unit	2	6.00-23.09											8.00 >	2.5
5	2D w/ 1 Axle Trailer	3	6.00-23.09	6.30-30.00										12.00-19.99	2.5
5	2D w/ 2 Axle Trailer	4	6.00-26.00	6.30-40.00	1.00-20.00									12.00-19.99	2.5
5	2D w/ 3 Axle Trailer	5	6.00-23.09	6.30-35.00	1.00-25.00	1.00-11.99								12.00-19.99	2.5
6	3 Axle Single Unit	3	6.00-23.09	2.50-6.29										12.00 >	3.5
7	4 Axle Single Unit	4	6.00-23.09	2.50-6.29	2.50-12.99									12.00 >	3.5
7	5 Axle Single Unit	5	6.00-23.09	2.50-6.29	2.50-6.29	2.50-15.00								20.00 >	3.5
7	6 Axle Single Unit	6	6.00-23.09	2.50-6.29	2.50-6.29	2.50-6.29	2.50-15.00							12.00 >	3.5
7	7 Axle Single Unit	7	6.00-23.09	2.50-6.29	2.50-6.29	2.50-6.29	2.50-6.29	2.50-15.00						12.00 >	3.5
8	Semi, 2S1	3	6.00-23.09	11.00-45.00										20.00 >	3.5
8	Semi, 3S1	4	6.00-26.00	2.50-6.29	13.00-50.00									20.00 >	5
8	Semi, 2S2	4	6.00-26.00	8.00-45.00	2.50-20.00									20.00 >	3.5
9	Semi, 3S2	5	6.00-30.00	2.50-6.29	6.30-65.00	2.50-11.99								20.00 >	5
9	Truck+FullTrailer (3-2)	5	6.00-30.00	2.50-6.29	6.30-50.00	12.00-27.00								20.00>	3.5
9	Semi, 2S3	5	6.00-30.00	16.00-45.00	2.50-6.30	2.50-6.30								20.00 >	3.5
10	Semi, 3S3	6	6.00-26.00	2.50-6.30	6.30-45.00	2.50-11.99	2.50-10.99							20.00 >	5
10	Truck (3)/trailer(4)	7	6.00-26.00	2.50-6.30	6.30-45.00	2.50-11.99	2.50-10.99	2.50-10.99						20.00 >	5
10	Truck (4)/trailer(3)	7	6.00-26.00	2.50-6.30	2.50-6.30	6.30-45.00	2.50-10.99	2.50-10.99						20.00 >	5
10	Truck (3)/trailer(5)	8	6.00-26.00	2.50-6.30	6.10-45.00	2.50-11.99	2.50-10.99	2.50-10.99	2.50-15.00					20.00 >	5
10	Truck (4)/trailer(4)	8	6.00-26.00	2.50-6.30	2.50-6.30	6.10-45.00	2.50-10.99	2.50-10.99	2.50-15.00					20.00 >	5
11	Semi+FullTrailer, 2S12	5	6.00-30.00	11.00-26.00	6.00-20.00	11.00-26.00								20.00 >	3.5
12	Semi+Full Trailer, 3S12	6	6.00-26.00	2.50-6.30	11.00-26.00	6.00-24.00	11.00-26.00							20.00 >	5
13	7 Axle Multi's	7	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00						20.00 >	5
13	8 Axle Multi's	8	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00					20.00 >	5
13	9 Axle Multi's	9	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00				20.00 >	5
13	10 Axle Multi's	10	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00			20.00 >	5
13	11 Axle Multi's	11	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00		20.00 >	5
13	12 Axle Multi's	12	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	20.00 >	5

APPENDIX D. WIM VENDOR VEHICLE CLASSIFICATION RULES

HESTIA VEHICLE CLASSIFICATION

Axle Spacing Criteria (Length in feet, Weight in Kips)
MT PERMANENT

ENGLISH UNITS

VEH CLS	VH	FHWA CAT	SUB CAT	STAT CAT	NO. AXLE	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	LENGTH	TOTAL WEIGHT
A	Car	2	2	2	0									2.0 - 20.0	
B	UnClass	14	3	14	0									2.0 - 20.0	
C	Moto	01	4	01	1									1.0 - 7.0	
D	Car	2	5	2	1									7.0 - 20.0	
E	UnClass	14	6	14	1									0 - 99.99	
F	Moto	1	7	1	2	0.1 - 6.6									
G	Car	2	8	2	2	6.6 - 10.0									
H	Pickup	3	9	3	2	10.0 - 15.0									0.01 - 15.0
I	Bus	4	10	4	2	22.0 - 40.0									
J	2ASU	5	11	5	2	10.0 - 15.0									15.0 - 60.0
K	2ASU	5	12	5	2	15.0 - 25.0									
L	UnClass	14	13	14	2	0 - 99.99									
M		1	14	1	3	3.0 - 6.6	2.0 - 8.0								
N		2	15	2	3	6.6 - 10.0	6.0 - 19.5								
O		3	16	3	3	10.0 - 15.0	6.0 - 23.0								0.1 - 15.0
P		4	17	4	3	20.0 - 40.0	2.9 - 6.0								
Q		5	18	5	3	15.0 - 20.0	6.0 - 25.0								10.0 - 60.0
R		6	19	6	3	6.6 - 20.0	3.3 - 6.0								
S		8	20	8	3	6.6 - 22.0	14.0 - 40.0								
T	UnClass	14	21	14	3	0 - 99.99	0 - 99.99								
U		2	22	2	4	6.6 - 10.0	10.0 - 18.0	0.1 - 3.3							
V		2	23	2	4	6.6 - 10.0	8.0 - 12.9	6.6 - 10.0							
W		3	24	3	4	10.0 - 15.0	6.0 - 40.0	0.1 - 3.3							.01 - 15.0
X		3	25	3	4	10.0 - 15.0	8.0 - 20.0	6.6 - 12.9							.01 - 15.0
Y		5	26	5	4	10.0 - 24.0	6.0 - 40.0	0.1 - 4.0							10.0 - 60.0
Z		5	27	5	4	10.0 - 15.0	8.0 - 20.0	6.0 - 10.5							10.0 - 60.0
AA		5	28	5	4	15.0 - 20.0	8.0 - 22.0	6.0 - 10.5							
AB		7	29	7	4	6.6 - 20.0	3.3 - 8.0	3.3 - 8.0							
AC		8	30	8	4	6.6 - 22.0	3.3 - 8.0	6.1 - 42.0							
AD		8	31	8	4	6.6 - 22.0	14.0 - 42.0	3.3 - 8.0							
AE	UnClass	14	32	14	4	0 - 99.99	0 - 99.99	0 - 99.99							
AF		3	33	3	5	10.0 - 15.0	0 - 99.99	1.5 - 3.3	1.5 - 3.3						3.0 - 15.0
AG		5	34	5	5	10.0 - 15.0	0 - 99.99	1.5 - 3.3	1.5 - 3.3						10.0 - 60.0
AH		5	35	5	5	15.0 - 20.0	0 - 99.99	1.5 - 3.3	1.5 - 3.3						
AI		7	36	7	5	6.5 - 20.0	3.2 - 8.0	3.2 - 8.0	3.2 - 8.0						

AJ		9	37	9	5	6.6 - 22.0	3.3 - 8.0	6.6 - 45.0	3.3 - 8.0						
AK		9	38	9	5	6.6 - 22.0	3.3 - 8.0	6.6 - 45.0	3.3 - 23.0						
AL		9	39	9	5	6.6 - 22.0	6.1 - 40.0	3.3 - 8.0	3.3 - 8.0						
AM		11	40	11	5	6.6 - 22.0	4.0 - 16.7	6.7 - 16.7	10.0 - 26.7						
AN	UnClass	14	41	14	5	0 - 99.99	0 - 99.99	0 - 99.99	0 - 99.99	0 - 99.99					
AO		10	42	10	6	6.6 - 22.0	3.3 - 8.0	3.8 - 8.0	12.0 - 50.0	3.3 - 25.0					
AP		12	43	12	6	6.6 - 22.0	3.3 - 8.0	10.0 - 27.0	6.7 - 30.0	10.0 - 30.0					
AQ		10	44	10	6	6.6 - 22.0	3.3 - 8.0	12.0 - 45.0	6.7 - 30.0	3.3 - 30.0					
AR		12	45	12	6	6.6 - 22.0	10.0 - 40.0	3.3 - 8.0	8.0 - 20.0	10.0 - 30.0					
AS		10	46	10	7	6.6 - 16.0	3.3 - 8.0	10.0 - 30.0	3.3 - 11.0	3.3 - 8.0	3.3 - 25.0				
AT		10	47	10	7	6.6 - 22.0	3.3 - 8.0	10.0 - 50.0	3.3 - 11.0	3.3 - 11.0	3.3 - 11.0				
AU		13	48	13	7	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0				
AV		10	49	10	8	3.3 - 22.0	3.3 - 20.0	3.3 - 8.0	10.0 - 40.0	3.3 - 11.0	3.3 - 30.0	3.3 - 11.0			
AW		13	50	13	8	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0			
AX		10	51	10	9	3.0 - 8.0	10.0 - 15.0	3.3 - 8.0	3.3 - 8.0	15.0 - 35.0	3.8 - 8.0	15.0 - 30.0	3.3 - 8.0		
AY		13	52	13	9	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0		
AZ		13	53	13	10	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0	2.0 - 50.0		
BE		7	58	7	6	6.50 - 15.0	3.25 - 6.0	3.25 - 6.0	3.25 - 6.0	3.25 - 15.0					
EX		99	0	14											

APPENDIX E. WEST VIRGINIA WIM ACCURACY ANALYSIS

LOCID	Frequency	Avg_A1mass	Std_A1mass	Avg_A23space	Std_A23space
3383	19431	9679.07	777.03	4.29	0.07
3340	8	9482.16	805.87	4.37	0.09
3389	905	15902.62	2258.65	4.51	0.14
3388	802	10165.45	1801.76	4.32	0.12
3386	490	9518.26	792.34	4.32	0.08
3302	391	10890.86	1590.32	4.29	0.26
3399	2290	16280.85	1812.62	4.19	0.11
3380	717	10642.19	1591.18	4.32	0.10
3534	2624	10453.35	1458.28	4.32	0.06
3429	4	9395.10	356.29	4.40	0.14
3440	326	10620.45	1365.43	4.43	0.13
3438	115	11581.46	1895.41	4.31	0.11
3307	257	9069.08	1250.08	4.30	0.09
3437	87	11145.55	2281.25	4.28	0.16
3281	71	8485.18	1720.12	4.27	0.22
3435	894	8880.71	896.94	4.30	0.13
3434	1086	9347.68	1020.46	4.30	0.15
3443	147	7673.70	1117.34	4.30	0.18
3400	628	9000.56	1214.79	4.37	0.12
3279	2181	9471.86	1721.23	4.02	0.60
3426	128	10517.71	1245.44	4.33	0.09
3313	4213	10324.31	1330.08	4.31	0.11
3319	821	10500.32	1701.95	4.28	0.08
3332	195	9631.46	1274.49	4.27	0.13
3477	1044	10427.87	2047.64	4.26	0.10
3318	6834	10108.21	1362.99	4.33	0.09
3331	2895	10422.39	1306.00	4.22	0.11
3416	692	8619.84	1065.26	4.31	0.10
3404	673	8357.35	2160.29	4.29	0.11
3368	433	9310.39	1672.08	4.32	0.16
3384	12758	19593.99	2961.00	4.32	0.12
3490	99	11410.00	3180.60	4.32	0.09
3301	344	10633.59	1307.38	4.25	0.14
3398	2406	10254.53	1016.21	4.33	0.10
3286	385	10224.96	1609.03	4.30	0.09
3315	331	9487.89	1357.78	4.33	0.10
3410	169	10466.33	2339.74	4.42	0.15
3312	3967	9853.10	990.29	4.22	0.12
3422	10518	9983.73	1693.26	4.30	0.09
3407	369	9024.85	1296.24	4.25	0.08

LOCID	Frequency	Avg_A1mass	Std_A1mass	Avg_A23space	Std_A23space
3343	58	12186.49	1606.76	4.40	0.20
3474	662	7740.41	1012.77	4.32	0.11
3466	613	7672.26	863.59	4.37	0.10
3320	455	11511.08	1963.38	4.35	0.09
3468	14070	10257.89	1175.69	4.30	0.07
3317	6453	11178.17	1521.67	4.33	0.08
3364	2198	10309.20	1533.14	4.44	0.12
3336	1112	9132.36	1301.20	4.36	0.10
5591	513	8031.75	800.45	4.30	0.09
3306	246	7992.02	1063.76	4.32	0.15
3390	165	9214.14	1145.05	4.36	0.15
3455	182	8372.02	1373.49	4.26	0.10
3325	3344	10093.11	1305.69	4.33	0.16
3403	649	11452.71	3132.01	4.79	0.42
3280	1832	10249.97	2484.62	4.02	0.60
3328	152	6386.09	854.04	4.36	0.11
3341	37	9967.38	1146.48	4.36	0.13
3314	516	9582.93	1178.01	4.32	0.13
3471	5866	10097.19	936.63	4.18	0.10
3433	4010	10489.52	926.84	4.33	0.12
3282	59	8390.14	1835.13	3.96	0.68
3415	716	8038.62	959.49	4.39	0.12
3344	29	12479.50	3098.13	4.29	0.10
3322	3485	8003.28	1072.53	4.33	0.12
3409	161	10380.48	2227.05	4.34	0.33
3424	762	10662.95	2177.96	4.31	0.11
3488	1922	10803.39	2176.32	4.30	0.09
3487	1130	6050.30	739.65	4.19	0.11
3333	220	9447.73	1219.01	4.27	0.08
3473	263	8463.50	1096.98	4.27	0.38
3339	127	11102.42	1494.23	4.32	0.11
3304	3363	10409.70	1086.60	4.31	0.19
3500	118	8408.67	1058.45	4.35	0.09
3401	43	9199.29	1840.01	4.33	0.15
3406	539	8896.92	1254.43	4.26	0.10
3427	126	9507.22	1054.57	4.32	0.09
3381	746	10152.60	1788.18	4.29	0.10
3305	2666	10524.48	1234.63	4.30	0.10
3327	162	6384.21	799.44	4.30	0.31
3285	5142	10527.62	1085.55	4.27	0.10
3497	175	12382.48	3032.04	4.40	0.14
3454	144	7800.94	890.44	4.23	0.09

LOCID	Frequency	Avg_A1mass	Std_A1mass	Avg_A23space	Std_A23space
3365	2045	9389.72	1498.19	4.43	0.13
3418	159	8818.18	1162.99	4.30	0.08
3501	92	9646.64	2299.34	4.27	0.09
3423	853	12169.91	1751.08	4.29	0.13
3465	628	8510.32	1074.32	4.36	0.12
3432	4164	10408.63	1021.19	4.30	0.12
3441	356	8741.52	1250.17	4.39	0.12
3287	399	7515.60	684.46	4.31	0.09
3300	3581	10487.42	1222.74	4.26	0.15
3338	132	11415.67	1355.22	4.30	0.35
3469	12685	10377.44	1268.22	4.28	0.07
3330	1880	10220.44	1424.90	4.21	0.21
3430	3	8894.61	1819.08	4.04	0.15
3472	6627	10236.72	1156.13	4.23	0.09
3323	3008	7324.52	1022.69	4.40	0.13
3372	248	9879.51	2354.97	4.30	0.10
3391	81	8840.57	1190.35	4.32	0.11
3444	157	8048.83	1323.81	4.29	0.15
3284	5600	10411.15	1006.24	4.34	0.10
3299	8263	10427.32	1070.10	4.27	0.10
3335	1264	9914.40	1121.26	4.33	0.09
3419	114	9239.50	1038.33	4.31	0.08
3489	158	10017.75	2198.08	4.38	0.08
3498	179	9553.80	1536.63	4.43	0.14
3369	414	8253.58	1127.99	4.23	0.12
3326	2065	14814.15	2434.23	4.13	0.32
3476	1158	10347.74	1400.91	4.35	0.08

APPENDIX F. NATIONAL DATA WIM ACCURACY ANALYSIS

Station (State.ID)	Year	freq	Avg_ A1mass	Stdev_ A1mass	Avg_ A23space	Stdev_ A23space
Illinois.0	2005	291612	10643.45	1041.05	4.28	0.08
Colorado.16	2006	156152	10705.48	1054.111	4.28	0.06
Kansas.48	2006	202275	11190.58	1098.749	4.26	0.08
Maryland.0	2006	88162	10520.1	1050.727	4.28	0.07
Minnesota.48	2006	6116	10598.95	1157.506	4.29	0.11
Arizona.0	2007	11727	11368.69	1715.58	4.30	0.15
Arizona.16	2007	909835	10600.66	1182.867	4.34	0.17
Arkansas.48	2007	1506964	11034.28	915.35	4.25	0.14
Colorado.16	2007	297167	10590.63	1094.352	4.27	0.10
Delaware.32	2007	55973	10853.55	1131.39	4.27	0.07
Illinois.0	2007	752907	11063.72	1047.676	4.29	0.12
Kansas.48	2007	368519	11127.47	1244.037	4.27	0.09
Maine.0	2007	50894	11108.37	1196.735	4.33	0.16
Maryland.0	2007	95989	10389.19	1074.836	4.28	0.08
Minnesota.48	2007	35359	10533.05	1206.966	4.29	0.11
Penn.48	2007	799302	10678.07	957.3561	4.30	0.12
Tennessee.48	2007	1011132	10945.51	1020.882	4.25	0.16
Virginia.32	2007	179117	10704.37	1022.813	4.27	0.09
Wisconsin.48	2007	50386	10548.65	1167.679	4.23	0.13
Arizona.0	2008	10797	10884.82	1511.553	4.29	0.14
Arizona.16	2008	786926	11363.64	1048.902	4.34	0.16
Arkansas.48	2008	784594	10933.51	939.1536	4.28	0.12
California.0	2008	689457	10946.46	1114.78	4.29	0.10
Colorado.16	2008	177568	10822.12	1074.163	4.28	0.10
Delaware.32	2008	86669	10908.09	1165.229	4.27	0.07
Illinois.0	2008	521916	10945.14	1024.138	4.30	0.11
Indiana.0	2008	111298	10691.71	1013.166	4.28	0.07
Kansas.48	2008	265263	11225.11	1101.246	4.31	0.15
Louisiana.0	2008	37213	10490.99	1024.523	4.30	0.10
Maine.0	2008	63696	11203.27	1320	4.33	0.16
Maryland.0	2008	56098	10475.25	1176.672	4.28	0.09
Minnesota.48	2008	20164	10430.11	1224.455	4.29	0.10
NewMex.0	2008	62888	10783.19	1334.758	4.30	0.11
NewMex.16	2008	358899	11486.73	1063.97	4.27	0.07
Penn.48	2008	889216	10605.44	988.5042	4.30	0.11
Tennessee.48	2008	861891	10925.15	1058.706	4.28	0.08
Virginia.32	2008	120861	10829.56	1017.354	4.28	0.09

Station (State.ID)	Year	freq	Avg_ A1mass	Stdev_ A1mass	Avg_ A23space	Stdev_ A23space
Wisconsin.48	2008	120925	10605.06	1282.272	4.28	0.10
Arizona.0	2009	10415	11111.8	1642.273	4.29	0.17
Arizona.16	2009	1027081	10952.63	917.2735	4.37	0.16
Arkansas.48	2009	1299321	11208.46	827.2676	4.28	0.09
California.0	2009	972002	11085.33	1119.723	4.34	0.15
Colorado.16	2009	271644	10635.25	946.9825	4.28	0.09
Delaware.32	2009	117930	10798.29	1146.588	4.27	0.06
Illinois.0	2009	669751	11203.63	926.3776	4.31	0.11
Indiana.0	2009	263409	10618.11	1030.907	4.27	0.07
Kansas.48	2009	340704	11385.77	966.4415	4.28	0.07
Louisiana.0	2009	53654	9986.67	961.159	4.29	0.10
Maine.0	2009	103057	10738.71	1239.344	4.31	0.14
Maryland.0	2009	67240	10423.54	1133.114	4.27	0.10
Minnesota.48	2009	31095	10972.18	1254.128	4.29	0.10
NewMex.0	2009	114048	10375.02	1153.691	4.30	0.10
NewMex.16	2009	786751	11357.34	936.966	4.27	0.06
Penn.48	2009	1156983	11110.42	939.1814	4.32	0.12
Tennessee.48	2009	1306699	11324.32	1004.148	4.28	0.08
Virginia.32	2009	163477	11023.59	980.8571	4.28	0.08
Wisconsin.48	2009	157038	10759.46	1197.854	4.28	0.09
Arizona.0	2010	38095	11131.33	1219.461	4.28	0.11
Arizona.16	2010	1147038	10879.1	915.3451	4.35	0.15
Arkansas.48	2010	1294537	11225.73	842.7098	4.28	0.08
California.0	2010	968028	11145.66	1108.066	4.42	0.17
Colorado.16	2010	287796	10700.16	938.8757	4.28	0.09
Delaware.32	2010	112946	10858.1	1212.389	4.27	0.08
Illinois.0	2010	741452	11130.73	972.8556	4.32	0.13
Indiana.0	2010	272641	10360.8	1005.716	4.29	0.09
Kansas.48	2010	353470	11459.34	990.644	4.28	0.07
Louisiana.0	2010	52617	10348.14	1077.335	4.33	0.13
Maine.0	2010	110791	11168.92	1369.277	4.31	0.14
Maryland.0	2010	66283	10435.33	1447.103	4.28	0.11
Minnesota.48	2010	29856	10653.89	1288.114	4.29	0.10
NewMexico.0	2010	123169	10386.32	1175.504	4.31	0.12
NewMexico.16	2010	826521	11447.72	952.2006	4.27	0.07
Pennsylvania.48	2010	1183293	10959.03	1040.589	4.31	0.12
Tennessee.48	2010	1345434	11201.22	984.1278	4.29	0.09
Virginia.32	2010	167054	11139.8	1019.367	4.28	0.07
Wisconsin.48	2010	159196	10947.23	1212.211	4.28	0.09
Arizona.0	2011	184717	11317.29	1149.648	4.28	0.09
Arizona.16	2011	1155077	11260.4	955.6858	4.28	0.08

Station (State.ID)	Year	freq	Avg_ A1mass	Stdev_ A1mass	Avg_ A23space	Stdev_ A23space
Arkansas.48	2011	1353994	11607.78	881.7467	4.29	0.09
California.0	2011	1063559	11129.7	1119.406	4.41	0.17
Colorado.16	2011	293934	11370.61	1048.082	4.28	0.09
Delaware.32	2011	106136	9161.252	2014.469	4.29	0.12
Illinois.0	2011	766413	10987.86	972.6294	4.33	0.13
Indiana.0	2011	281210	10792.68	1104.052	4.29	0.09
Kansas.48	2011	337901	11559.4	1353.644	4.28	0.07
Louisiana.0	2011	62275	10468.22	982.8842	4.37	0.15
Maine.0	2011	67521	11631.41	1712.109	4.31	0.13
Maryland.0	2011	72373	10494.39	1062.454	4.28	0.08
Minnesota.48	2011	32050	10608.19	1207.91	4.29	0.10
NewMexico.0	2011	118496	10719.84	1223.911	4.28	0.08
NewMexico.16	2011	775488	11451.06	959.8027	4.28	0.09
Pennsylvania.48	2011	1220542	11298.32	1052.392	4.31	0.12
Tennessee.48	2011	1370815	11195.81	1000.39	4.28	0.08
Virginia.32	2011	157538	10962.42	959.623	4.27	0.10
Wisconsin.48	2011	161033	10653.04	1136.147	4.27	0.08
Arizona.0	2012	126965	11439.54	1197.632	4.25	0.13
Arizona.16	2012	284083	11039.55	1279.289	4.28	0.09
Arkansas.48	2012	899808	11557.03	849.5224	4.28	0.09
California.0	2012	697864	11261.71	1116.151	4.34	0.15
Colorado.16	2012	150283	11570.98	989.2936	4.28	0.09
Delaware.32	2012	66136	9599.584	2661.704	4.29	0.12
Illinois.0	2012	502769	11525.29	983.2978	4.28	0.07
Indiana.0	2012	182410	11352.39	1190.623	4.29	0.10
Kansas.48	2012	186931	11572.55	898.5465	4.28	0.07
Louisiana.0	2012	42408	10919.37	1116.187	4.35	0.15
Maryland.0	2012	44704	10630.84	1041.046	4.28	0.09
Minnesota.48	2012	19948	10714.93	1180.451	4.29	0.10
NewMexico.0	2012	61736	10799.09	1221.164	4.28	0.08
NewMexico.16	2012	397979	11359.48	972.4689	4.29	0.12
Pennsylvania.48	2012	701573	11286.61	1143.464	4.31	0.12
Tennessee.48	2012	815646	10948.53	973.407	4.28	0.07
Virginia.32	2012	111399	10902.26	921.8377	4.28	0.09
Wisconsin.48	2012	107690	10563.26	1005.269	4.27	0.07

APPENDIX G. TUNING PROCEDURE FORMULATION

Step 1 - Define baseline relationships (i.e., standards). Define the baseline GVW-A1W and A1W-A12S relationships based on Class 9 1-2-2 and 1-2-1-1 vehicles. For the effort in this study, the LTPP data were employed, but other data of known quality could also be used.

- A1W vs. GVW (by bin) relationship, denoted as *Baseline data (BD)*.
  $BD = \{(BD^{A1W,g}, BD^{GVW,g})\}$,
  where
  - g : $g = \{1, 2, \ldots G\}$, referring to G GVW bins;
  - $BD^{A1W,g}$: Average A1W value of the baseline data (*BD)* in GVW bin g ; and
  - $BD^{GVW,g}$: Average GVW value of the baseline data (*BD*) in GVW bin g.

- Log-Log Regression of (A1W/A12S) and A12S of baseline data, denoted as *LLRBD.*
  $LLRBD = \mathrm{Log}_{10}(BD_j^{A1W}/BD_j^{A12S}) = a_b + b_b \times \mathrm{Log}_{10}(BD_j^{A12S})$,
  where
  - $LLRBD$: Log-Log Regression of the Baseline Data;
  - BD_j^{A1W} : j th observation of the baseline data with its attribute A1W;
  - BD_j^{A12S} : j th observation of the baseline data with its attribute A12S;
  - j : $j = \{1,2,\ldots J\}$, referring to J vehicle samples;
  - a_b : Constant of the baseline data regression model; and
  - b_b : Coefficient of the baseline data regression model.

Step 2 - Calculate A1W differences. Identify the Class 9 1-2-2 and 1-2-1-1 vehicles for the WIM station to be adjusted (observation). Calculate the difference between each observation's A1W and the *BD* A1W in the corresponding GVW bin .

- $D_{i,t}^{A1W,g} = O_{i,t}^{A1W,g} - BD^{A1W,g}$,
  where
  - i : $i = \{1,2,\ldots I\}$, referring to I vehicle samples;
  - t : Observation timestamp;
  - $O_{i,t}^{A1W,g}$: Observation i's A1W attributes with its GVW value in bin g; and
  - $D_{i,t}^{A1W,g}$: A1W difference between observation (i, t) and the *BD* value in bin g.

Step 3 - Generate time series line. Average the A1W differences for each hour in the analysis period so that there is one value per hour on which to base the time series analysis. A different analysis time period could be used, depending on the volumes and rate of temperature change.

- $Y = \{(\overline{D_{i,t}^{A1W,g}})_y\}$,
  where
  - y : Hour indicator;
  - Y : Time-series, $Y = \{1\ldots y\}$; and
  - $(\overline{D_{i,t}^{A1W,g}})_y$: Average of $D_{i,t}^{A1W,g}$ in hour y, $t \in y$.

Step 4 - Decompose time series. Apply additive time series analysis and decompose into Trend, Seasonal, and Irregular components.

- Y = T+S+ I,

where

T	:	Trend component of Time-Series Y;
S	:	Seasonal component of Time-Series Y; and
I	:	Irregular component of Time-Series Y.

Step 5 - Calculate and apply time series adjustments. A single adjustment is calculated to increase or decrease the Trend, Seasonal, and Irregular lines to be zero. This difference is calculated as a fixed adjustment (rather than a percentage) for each hour in the study period. Therefore, all observations within a given hour will be adjusted by the same fixed amount. These adjustments are applied to each observed A1W for use in the remaining steps.

- $O'^{A1W,g}_{i,t} = O^{A1W,g}_{i,t} - (\overline{D^{A1W,g}_{i,t}})_y$,

where

$O'^{A1W,g}_{i,t}$: First adjusted value for $O^{A1W,g}_{i,t}$ (i.e. A1W after time-series process).

Step 6 - Generate Log-Log Regression line from adjusted A1W. A Log-Log Regression line is developed from the adjusted observations in Step 5 covering the full analysis period, denoted as *LLROD*.

- $LLROD = \mathrm{Log}_{10}(O'^{A1W,g}_{i,t}/O^{A12S,g}_{i,t}) = a_o + b_o \times \mathrm{Log}_{10}(O^{A12S,g}_{i,t})$.

where

LLROD	:	Log-Log Regression from Observed Data after time series adjustment;
a_o	:	Constant of the fitted regression model with adjusted observed data; and
b_o	:	Coefficient of the fitted regression model with adjusted observed data.

Step 7 - Calculate Log-Log Regression adjustments. For each observation, the difference between the baseline Log-Log Regression (*LLRBD* in Step 1) and the adjusted data Log-Log Regression (*LLROD* in Step 6) is calculated as a fixed value. This fixed value is applied to the adjusted A1W observation from Step 5.

- $O''^{A1W,g}_{i,t} = [\,(O'^{A1W,g}_{i,t}/O^{A12S,g}_{i,t}) + 10\hat{}(LLRBD - LLROD)] \times O^{A12S,g}_{i,t}$,

where

$O''^{A1W,g}_{i,t}$: Second adjusted value for $O^{A1W,g}_{i,t}$.

Step 8 - Generate percentage adjustment for each observation. Each observation's final adjusted A1W from Step 7 is used to compute a percentage adjustment based on the original unadjusted A1W.

- $PR_{i,t} = (O''^{A1W,g}_{i,t} - O^{A1W,g}_{i,t}) / O^{A1W,g}_{i,t}$,

where

$PR_{i,t}$: Percentage adjustment for observation (i, t).

<u>Step 9 - Generate adjustment matrix by hour</u>. The percentage adjustments from Step 8 are aggregated into hourly bins for each individual day, with all values being averaged to produce a single percentage adjustment for each hour of each day.

- $\overline{PR} = \{(\overline{PR_{\iota,t}})_h\}$,
  where

  $\overline{PR}$: Average percentage adjustment for each hour h, h = {1,2,…H}; and
  $(\overline{PR_{\iota,t}})_h$: Hourly average percentage value.

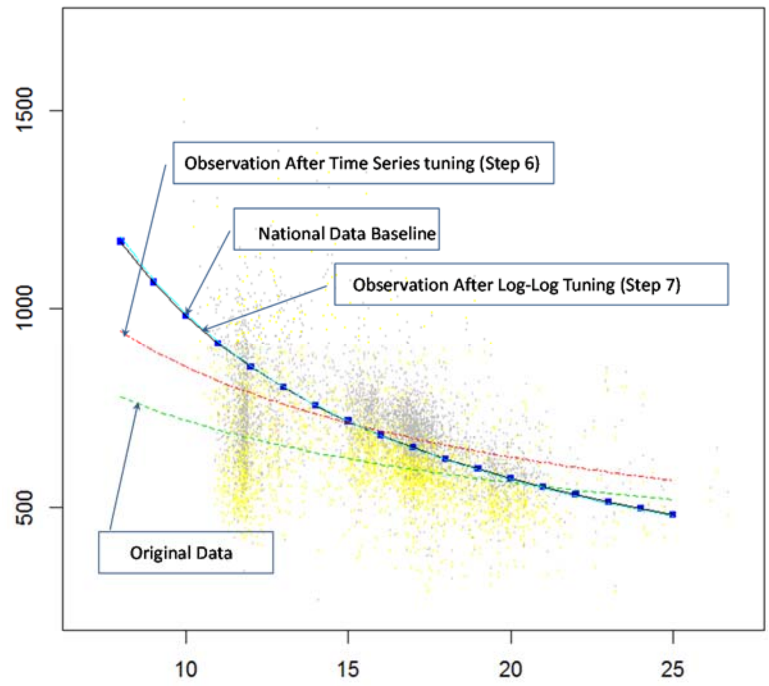
APPENDIX H. NATIONAL DATA FAW-GVW STANDARD

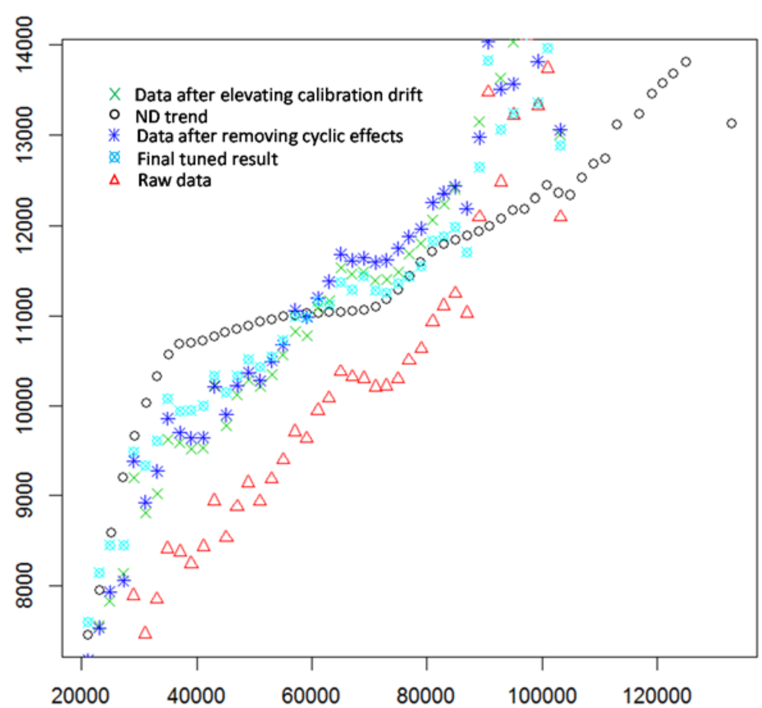
GVW_bin	GVW_mean	FAW_mean
20000	21079.01	7467.68
22000	23063.9	7953.026
24000	25072.36	8598.371
26000	27155.71	9202.462
28000	29166.65	9662.179
30000	31136.04	10024.32
32000	33103.83	10321.47
34000	35039.6	10565.38
36000	36995.4	10684.95
38000	38981.58	10703.65
40000	40977.54	10728.75
42000	42966.02	10767.74
44000	44954.92	10823.68
46000	46940.8	10854.19
48000	48921.61	10891.53
50000	50905.45	10932.41
52000	52996.46	10963.78
54000	55094.03	10992.56
56000	57075.69	11012.47
58000	59062.61	11027.14
60000	61051	11032.51
62000	63037.62	11040.11
64000	65026.27	11043.4
66000	67017.68	11050.48
68000	69014.84	11062.3
70000	71008.78	11105.75
72000	72994.91	11180.52
74000	74963.89	11293.6
76000	76911.45	11438.53
78000	78843.82	11591.32
80000	80856.96	11716.46
82000	82956.34	11797.63
84000	84951.73	11842.78
86000	86953.31	11892.54
88000	88942	11937.21
90000	90927.49	11998.19
92000	92919.89	12083.62
94000	94878.91	12168.63
96000	96879.87	12184.99
98000	98867.04	12307.11

GVW_bin	GVW_mean	FAW_mean
100000	100873.7	12441.98
102000	102807.4	12359.38
104000	104863.3	12339.93
106000	106954.2	12523.28
108000	109013.4	12683.1
110000	111058.3	12738.9
112000	112991	13117.01
114000	114938.8	12944.48
116000	116918	13229.84
118000	119007.4	13453.87
124000	124934.7	13804.16
134000	134951.1	12556.26

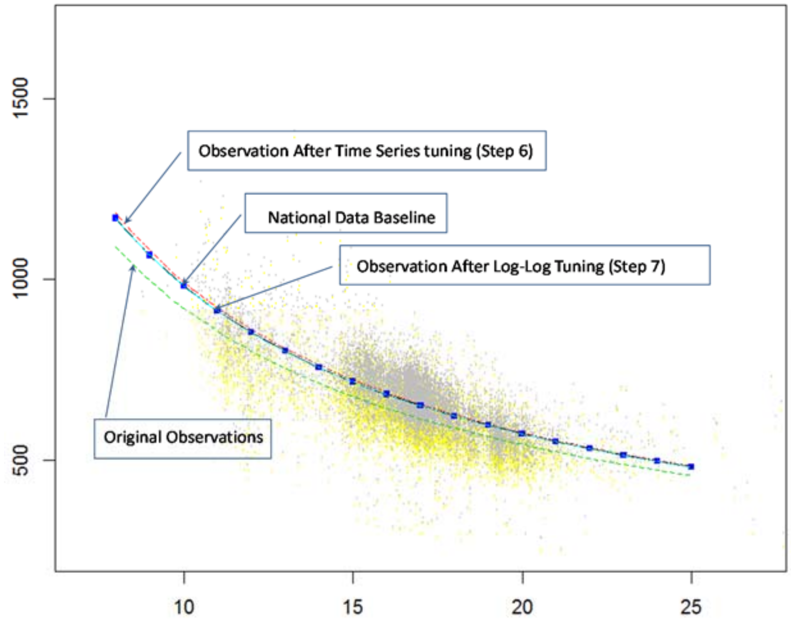
APPENDIX I. TUNING RESULTS FOR SITES 1, 5, 6, 12

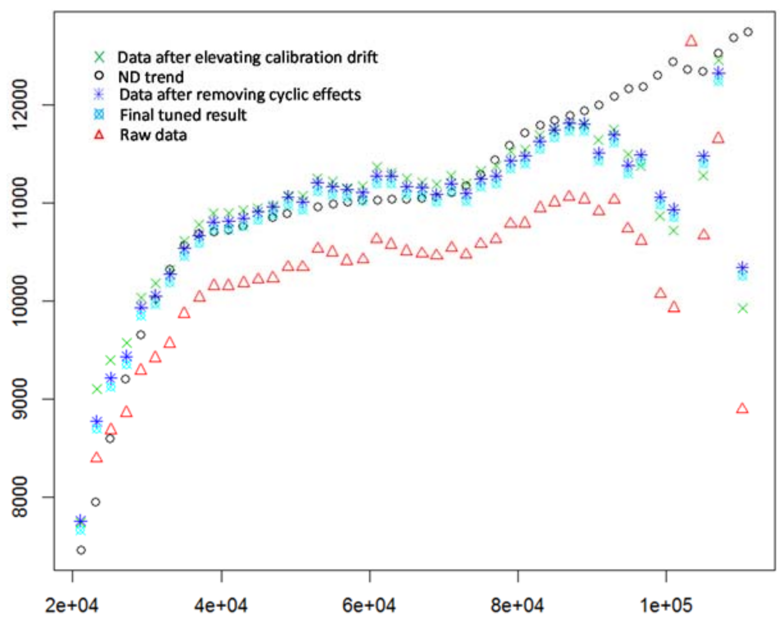
Site 1. I-64 in Summers County (Stations 3279, 3280, 3281, 3282)



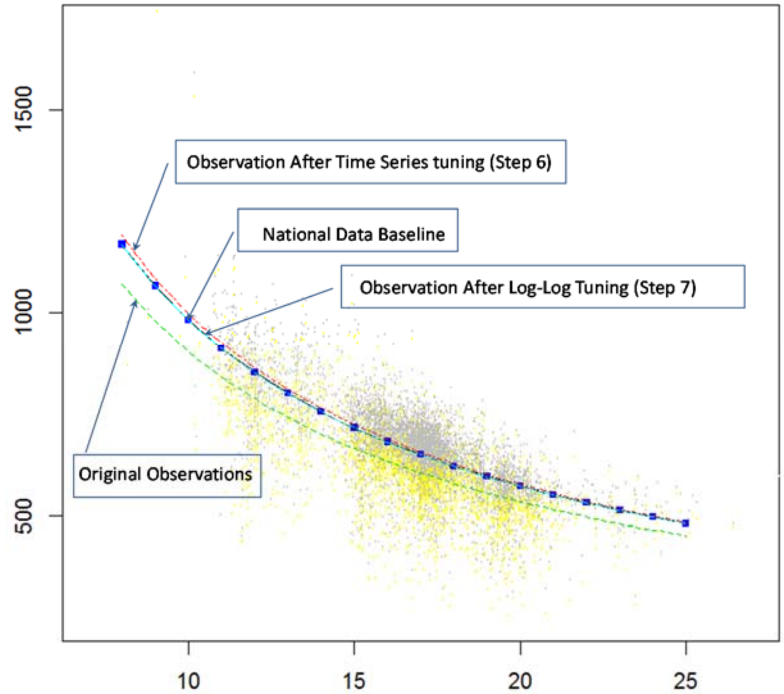


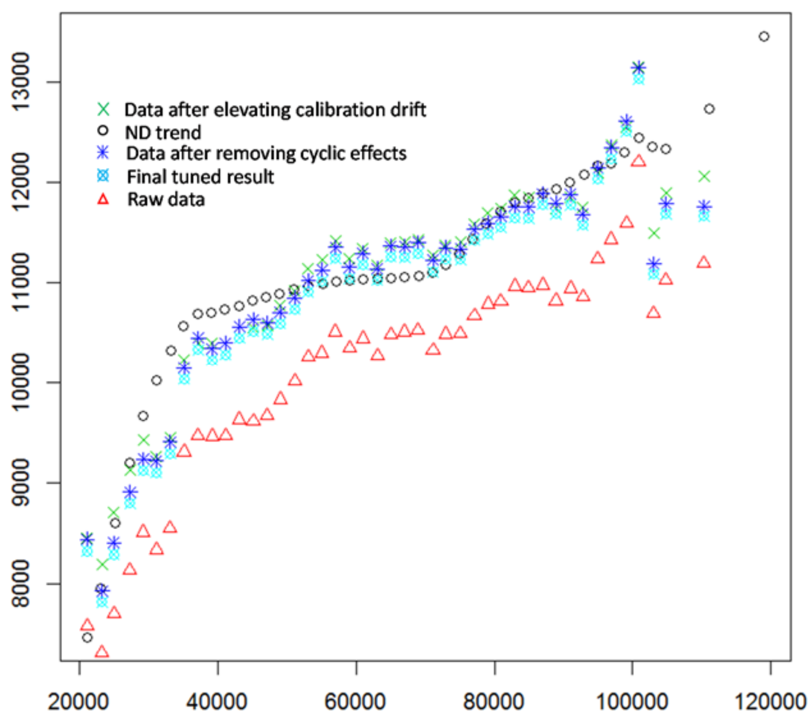
Site 5. I-79 in Lewis County (Stations 3299, 3300, 3301, 3302)



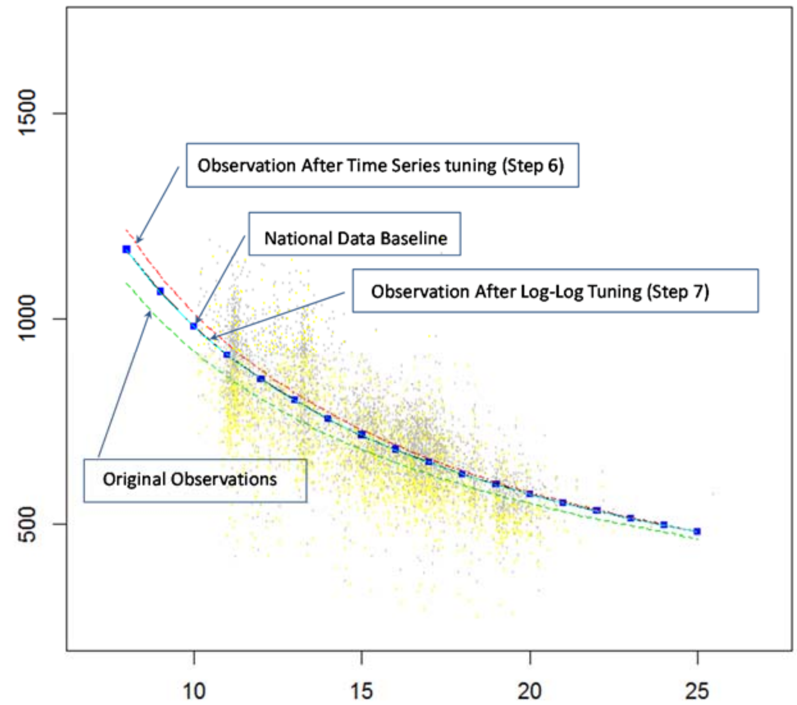


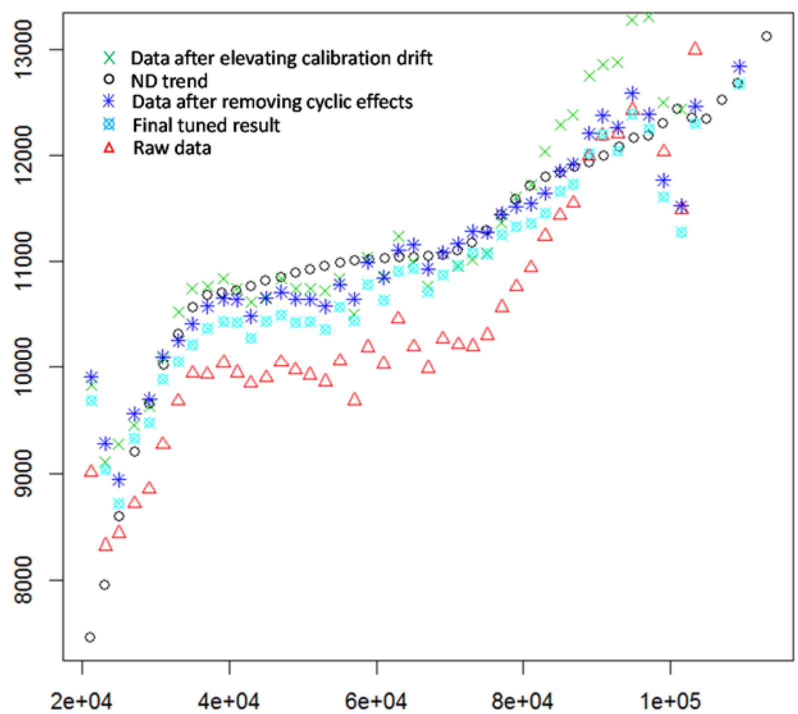
Site 6. I-79 in Kanawha County (Stations 3304, 3305, 3306, 3307)





Site 12. US 460 in Mercer County (Stations 3330, 3331, 3332, 3333)





APPENDIX J. PERMIT DATABASE SCHEME

Field Name	Type	Description
TripRequID	nvarchar(12)	
PermitID	nvarchar(20)	
TripFrom	nvarchar(100)	
TripTo	nvarchar(100)	
Routes	nvarchar(MAX)	
PDate	nvarchar(10)	
StartDate	nvarchar(10)	
EndDate	nvarchar(10)	
PermitTypeName	nvarchar(60)	
PermitType	int	
HaulerName	nvarchar(50)	
USDOT	nvarchar(20)	
City	nvarchar(25)	
State	nvarchar(2)	
TrkLic	nvarchar(10)	
TrkState	nvarchar(2)	
TrlrLic	nvarchar(10)	
TrlrState	nvarchar(10)	
Height	nvarchar(20)	
Width	nvarchar(20)	
Length	nvarchar(20)	
GrossWt	nvarchar(7)	
NumAxles	nvarchar(10)	
Loads	nvarchar(200)	
Spacing	nvarchar(MAX)	
CmpStartDate	datetime	
CmpPDate	datetime	
CmpEndDate	datetime	
inUse	int	
Disposition	int	