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APPLICATION OF WIM AND PERMIT DATA

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16. Abstract

The objective of this project was to (1) improve the procedures for processing and evaluation of the quality of the WIM data, (2) develop an analytical procedure to identify legal, permitted and illegal vehicles in the WIM records, (3) develop a set of algorithms to evaluate fatigue damage accumulated in steel bridges and (4) make recommendations regarding which traditional WIM stations is to be converted to Virtual Weigh Stations. ALDOT collects traffic data including records of millions of vehicles at each of the 12 Weigh-in-Motion (WIM) site every year on a continuous basis. Every day the Maintenance Bureau issues 500 to 600 oversize or overweight permits. Knowledge of the actual loads including illegally overloaded vehicles can help in day-to-day and planned maintenance procedures and law-enforcement efforts. ALDOT provided WIM data from 12 WIM stations for the years 2014 to 2016 and issued permit data by ALDOT for the year 2014 and 2015. It was found from the developed procedures that two of the WIM stations were not functioning properly and the WIM data could not be used. The 20% of trucks that are overloaded create more than 50% of the total damage for the traffic combined from all the locations. 16-18% of trucks that are illegally overloaded create more than 40% of the total damage. Based on the truck traffic recorded at WIM site 931 (Athens), the fatigue life of steel girder bridges along the route is consumed four times faster than expected for a design life of 75 years. For traffic recorded at WIM sites other than 931 (Athens), 942 (Pine Level) and 961 (Mobile), the fatigue life of steel girder bridges is consumed slower than expected for a design life of 75 years. Two computer apps were developed for implementation by ALDOT of the developed procedures. The computer app, ALDOT_WIM_QC v1.0, can be used to evaluate the quality of the WIM data and maintain the "health" of WIM systems. Another application, ALDOT_WIM_DAI v1.0, can be used to evaluate the fatigue damage in a steel girder bridge due to the traffic recorded at the WIM site. The results of the fatigue damage calculations can be used to evaluate the significance of the truck traffic along various routes and the impact of the various FHWA Vehicle Classes on the total damage.

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Research Report

ALDOT Project

APPLICATION OF WIM AND PERMIT DATA

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ABSTRACT

The objective of this project was to (1) improve the procedures for processing and evaluation of the quality of the WIM data, (2) develop an analytical procedure to identify legal, permitted and illegal vehicles in the WIM records, (3) develop a set of algorithms to evaluate fatigue damage accumulated in steel bridges and (4) make recommendations regarding which traditional WIM stations is to be converted to Virtual Weigh Stations. ALDOT collects traffic data including records of millions of vehicles at each of the 12 Weigh-in-Motion (WIM) site every year on a continuous basis. Every day the Maintenance Bureau issues 500 to 600 oversize or overweight permits. Knowledge of the actual loads including illegally overloaded vehicles can help in day-to-day and planned maintenance procedures and law-enforcement efforts. ALDOT provided WIM data from 12 WIM stations for the years 2014 to 2016 and issued permit data by ALDOT for the year 2014 and 2015. It was found from the developed procedures that two of the WIM stations were not functioning properly and the WIM data could not be used. The 20% of trucks that are overloaded create more than 50% of the total damage for the traffic combined from all the locations. 16-18% of trucks that are illegally overloaded create more than 40% of the total damage. Based on the truck traffic recorded at WIM site 931 (Athens), the fatigue life of steel girder bridges along the route is consumed four times faster than expected for a design life of 75 years. For traffic recorded at WIM sites other than 931 (Athens), 942 (Pine Level) and 961 (Mobile), the fatigue life of steel girder bridges is consumed slower than expected for a design life of 75 years. Two computer apps were developed for implementation by ALDOT of the developed procedures. The computer app, ALDOT_WIM_QC v1.0, can be used to evaluate the quality of the WIM data and maintain the "health" of WIM systems. Another application, ALDOT_WIM_DAI v1.0, can be used to evaluate the fatigue damage in a steel girder bridge due to the traffic recorded at the WIM site. The results of the fatigue damage calculations can be used to evaluate the significance of the truck traffic along various routes and the impact of the various FHWA Vehicle Classes on the total damage.

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CHAPTER 1 INTRODUCTION

1.1. Background

Bridge owners need to know the actual live loads for many bridge management tasks. There is an enormous weigh-in-motion (WIM) database collected by states, for various locations, practically covering the whole nation, but it is often under-utilized by bridge engineers. Bridges are affected by heavy traffic, and the major factors are traffic volume, weight and axle configuration of the vehicles, and multiple presence, i.e., occurrence of multiple vehicles in lane and adjacent lanes. Most of the damage to bridges is caused by overloaded vehicles. The magnitude of traffic loads is controlled by:

- Legal load limits
- Permit loads, numbers and weights
- Control of illegally overloaded vehicles

The truck traffic recorded by WIM stations includes vehicles that represent three groups of vehicles: legal, permit and illegal. Separation of WIM data into these three corresponding groups is not a trivial task. In particular, the distinction between permit and illegal vehicles requires additional information and special data analysis procedures.

Beginning in the 20th century, many states sponsored studies on the effects on bridges of overweight vehicles. Culmo et al. 2004 did a study on the behavior of steel bridges for specific permit trucks for Connecticut. Reisert and Bowman conducted a study of fatigue of older steel bridges from overweight and oversized loads in Indiana in 2005. Also, a study was done by F. L. Roberts et al. 2005 on the effects of specific commodities transporting vehicles on Louisiana infrastructure. Later in 2012, a multi-phase study in Wisconsin on the impact of overweight vehicles was done by H. Bae and M. Oliva 2009, 2012. Also, a laboratory test and numerical simulation were performed for deck deterioration as part of the Wisconsin study.

1.2. Problem Statement

Permit regulations and monitoring procedures were developed to provide the safe operation of transportation structures (Luskin and Walton 2001; Stith 2006; Taylor et al. 2000; “Truck Weights and Highways” 2003). However, the problem of controlling the haulers violating the law remains unsolved, as well as the question: to what extent the vehicles can be overloaded? Several sources reported about the relative proportion of illegal vs. law-abiding haulers (“2013 New Jersey Traffic Monitoring Program” n.d.; Fiorillo and Ghosn 2016; Luskin and Walton 2001; Taylor et al. 2000).

The problem of illegal overloading of trucks goes far beyond the safety of the roads and bridges. The violators create a high competition in the transportation service market, where the operators that follow the permitted limits stay at a disadvantage. Most states follow the federal weight limits to protect the roads and bridges from progressive damage. However, requests to increase axle load limits to reduce transportation costs are common as reported in Luskin and Walton 2001; Stith 2006.

Knowledge of the actual loads including illegally overloaded vehicles can help in day-to-day and planned maintenance procedures and law-enforcement effort. Nowadays, the traffic load monitoring systems are rapidly developing and are incorporated by State DOTs (Office of Freight Management and Operations 2017; *Traffic Monitoring Guide* 2016). The effects caused by legal vehicles and permit vehicles can be assessed, but it is also important to evaluate the damage caused by illegally overloaded vehicles.

1.3. Research Objective

The main goal is to develop practical procedures for processing WIM and issued permit data for the evaluation of traffic-induced damage to bridges. The long-term vision of this project is to implement the developed procedures at WIM stations and Virtual Weigh Stations where data can be assessed in real-time, so those measurements can be used by ALDOT for evaluating the effects of heavy loads in the traffic stream on bridges and roadways.

Objectives:

1. Improve the procedures used to process WIM data from the raw measurements.
2. Develop a Quality Control (QC) procedure to improve the quality of the WIM data.
3. Demonstrate the developed QC procedure on WIM data collected by ALDOT for the years 2014 to 2016.
4. Provide ALDOT with a computer app to evaluate the quality of the WIM data and maintain the “health” of WIM systems on routine basis.
5. Develop an analytical procedure to identify legal, permitted and illegal vehicles in the traffic.
6. Demonstrate the identification of issued permits in WIM data for the years 2014 and 2015.
7. Develop a procedure to convert the raw measurements into an index of accumulated damage for the bridges along the route. It will provide an excellent planning tool for ALDOT and will provide an understanding of the significance of the truck traffic along various routes and the impact of illegal and permitted overweight trucks on the bridges.
8. Provide ALDOT with a computer app to assess the damage caused by traffic on bridges. The estimation of damage accumulation index procedure is the first step towards the long-term vision

of incorporating tracking of damage accumulation into the bridge management program of ALDOT.

9. Provide WIM data analysis that will assist ALDOT in prioritizing the conversion of traditional WIM stations into Virtual Weigh Stations. Many of the traditional WIM stations will be upgraded to Virtual Weight Stations in the future. Data analysis results are provided that will help prioritize the order of upgrading of these stations.

1.4. Organization of Report

The research approach, developed procedures, practical examples and corresponding results are documented in this report. This report is divided into 7 chapters and 6 appendices:

Chapter 1. Introduction

This chapter is an introductory chapter providing the background, problem statement and research objectives.

Chapter 2. Alabama Traffic Monitoring Devices and Database

In this chapter, a literature review of the state of practice on the development and practice of WIM systems is discussed. The advantages and disadvantages of many types of WIM systems in existence are also discussed. Later, the WIM systems that are used in the state of Alabama is discussed. Mainly, the WIM database and ALDOT issued permit database were used. WIM data from 12 traditional WIM stations were shared with the research group that are in the state of Alabama. The various formats of WIM data and the conversion process and summary of available WIM data is discussed.

Chapter 3. Quality Control Procedure for WIM traffic data

This chapter discusses a proposed procedure to check the quality of the traffic data and detect the root cause of questionable recorded traffic data. Inconsistency in recording due to communication failure, operational problems with the sensor and drift in calibration can be interpreted from this proposed procedure. The proposed procedure consists of a completeness check, logical checks, and statistical checks. A review of the literature to identify the state-of-the-art was performed and the database of issued permits is used to establish limits for threshold parameters. A computer app “ALDOT_WIM_QC v1.0” was developed and delivered to ALDOT to process the WIM data using the developed QC procedures.

Chapter 4. Identification of issued permit vehicles in WIM traffic database

This chapter discusses a procedure to identify the permit vehicles in the WIM data. The first step is the separation of legal traffic so that the remaining file includes only permit vehicles and illegal traffic. Then

WIM data without legal vehicles are sorted out using the parameters of issued permits to identify vehicles that have a permit. The remaining vehicles can be considered as illegal traffic. Issued permit data for years 2014 and 2015 were available, so those years are used to demonstrate the procedure.

Chapter 5. Bridge Damage Accumulation

In this chapter, a procedure to quantify damage accumulated on different components of a bridge is presented. Every passage of a truck creates stress cycles in the bridge components and damage is accumulated at fatigue prone details. The procedure allows the damage induced by a single truck alone to be evaluated, or the damage from all trucks in the WIM database or for only a desired category of trucks in the traffic stream. For example, damage due to the overloaded trucks in the WIM traffic, or the trucks with issued permits can be assessed. Also, the damage caused by the different FHWA classes of vehicle can be assessed. Comparisons of the damage at various WIM sites are possible and are reported for years 2014 and 2015. Most of the comparisons reported here are for generic bridges, but the procedure can be applied to a particular bridge. An example showing the application of the procedure to assess the damage specific to a particular bridge is included in Chapter 6. A computer app “ALDOT_WIM_DAI v1.0” was developed and delivered to ALDOT for the processing of WIM data using the damage accumulation procedures.

Chapter 6. Identifying Priorities for WIM Sites Upgrade

This chapter summarizes the results of the previous steps. Based on the quality control analysis, permit database analysis and assessment of the nominal fatigue damage at the WIM sites, recommendations are made regarding which sites are best candidates for an upgrade to Virtual Weigh Stations. These recommendations are made based on which sites would benefit most from having better control of overweight vehicles.

Chapter 7. Summary, Conclusions, and Recommendations

This chapter contains the conclusions of the current study and discussions of future research in the area.

CHAPTER 2 ALABAMA TRAFFIC MONITORING DEVICES AND DATABASES

2.1. Introduction

WIM systems and Continuous Count Stations (CCS) are the two primary sources that collect traffic data (Hallenbeck, M. and H. Weinblatt 2004). CCS is also referred to as Automatic Traffic Recorders (ATR) in many publications. WIM systems can collect both traffic volume and load spectra whereas the CCS can collect only traffic volume. Since the load spectra are important for bridge load assessment, the scope of this project and report is limited to WIM systems only. Alabama traffic databases used in this project are the WIM database and issued permit database by ALDOT. The WIM database consists of traffic data from 12 WIM stations for the years 2014 to 2016 and issued permit database consists of data for the years 2014 and 2015. Use of WIM systems in the State of Alabama dates back to as early as 1986 (Cunagin 1986).

2.2. Weigh-in-Motion Systems

WIM data collection provides a powerful tool for traffic load assessment (Ramesh Babu et al. 2019a). Each traffic record collected at the WIM site includes a detailed description of the vehicle configuration (*Traffic Monitoring Guide* 2001b). The information recorded for each vehicle in the WIM database includes the exact time and date, lane and direction code, speed, GVW, speed, individual axle loads, individual axle spacing and class of vehicle based on FHWA Classification scheme (Cambridge Systematics, Inc. 2007). One of the first WIM systems was developed in 1952 by the United States Bureau of Public Roads (predecessor of FHWA), (Norman and Hopkins 1952). It was just a reinforced concrete platform instrumented with resistance wire strain gauges. The vehicle weight was calculated manually by making use of the output from the oscilloscope attached to strain gauges. Contemporary WIM systems are very different from the sensors developed in the 1960s.

Recently, FHWA along with State DOTs have collected a substantial weigh-in-motion (WIM) database. As of 2011, WIM systems have been in operation for more than 20 years in most states in the U.S. Over 700 portable and permanent WIM stations are currently in operation around the country (Ghosn et al. 2011). Despite the advantages of WIM technologies, a decrease in WIM research has been observed since 2000 (Pigman et al. 2012). One of the reasons is that the setting of permanent WIM devices, as well as following service, is quite costly. Therefore, the WIM systems are usually installed on busy state roads or interstate highways.

There is a variety of Weigh-in-Motion technologies available for permanent or temporary traffic data collection. ASTM E1318-09 (*ASTM E1318 - 09 - Standard Specification for Highway Weigh-in-Motion*

(WIM) Systems with User Requirements and Test Methods 2009) classifies WIM systems into Type I to Type IV systems depending on the performance requirements of the WIM systems. Usually, WIM sites across the US are equipped with the following types of weigh-in-motion (WIM) systems: piezoelectric sensor, bending plate, single load cell, quartz-piezoelectric sensor and B-WIM systems (Al-Qadi et al. 2016a; McCall and Vodrazka 1997a).

Bending plate sensor consists of two scales and inductive loops for vehicle count. The central principle is based on using strain gauges attached to the weigh pads and re-computing the axle loads from the strains measured. These systems were designed for long-term (over ten years) monitoring of traffic, moving with speed from 3 to 124 mph. Calibration of these weighing systems is performed using test trucks according to (ASTM E1318 - 09 2009). The expected accuracy of measurement for Type I WIM sensors is 10% for GVW and 25% for axle load and axle spacing group (Table 3.3, McCall and Vodrazka 1997).

Piezoelectric WIM sensors can be divided into three basic types based on piezoelectric material: piezoceramic sensors, piezopolymer sensors, and piezo quartz sensors. The first two types are highly temperature dependent and mostly used for vehicle count and classification (Al-Qadi et al. 2016b). Piezoquartz WIM sensors are widely used in the regions prone to frequent freeze-and-thaw cycles due to their low sensitivity to temperature fluctuations (White et al. 2006). They also belong to the ASTM E1318 Type I WIM systems and, thus, can be used for measuring vehicle weight with the sufficient accuracy (10% for GVW and 25% for axle load and spacing). A principle of piezoelectric sensor operation is based on the difference in voltage due to the applied force. Calibration procedure determines the force-voltage relationship. However, this type of system is only accurate in case of dynamic load, while for static or slow-motion speed measurements there is a substantial error.

Load cell-based WIM systems utilize a similar mechanism as bending plates. The weight sensor is usually a strain-gauge type, which converts the applied force into the proportional electrical signal. The load cell WIM systems are commonly used in conjunction with the inductance loops to eliminate incorrect records and activate the principle system (Al-Qadi et al. 2016b).

The B-WIM systems are built on a combination of strain gauges attached to the bottom surface of the main longitudinal members of a bridge along with axle detectors (*SiWIM Bridge Weigh-in-Motion Manual: 4th Edition* 2011). The principle of B-WIM system performance is based on the comparison of measured and modeled bending moments. The bending moments are calculated from the recorded strains and mechanical properties of structural members.

Virtual Weigh Stations utilize practically the same WIM scale systems along with the digital cameras and software to process the visual information in real time. These systems can recognize the characters on vehicle license plates and analyze this information along with the GVW, axle weight, and vehicle class, obtained from the traditional sensors, such as listed above.

There are several factors, which can affect the accuracy of measurements collected by any type of WIM systems, such as pavement roughness (causing bouncing axle movement or dynamic impact) and temperature effects. However, the dynamic portion of the load is usually pre-evaluated and eliminated in the final measurements.

2.3. Alabama WIM Database

There are 13 WIM sites for collection of weigh-in-motion data in Alabama, and each site is equipped with one of these systems: traditional WIM, SiWIM or Bridge WIM, and Virtual Weigh Station. WIM data collection from the location on US-231 using SiWIM system has been terminated. The visual information collected at Virtual Weight Station at WIM site 965 (Shorter, I85) has a technology to record the following information: license plate, a picture of the vehicle, axle configuration, axle weight, time and speed of the vehicle. The bending plate systems at WIM site 965 (Shorter, I-85) are shown in Figure 1. However, the data is not stored and thus, not available for analysis. Therefore, for the project reported here the sources of data are the 12 traditional WIM stations. All the traditional WIM stations except one are equipped with a permanent bending plate system consisting of two scales and inductive loops (*ASTM E1318 - 09*, 2009). However, there is a future possibility that data in real time may be obtained from both the traditional WIM and Virtual Weigh Stations. ALDOT uses WIM systems from International Road Dynamics Inc. (IRD).

Figure 1. Bending Plate Systems in WIM Location 965 (Shorter, I-85)

The location of each traditional WIM station in the state of Alabama is shown in Table 1. The WIM locations along with their respective latitude and longitude coordinates are shown. The direction of travel in all of the WIM locations are North-South or Northeast-Southwest (N-S or NE-SW) and lane of travel indicates the 1 being the rightmost lane and 2, 3 and 4 are other lanes. Also, the location of the WIM stations on the map of the state of Alabama is shown in Figure 2. More in detail summary of available WIM data in each WIM location is discussed in subsequent sections of this chapter.

Table 1. WIM station locations in the State of Alabama

Station code	**Name**	**Location**	**Latitude**	**Longitude**	**Direction of Travel**	**Lane of Travel**			
911	Alex City	US280 Coosa Co.	32.449819	-87.492372	N-S or NE-SW	1	2	3	4
915	Sunflower	US43 Washington Co.	31.367501	-88.032962	N-S or NE-SW	1	2	3	4
918	Bucksville	I20 Tuscaloosa Co.	33.276556	-87.099040	N-S or NE-SW	1	2	3	-
931	Athens	I65 Limestone Co.	34.844252	-86.933136	N-S or NE-SW	1	2	3	4
933	Muscle Shoals	AL157 US72 Colbert Co.	34.777264	-87.669088	N-S or NE-SW	1	2	3	4
934	Sumiton	US78 Walker Co.	32.860486	-87.240263	N-S or NE-SW	1	2	3	4
942	Pine Level	US231 Montgomery Co.	32.015582	-86.030366	N-S or NE-SW	1	2	3	4
960	Whatley	US84 Clark Co.	31.646739	-87.705445	N-S or NE-SW	1	2	-	-
961	Mobile	I65 Mobile Co.	30.889663	-88.023691	N-S or NE-SW	1	2	3	4
963	Grand Bay	I10 Mobile Co.	30.499070	-88.321659	N-S or NE-SW	1	2	3	4
964	Ozark	US231 Dothan Co.	31.370076	-85.565963	N-S or NE-SW	1	2	3	4
965	Shorter	I85	32.392695	-85.984328	N-S or NE-SW	1	2	3	4

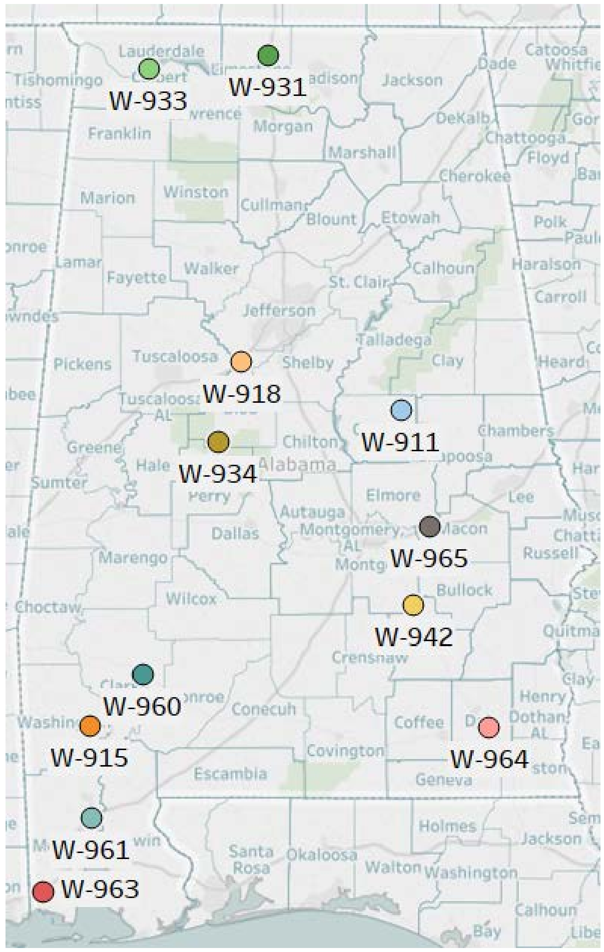


Figure 2. Locations of WIM stations in the state of Alabama.

2.3.1. Raw WIM records

Once the vehicles are recorded by WIM sensors, the records (or data) are transferred over a dial-up line using cell modems and stored in ALDOT's data storage medium. Later the data was uploaded to Auburn University data storage medium by an ALDOT personnel. All the data are in an encrypted format and is a so-called "Raw" format. The raw format can be defined as data free from QC and just downloaded from the storage medium (Pelphrey, J and C. Higgins 2006).

2.3.2. WIM data formats

The traffic data collected by WIM systems are available in different data formats. For instance, in TMG there is Station Description format, Traffic Volume format, Vehicle Classification format, Weight format and five other formats (*Traffic Monitoring Guide* 2016). In LTPP, depending on the type of software that processes the WIM data it has different formats (Federal Highway Administration 2015; Office of Federal Highway Administration n.d.). LTPP Traffic Quality Control (LTQC) software has 4-card (Classification card) and 7-card (Weight card) data formats. At many WIM locations data is processed by vendor's software that can produce data in a variety of formats (Office of Federal Highway Administration). WIM system vendor of ALDOT, IRD has an option to choose from a variety of data formats (International Road Dynamics Inc. 2017). Next section of the report discusses in more detail the formats used to process WIM data in this project.

2.3.3. WIM Data conversion

The WIM data provided to the research group contains data from 12 traditional WIM sites from Jan 2014 until December 2016. All the data were in encrypted and in Raw data format. WIM vendor software "iAnalyze" was required to decrypt to the data. A license was shared with the research group for iAnalyze software. Alabama uses the FHWA 13 vehicle classification system with small modifications and class 0 as a bin to classify the records that have improperly recorded vehicles, axles greater than 13, and vehicles outside threshold limits of axle spacing and weight of classes 1-13. FHWA 13 vehicle classification system is shown in Figure 3. Improperly recorded vehicles can be those vehicles that are not appropriately positioned on the sensor and has other potential violation conditions (in appendix f of (International Road Dynamics Inc. 2017)). Vendor-provided software has a built-in algorithm to flag that kind of vehicle. A detailed description of ALDOT's vehicle classification scheme based on axle configuration and weight is shown in Appendix A and Appendix B.

The WIM data containing properly recorded Class 0 and Class 4-13 is of interest in this project. Classes1-3 are eliminated since these records are mostly cars and motorcycles. The flowchart in Figure 4 shows the step by step procedure of data conversion. The Class 0 data was decrypted using iAnalyze by selecting IRD ASCII Raw Data format. The initial step after decrypting Class 0 was to eliminate the records that had improperly recorded vehicles. The Class 4-13 data was decrypted using iAnalyze by selecting TMG 2001 Truck Weight Data format. Therefore, the remaining database contains properly recorded Class 0 vehicles and Classes 4-13. For efficient processing of WIM data, it was decided to use two different kinds of data formats for decrypting the Raw WIM data. Special Matlab routines were used to convert data to user-friendly Matlab table format.

The summary of the WIM data received for each month for years 2014-2016 is shown in Table 2. The data for a few months in some of the WIM location was missing. The summary of a number of records available in each year and WIM location is shown in Table 3.

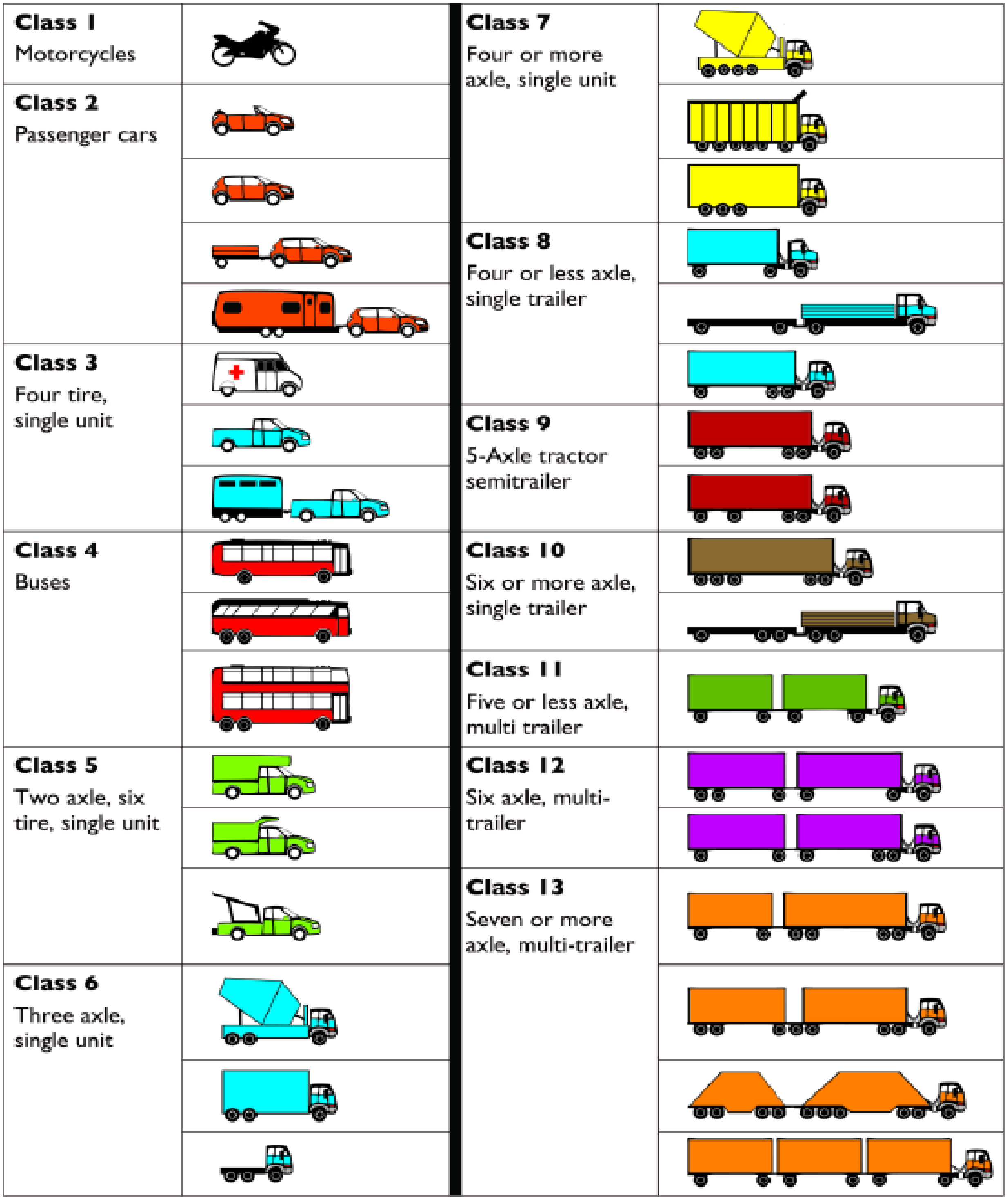


Figure 3. FHWA 13 Vehicle Category Classification *(Traffic Monitoring Guide, 2016)*

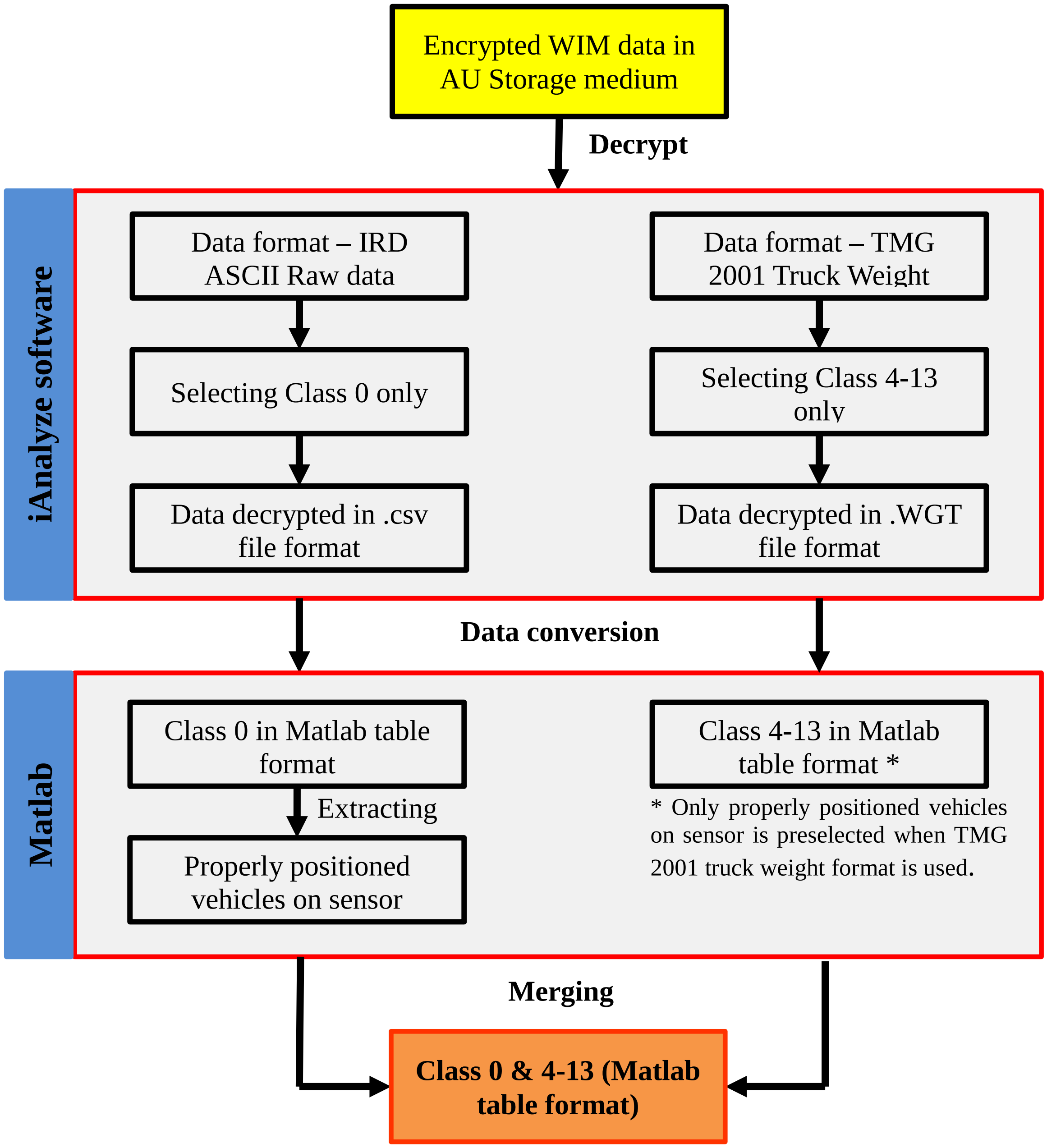


Figure 4. WIM Data conversion flowchart

Table 2. Summary of received WIM data for years 2014-2016

Station code	2014												2015												2016											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
911	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
915	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
918	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
931	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
933	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
934	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
942	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
960	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
961	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	x	x	x	x	x	x	x	x	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
963	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	x	x	x
964	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	x	x	x	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
965	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Legend: ✓ – Data is present; x – Data not available

Table 3. Summary of number of records for years 2014-2016

Station code	Name	Location	2014	2015	2016	Total
911	Alex City	US280 Coosa Co.	1,092,751	863,592	1,262,220	3,218,563
915	Sunflower	US43 Washington Co.	652,295	676,997	771536	2,100,828
918	Bucksville	I20 Tuscaloosa Co.	1,163,845	119,302	-	1,283,147
931	Athens	I65 Limestone Co.	3,655,980	4,024,460	4,260,765	11,941,205
933	Muscle Shoals	AL157 US72 Colbert Co.	977,580	931,817	826,870	2,736,267
934	Sumiton	US78 Walker Co.	688,388	516,595	649,083	1,854,066
942	Pine Level	US231 Montgomery Co.	1,262,375	1,074,754	1,145,221	3,482,350
960	Whatley	US84 Clark Co.	521,484	509,497	555,826	1,586,807
961	Mobile	I65 Mobile Co.	2,136,008	191,853	1,821,562	4,149,423
963	Grand Bay	I10 Mobile Co.	6,088,720	7,503,103	3406241	16,998,064
964	Ozark	US231 Dothan Co.	1,217,687	278,020	1149733	2,645,440
965	Shorter	I85	2,441,637	1757523	2,593,647	6,792,807
TOTAL						58,788,967

2.4. ALDOT issued Permit database

The Maintenance Bureau of Alabama DOT issues about 500-600 permits per day. About 200 of them are permits for overweight. The issued permit data for the years 2014 and 2015 was made available to AU research team. The annual reports are in the form of tables and they include permit ID, the validity of the permit, original and final destination, authorized roads, description and FHWA class of vehicle, GVW, axle load and axle spacing. The data also includes information about the size of the vehicle (e.g., over width or length). Annual permits are issued, but each trip accomplished within the annual permit is also listed as a separate row in the database. The total number of issued permits is 123,602 for 2014 and 122,539 for 2015.

To process the database, special Matlab routines were developed. More detailed discussion of the permit database is provided in Chapter 4 of this report.

2.5. Summary

In this chapter, a literature review of the state of practice on the development and use of WIM systems is discussed. The WIM systems that are used in the state of Alabama are described. Also, the databases that were used in this project are described. Mainly, the WIM database and ALDOT issued permit database were used. WIM data from 12 traditional WIM stations were available to the research group. The various formats of WIM data and the conversion process and summary of available WIM data is discussed.

CHAPTER 3 QUALITY CONTROL PROCEDURE FOR WIM TRAFFIC DATA

3.1. Introduction

Traffic-induced loadings are one of the primary factors affecting the service and fatigue life of bridges and pavements. The major source of information about traffic loading is the Weigh-in-Motion (WIM) database. However, poor quality of traffic data may lead to misinterpretation and incorrect estimation of the load effects. The errors may occur due to WIM system malfunction, out-of-calibration or irregular vehicle position on the sensor. If the error in recorded WIM data is not recognized and eliminated at the earlier stage, the quality of the entire data accumulated is questionable. Therefore, it is essential to use a Quality Control (QC) procedure.

3.2. Literature Review

So far, WIM records were used by ALDOT's Weight Enforcement team to screen weight violators and the Transportation Planning Division for the statistical analysis of the traffic mix. Accurate traffic data from WIM stations are also needed for accurate bridge evaluation, design and fatigue analysis. For instance, a significant number of incorrectly recorded vehicles that create high load effects may lead to over conservative design or unrealistically high estimated fatigue damage. Therefore, the development of the detailed quality control procedure was an essential step in this study.

Two types of error occur in long-term WIM data collection: random (occurring individually), and systematic errors (occurring frequently and affecting some records). The errors are usually associated with the WIM system malfunctioning, mis-recording, non-typical vehicle configuration, vehicle position on the sensor, and other causes. There are a number of case studies related to traffic data quality checks that are analyzed and employed by many state agencies in the US (Ramesh Babu et al. 2019b) (Turochy et al. 2015), (Elkins and Higgins 2008), (Southgate 1990), (Ramachandran et al. 2011a), (Qu et al. 1997), (Quinley 2010b), (SHRP 2 Research Reports 2015), Sivakumar et al. (2011), etc.). However, there is no documented state-specific quality control (QC) procedure employed by Alabama DOT.

Thus, a comprehensive quality control (QC) procedure is being developed in this project to ensure adequate quality of the data. A review of the literature to identify the state-of-the-art on quality control and assurance was performed to develop an effective QC procedure. The literature review was focused on various QC programs developed to monitor the quality of traffic data collected by WIM systems. As many states gather traffic data as part of FHWA's Highway Policy Management System (HPMS) submittal and traffic inputs for AASHTO's Mechanistic-Empirical Pavement Design Guide (MEPDG), the quality of the traffic data should meet minimum requirements prescribed in the respective guides (Quinley 2010a). For the benefit of each state Department of Transportation (DOT), FHWA and AASHTO have documents of guidelines to achieve maximum performance of their investment in traffic monitoring programs and equipment. Three important documents recommend the guidelines for WIM data QC: Traffic Monitoring Guide (TMG), AASHTO Guidelines for Traffic Data Programs (TDP) and HPMS field Manual (Vandervalk-Ostrander, A. 2009). Apart from this, there is FHWA's Long-Term Pavement Performance Program (LTPP) that collects traffic data as a part of pavement study (Office of Federal Highway Administration n.d.). Literature findings of QC checks in national standards and of common practices are discussed in the following sections.

3.2.1. QC checks in national standards

The traffic data collected by WIM systems are available in different data formats. For instance, in TMG there is Station Description format, Traffic Volume format, Vehicle Classification format, Weight format and five other formats (*Traffic Monitoring Guide (2001)* 2001). In LTPP, depending on the type of software that processes the WIM data it has different formats. LTPP Traffic Quality Control (LTQC) software has 4-card (Classification card) and 7-card (Weight card) data formats. At many WIM locations data is processed by vendor's software that can produce data in a variety of formats (Federal Highway Administration 2015; Office of Federal Highway Administration n.d.). TMG contains a compendium of QC criteria used by various states and recommends the checks used in Traffic Monitoring Analysis System (TMAS). TMAS includes QC checks for Station, Classification, Volume and Weight data format (*Traffic Monitoring Guide (2001)* 2001). Before data is updated in HPMS, it is filtered through TMAS checks (Office of Highway Policy Information 2017). TDP recommends minimum validation criteria for weight, classification, and vehicle count data. LTPP has the most rigorous quality control checks. Traffic data stored in a database known as the LTPP national information management system (IMS) and should comply with QC checks mentioned in IMS manual (Federal Highway Administration 2015; Office of Federal Highway Administration n.d.).

3.2.2. QC checks of common practices

As the use of WIM data is beyond just submitting data to HPMS and MEPDG, the quality control of the traffic data can be tailored according to customer needs. Some states have developed their QC programs to meet customer needs and achieve maximum performance (Vandervalk-Ostrander, A. 2009). The need for adequate quality of traffic data in bridge design has been studied extensively in NCHRP report 683 (Sivakumar et al. 2008). The QC checks developed in state DOT's QC programs, research papers, NCHRP reports, and journal articles are reviewed and listed in Table 4.

Table 4. Literature findings of QC checks of common practices

Reference	Findings
WIM data Quality Assurance (1994) (Hellenbeck 1994)	Class 9 histogram check of the unloaded peak between 28- 34 kips and loaded peak between 74-84 kips was proposed.
States' Successful Practices Weigh-In-Motion Handbook (1997) (McCall and Vodrazka 1997b)	The QC checks of LTPP's traffic quality control software (LTAS), FHWA's vehicle travel information system software (VRTIS) and Caltrans quality assurance programs are reported.
Quality Assurance of Weigh-In-Motion data (2000) (Southgate 2000)	A check to verify the calibration of sensors is proposed.
Traffic Data Editing Procedures: Traffic Data Quality (2002) (Flinner and Horsey 2002)	120 QC checks rule list was developed for volume, weight, classification cards.
Quality Control Procedures for Weigh-in-Motion Data (2004) (Nichols and Bullock 2004)	The DMAIC model (tool in Six Sigma project model) was proposed to improve the accuracy of the traffic data.
Calibration of LRFR Live Load Factors for Oregon State-Owned Bridges using WIM Data (2006) (Pelphrey, J and C. Higgins 2006)	A set of QC checks is recommended before using the data for calibrating live load factors for bridge load rating.
Enhancement of bridge live loads using weigh-in-motion data (2007) (Sivakumar and Ibrahim 2007)	The filtering criteria to eliminate unrealistic data used on New York WIM data are presented.
QC Procedures for Archived Operations Traffic Data: Synthesis of Practice and Recommendations (2007) (Shawn Turner 2007)	QC criteria are established for archived data. Archived data from 9 states were surveyed.
WIM Data Analyst's Manual (2010) (Quinley 2010a)	Extensive QC checks on WIM data and tasks of WIM Data analyst are reported.
NCDOT Quality Control Methods for Weigh-in-Motion Data (2011) (Ramachandran et al. 2011b)	Rule list of QC for Weight cards and Class cards which are similar to LTPP QC is used. Weight range peaks for Classes 4-13 is established.
Protocols for Collecting and Using Traffic Data in Bridge Design (NCHRP 683) (2011) (Sivakumar et al. 2008)	Filters to data scrubbing and QC checks on the reminder of scrubbed data are proposed.
Cleaning Weigh-in-Motion Data: Techniques and Recommendations (2011) (OBrien 2011)	Different filtering criteria are proposed for each country considered in this study. A unique way to detect ghost and split axles were developed.
Validation of TMG Traffic Data Check Algorithms (2013) (Li et al. 2013)	The paper concludes the TMG checks are still valid. Framework to check suitableness of the data is presented in case of exceptional patterns.
Calibration of AASHTO LRFD Concrete Bridge Design Specifications for Serviceability (2014) (Wagdy G. Wassef et al. 2014)	A set of filtering criteria on WIM data for eliminating questionable records. Additional criteria for using data in fatigue limit state calibration is also used.
Development of Alabama Traffic Factors for use in Mechanistic-Empirical Pavement Design (2015) (Turochy et al. 2015a)	A set of QC checks consisting of threshold and rational checks are proposed.
Bridge Live Load Models in U.S. and Europe (2018) (Ramesh Babu, A., et al. 2018)	A comparison of QC checks in the USA and Europe is performed.

3.3. Quality Control Algorithm

Based on the literature review, many QC checks were recommended for a particular data format (For Ex. TMG or LTPP formats). For bridge live load modeling, vehicle weight, configuration, traffic volume, and timestamp are essential. For example, TMG's Weight format or LTAS's 7-card format includes axle weight and configuration information but is limited to FHWA vehicle classes 4-13 (*Traffic Monitoring Guide (2001)* 2001). If the state uses another classification system than FHWA (13 vehicle category classification) the vehicles that do not meet the FHWA limits are categorized into an "unclassified" group, such as Class 0.

In the proposed procedure it is recommended to obtain data in a so-called "RAW format" rather than pre-processed. RAW format can be defined as data free from QC and just downloaded from the storage medium (Pelphrey, J and C. Higgins 2006). Many WIM system vendor's software provides an alternative to extract this data in RAW format rather than one of the TMG or LTPP's formats. For example, the Alabama WIM data is classified into FHWA Classes 0-13. However, when extracted using TMG's weight data format, only Classes 4-13 are obtained. It matters what kind of data Class 0 contains, in this case, the records that have improper positioning of vehicles on sensors, axles greater than 14, and vehicles outside threshold limits of axle spacing and weight of Classes 1-13 are placed in Class 0. The latter criteria, vehicles outside threshold limits that are in Class 0 is of importance (Olga Iatsko 2018).

Selection and sequential order of the quality control criteria are critical to ensuring only questionable records are eliminated. The proposed QC procedure consists of 3 sets of checks: completeness, logical and statistical. The proposed procedure is shown in the form of a flowchart in Figure 5. The logical checks are based on threshold limits. Selection of threshold limits is a critical factor so that the correct data is not eliminated. Some of the threshold limits were based on the limits recommended in previous studies (Ramesh Babu, A., et al. 2018; Sivakumar et al. 2008; Wagdy G. Wassef et al. 2014). However, after examination of filtered records, it was observed some records which appear to be real are being eliminated just because they are out of limits. So, the threshold limits are set by analyzing the source where accurate vehicle configuration information is available, such as issued permit data, police citation data. This is important because the vehicle which is not the typical vehicle in the traffic but are real and should not be eliminated.

The statistical checks are applied to the accumulated data set rather than individual vehicle record. Most of the statistical checks are applied to vehicle Class 9, as it is the most common vehicle class in the traffic stream. Minnesota DOT first developed the checks on Class 9 vehicles and then used in Long-Term Pavement Performance (LTPP) (Hellenbeck 1994). As of now, the developed statistics are used by many national (Office of Federal Highway Administration n.d.) and state agencies (*Traffic Monitoring Guide*

(2001) 2001) as a way to maintain “health” of the WIM systems. LTTP’s annual Standard Data Release can be used to compare statistical check limits as the LTTP WIM sites are regularly maintained (“LTPP InfoPave - Standard Data Release” n.d.). Statistical check limits reported in the literature was consistent in many cases. Therefore, standard limits are used in the proposed procedure.

3.3.1. Completeness check

This first set of check is used to identify missing data in the accumulated database. The algorithm can be developed to check whether the data is present in each hour of the day or just in each day of a month based on user preference. The hour of the data with no records can be flagged, and possible cause of missing data can be investigated. Probable causes of missing data may be communication failures or system malfunction.

3.3.2. Logical checks

These checks were developed based on the common practice reported in the literature. All the filtering criteria in the logical checks are applied to each individual vehicle record. The individual records containing obvious errors, such as but not limited to, empty rows, zero-weight vehicles are eliminated. The proposed set of filtering criteria in logical checks is shown in Table 5. Each criterion is categorized by the type and a unique error code is given. Each filtering criteria has a threshold limit(s) and if the records are outside the limit(s), then the records are eliminated from further analysis. The criterion that can be modified depending upon availability of issued permit data is indicated. The filtering criteria such as error code 3.c, 3.d, 3.e and 3.j can be modified by analyzing permit database. In case the issued permit database is not available, then the threshold limits mentioned in Table 5 can be used. Usually, there is a limitation on the number of the axles that can be recorded by WIM sensors. That limit is part of the logical check filtering criteria.

3.3.3. Statistical checks

The statistical checks are applied to identify the anomalies in the traffic patterns and possible reasons causing the anomaly. Checks can be applied on accumulated data on a monthly basis to detect the possible malfunctions and their reasons, such as communication failures, operational problems with the sensor and drift in the calibration of the systems.

The flowchart of statistical checks is highlighted in Figure 5. First, in the vehicle class distribution check the percentages of vehicles distributed among the classes in the accumulated database is compared with historical data. If it is done on a monthly basis then it should be compared with the corresponding month of previous years if that data is available. As an alternative, it can also be compared with the data from

ATR or any vehicle classification equipment if available. If the statistics are not matching with the historical data, the possible cause would be operational problems in the sensor. After this check, the rest of the checks are on vehicle Class 9. If the large percentage of trucks in vehicle Class 9 are above 100 kips, then there might be a problem with the sensor. It is hard to say what percentage of trucks should be above 100 kips because the truck statistics vary by region. One possible way to check is to compare the percentage to that for a nearby WIM station. Alternatively, the Class 9 records of all the WIM stations in the state can be plotted separately on the same Cumulative Distribution Function (CDF) plot for comparison. One such example is shown in the next section.

Table 5. Logical checks filtering criteria

Type	**Error code**	**Filtering criteria**	**Threshold limits**
WIM station description	**1.a**	FIPs state code	≠ (01)*
	1.b	Station ID	Alabama WIM station ID*
	1.c	Direction of travel code	≠ (0-9)
	1.d	Lane of travel	≠ (0-9)
Period of travel	**2.a**	Invalid year	Null or irrespective year
	2.b	Invalid month	≠ (1-12)
	2.c	Invalid day	≠ (1-31)
	2.d	Invalid hour	≠ (0-23)
Vehicle configuration	**3.a**	Records with zero GVW	= 0
	3.b	Records with zero axle spacing	= 0
	3.c	Number of axle (Naxle)	≠ (2-14)**
	3.d	Axle weights (Waxle)	≠ (1 kips -70 kips)**
	3.e	Axle spacing (Saxle)	≠ (3.33 ft - 180 ft)**
	3.f	Number of axles = Number of axle spaces + 1	Naxle ≠ Saxle +1
	3.g	Number of axles = Number of axle weights	Naxle ≠ # of Waxle
	3.h	Sum of axle weights +/- 10% of GVW	> or < than 10% of GVW
	3.i	Minimum first axle spacing	< 6ft
	3.j	Length of the vehicle (L)	> 220 ft**
	3.k	Invalid vehicle class	≠ (0-13)*
Duplicates	**4.a**	Identical records (rows)	If duplicated

*Depending upon state

**Can be modified based on issued permit data

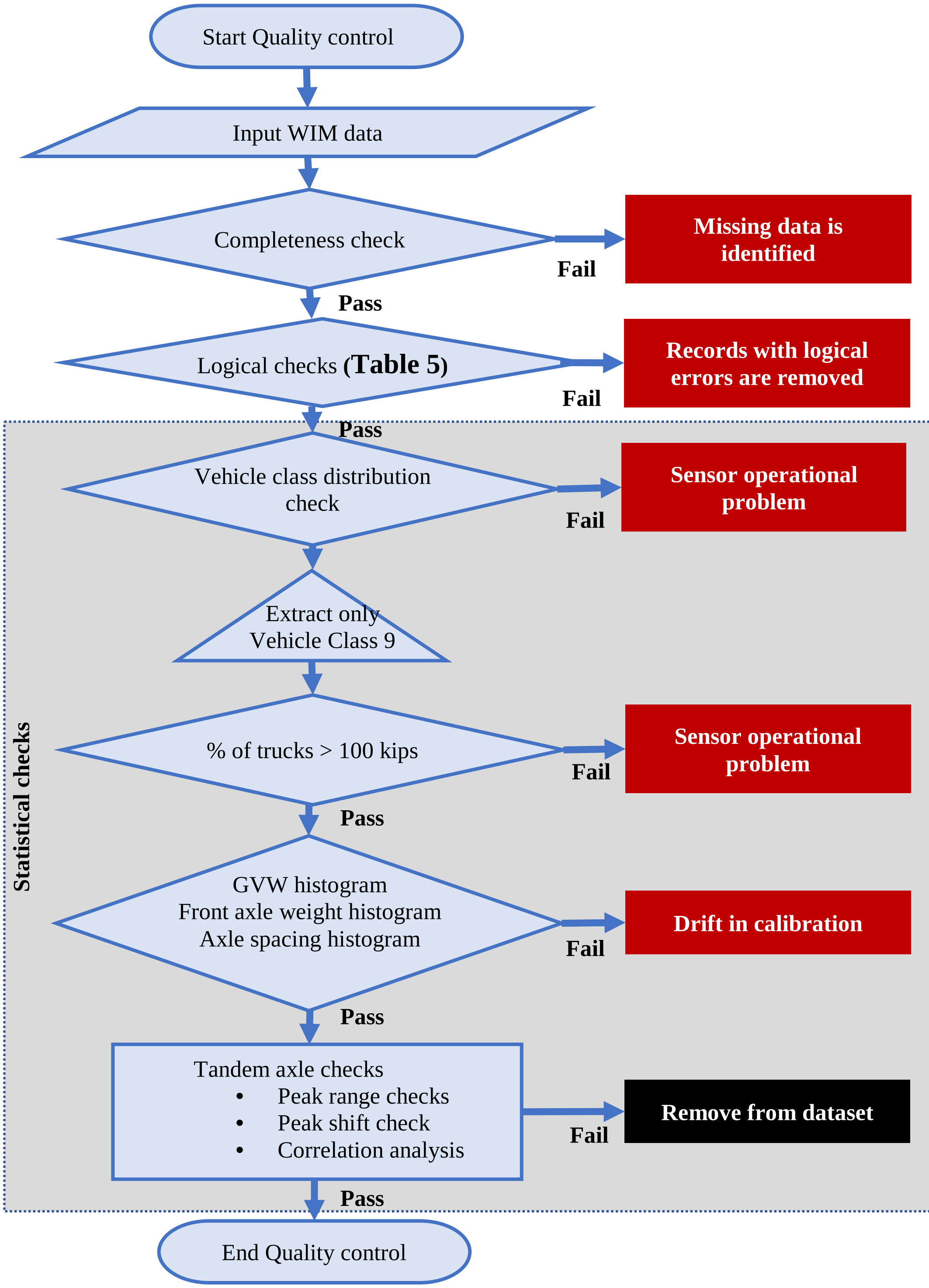


Figure 5. Flowchart of a QC procedure.

After that gross vehicle weight (GVW) histogram, front axle weight histogram and CDF plot of tandem axle spacing are plotted, the check fails if the peaks are out of limits, then the possible reason would be a system out of calibration. In GVW histogram check, 4-kip bin width histogram is plotted, if the data is correct, then there is an unloaded peak between 28 and 36 kips and a loaded peak between 72 and 80 kips. Then in front axle weight histogram check, a 1-kip bin width histogram is plotted, and usually, one peak between 8 and 12 kips is seen. In CDF plot of tandem axle spacing, the spacing of 4 feet is seen fairly constant.

The last set of the statistical check based on tandem axle load determines if the considered dataset should be eliminated from further analysis. This set of check was developed in reference *28*. A 2-kip histogram of tandem axle load with considered dataset along with historical data of corresponding month of previous years is plotted. The first peak is seen between 14 and 16 kips and the second peak between 32 and 38 kips. If the peak is shifted out of these limits, it can be visualized. The correlation analysis is performed by comparing to historical data, the considered dataset is compared with the corresponding month of the previous year. If the Pearson correlation is less than 0.85, then it is statistically insignificant and is treated as failed (Everitt 2011). It is almost impossible that the considered dataset fails all the checks before the tandem axle check and can pass only tandem axle checks. The rigorous statistical check can determine the validity of the data.

3.4. Quality Control Results

The WIM data from 12 WIM stations for the years 2014-2016 and issued permit data for the years 2014-2015 was obtained from Alabama DOT. The WIM data was obtained in Raw format, and it was encrypted initially. The data was decrypted and processed in Matlab table format as outlined in Figure 4. Therefore, the remaining database contains properly recorded Class 0 vehicles and Classes 4-13. Classes 1-3 are eliminated since these records are mostly cars and motorcycles. Technical difficulties were encountered in the decryption of the data from WIM stations 915 and 965 using iAnalyze, so that data was not used further in this project.

The remaining database is run through the proposed QC procedure shown in Figure 5. It was decided to use the threshold limits mentioned in Table 5. Logical checks filtering criteria after the analysis of issued permit data of Alabama. Also, all vehicles of GVW less than 20 kips were eliminated in remaining classes before the QC procedure was performed due to limitations in the processing capacity. But, the upper tail of the traffic data is of importance in bridge live load modeling, so elimination of these lightweight vehicles is not significant. The Class 0 contained some vehicles which were just outside the threshold limits of GVW of Classes 1-13 but still correct records that contributed to the end of the tail. To indicate the importance of Class 0, the plot of “Class 0 & 4 -13” and “Class 4-13” is shown in Figure 6 for WIM station 911 of the year 2014 as an example after the data was processed through proposed QC procedure. It is clearly seen how the upper tail of the traffic data changes when Class 0 is included. The completeness check indicated inconsistency in recording, missing some days of recording. The results of the completeness check is shown in Table 6. The total number of days in each month of the availability of the WIM data is listed. The summary of available WIM data before and after logical check filtering is shown in Table 7.

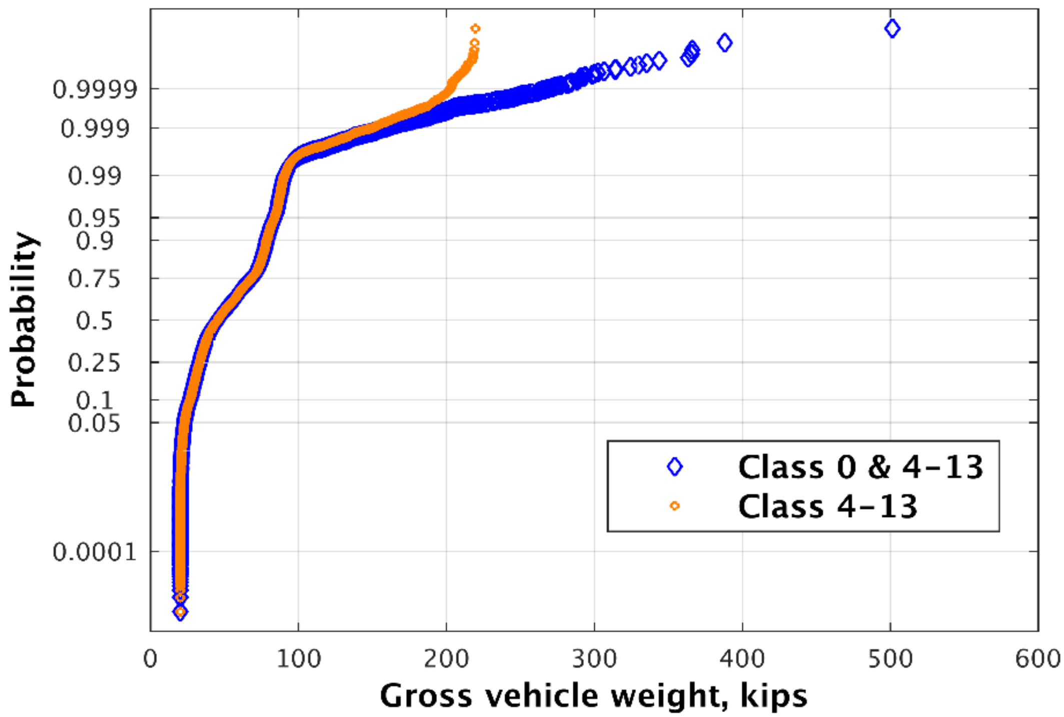


Figure 6. Cumulative Distribution Function of gross vehicle weight of “Class 0 & 4 -13" and "Class 4-13" for WIM station 911, year 2014.

Table 6. Completeness check of all WIM stations in state of Alabama for years 2014 to 2016

WIM Location	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
911	2014	30	28	30	29	30	29	30	30	29	30	29	30
	2015	30	27	30	29	30	29	30	30	29	30	29	30
	2016	30	28	30	29	30	29	30	30	29	30	29	30
931	2014	30	27	30	30	31	30	31	30	30	31	30	31
	2015	30	27	31	29	30	30	31	31	30	31	30	31
	2016	31	29	31	29	31	30	31	31	29	30	30	31
933	2014	30	27	30	29	31	30	31	30	30	30	29	30
	2015	30	27	31	30	30	30	31	30	29	30	30	31
	2016	30	28	30	29	30	29	30	31	29	15	29	30
934	2014	24	21	30	27	18	29	30	30	29	30	14	29
	2015	30	27	30	29	30	29	30	31	29	27	29	30
	2016	30	28	30	29	30	5	31	31	29	30	30	30
942	2014	28	23	30	29	30	30	30	30	29	30	29	30
	2015	30	27	31	29	30	29	30	30	29	30	30	31
	2016	30	28	30	29	30	29	30	30	29	30	29	30
960	2014	30	27	31	29	30	29	30	30	29	30	12	30
	2015	8	27	27	30	30	29	30	30	29	30	29	30
	2016	30	23	30	29	30	29	30	30	29	30	29	30
961	2014	31	28	30	30	30	29	30	30	29	7	0	0
	2015	0	0	0	0	0	0	0	0	0	0	0	30
	2016	30	28	25	29	30	29	30	2	0	13	29	30
964	2014	29	27	31	29	30	29	30	30	29	30	29	30
	2015	30	27	21	0	0	0	0	0	0	0	0	30
	2016	27	28	30	29	31	29	30	30	29	3	1	30

Table 7. Number of records in Alabama Weigh-in-Motion database

WIM station	Before logical checks			After logical checks			Records eliminated by logical check (%)	Total records after logical check
	2014	2015	2016	2014	2015	2016		
911 (US280)	399,514	378,359	430,793	357,854	350,493	361,684	11%	1,070,031
918 (I20)	1,002,049	116,661	N/A*	743,287	33,739	N/A*	31%	777,026
931 (I65)	1,730,840	1,941,813	1,985,302	1,584,347	1,548,620	1,350,318	21%	4,483,285
933 (AL157)	524,116	456,251	382,906	427,505	411,725	350,085	13%	1,189,315
934 (US78)	180,634	113,529	148,192	169,407	112,120	134,012	6%	415,539
942 (US231)	806,305	707,222	733,913	787,426	689,126	713,436	3%	2,189,988
960 (US84)	317,502	292,802	313,075	305,565	282,311	301,933	4%	889,809
961 (I65)	1,298,636	115,589	1,150,865	851,184	115,364	1,101,595	19%	2,068,143
963 (I10)	7,936,829	8,481,882	3,669,721	4,972,917	5,284,795	2,283,603	38%	12,541,315
964 (US231)	660,591	148,357	607,532	642,336	135,825	587,857	4%	1,366,018

*Data not available

In Table 8 the example of error vehicles detected by QC procedure and in Table 9, the percentage of records eliminated by each logical check filtering criteria is shown. The minimum, maximum and average percentage of eliminated records of all the considered WIM stations combined is shown. Most of the records are eliminated by logical error code 3.d, 3.e and 3.i. Data from WIM station 918 was completely eliminated after logical checks as it contained may erroneous records and some corrupted files were found during decryption.

Table 8. Example of error vehicles detected by QC procedure

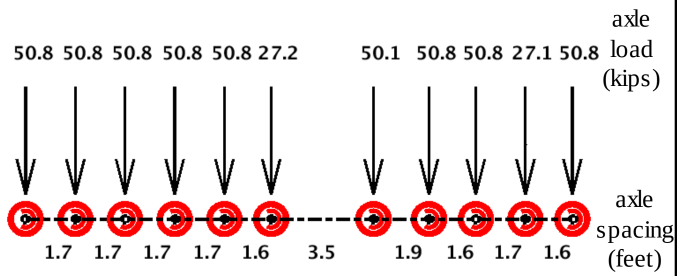
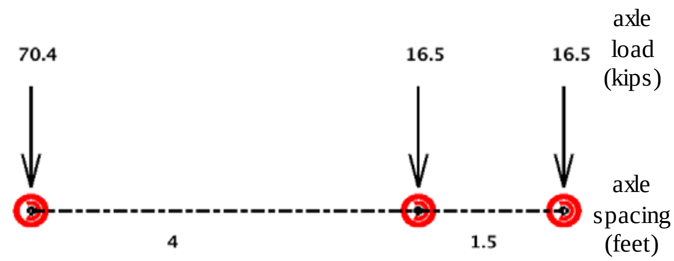
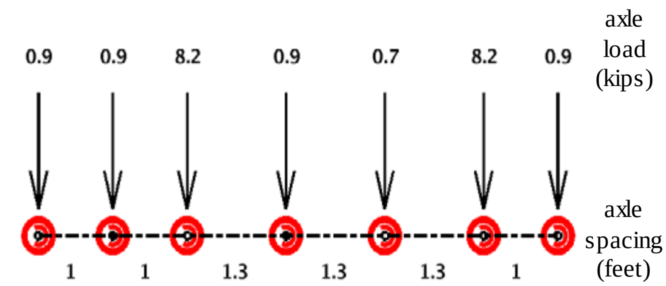
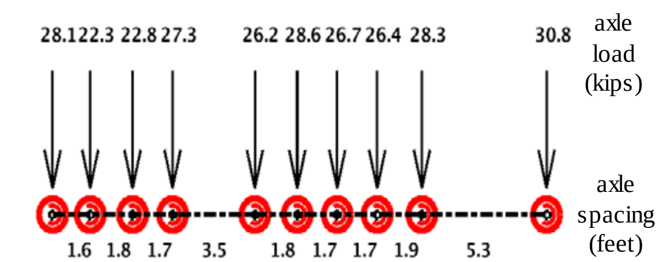
Error vehicle detected by QC procedure	Recorded by WIM sensor			Logical check error code
	GVW	No. of axles	Vehicle Class	
	513 kips	11	0	3.e, 3.i
	103.5 kips	3	6	3.d, 3.e, 3.i
	27.8 kips	7	10	3.d, 3.e, 3.h, 3.i
	269 kips	10	0	3.e, 3.i

Table 9. Summary of percentage of vehicles eliminated by each logical check filtering criteria

Error code	Filtering criteria	Threshold limits	Records eliminated (%)		
			Min.	Max.	Avg.
1.a	FIPs state code	Null or invalid state code*	0.0	0.0	0.0
1.b	Station ID	Null or invalid station ID*	0.0	0.0	0.0
1.c	Direction of travel code	≠ (0-9)	0.0	0.0	0.0
1.d	Lane of travel	≠ (0-9)	0.0	0.0	0.0
2.a	Invalid year	Null or irrespective year	0.0	0.0	0.0
2.b	Invalid month	≠ (1-12)	0.0	0.0	0.0
2.c	Invalid day	≠ (1-31)	0.0	0.0	0.0
2.d	Invalid hour	≠ (0-23)	0.0	0.0	0.0
3.a	Records with zero GVW	= 0	0.0	0.0	0.0
3.b	Records with zero axle spacing	= 0	0.0	0.0	0.0
3.c	Number of axle (Naxle)	≠ (2-22)**	0.0	0.0	0.0
3.d	Axle weights (Waxle)	≠ (1 kips -70 kips)**	1.0	61.5	10.3
3.e	Axle spacing (Saxle)	≠ (3.33 ft - 180 ft)**	6.0	93.0	55.9
3.f	Number of axles = Number of axle spaces + 1	Naxle ≠ Saxle +1	0.0	11.6	1.2
3.g	Number of axles = Number of axle weights	Naxle ≠ # of Waxle	0.0	0.0	0.0
3.h	Sum of axle weights +/- 10% of GVW	> or < than 10% of GVW	0.0	12.5	1.3
3.i	Minimum first axle spacing	< 6ft	0.7	67.3	30.6
3.j	Length of the vehicle (L)	> 220 ft**	0.0	7.6	0.8
3.k	Invalid vehicle class	≠ (1-13)*	0.0	0.0	0.0
4.a	Identical records (rows)	If duplicated	0.0	0.1	0.0

The statistical checks are performed on the remainder of the data. The results of some of the statistical checks are shown from Figure 7 to Figure 9. In Figure 7 (a), the CDF plot of Class 9 vehicles for all the WIM stations for the year 2014 are shown. This plot shows that WIM station 963 has a different traffic pattern than other WIM stations within the state. The WIM station 963 is located at 5.0 miles east of Mississippi border on I-10 in Grand Bay. Further investigation was made to validate the data by comparing it with Mississippi WIM station 301515 located at 3.7 miles west of Alabama state border on I-10 for the year 2013. The WIM station AL 963 and MS 301515 are on the same line on I-10 at 30.2 miles apart. Figure 7 (b) is a CDF plot to show the discrepancy in GVW of Class 9 trucks between station 963 of Alabama with station 301515 of Mississippi. The results of statistical checks for GVW of Class 9 are shown for some of the representative locations. In Figure 8 (a) for WIM station 915, the peaks are within limits, whereas in Figure 8 (b) for WIM station 963 it is clearly seen to be out of the limits. To determine whether the data set should be removed from further analysis, the tandem axle load check is performed. In Figure 9 (a), for WIM station 931 the peaks are within limits and calculated Pearson correlation coefficients shown in the top right corner of the figure is below 0.85. Whereas, in Figure 9 (b) for WIM station 963 there are no peaks and calculated correlation coefficients are less than 0.85. The correlation coefficients of less than 0.85 are highlighted.

In summary, the data from WIM stations 918 and 963 were eliminated entirely. The statistical check and comparison of data with Mississippi data for WIM station 963 indicated the poor quality of the data. For other WIM stations, the data retained after logical check filtering is treated as good quality WIM data. The data was processed by the proposed QC procedure and shared with Alabama DOT. Alabama DOT confirmed the existence of a problem with WIM stations 918 and 963. The proposed procedure can also aid in identifying the most appropriate traditional WIM sites to be transitioned to Virtual WIM stations.

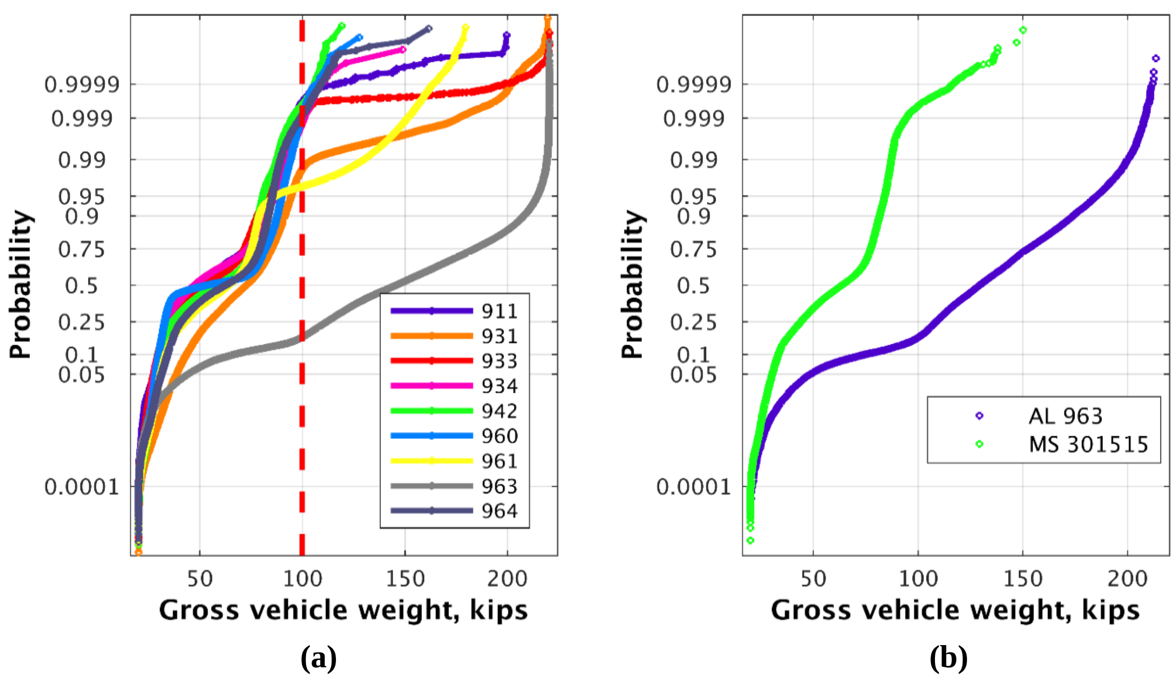


Figure 7. Cumulative Distribution Function plot of Class 9 vehicles of (a) all WIM stations in Alabama for the year 2014 (b) WIM station AL 963 of Alabama and MS 301515 of Mississippi

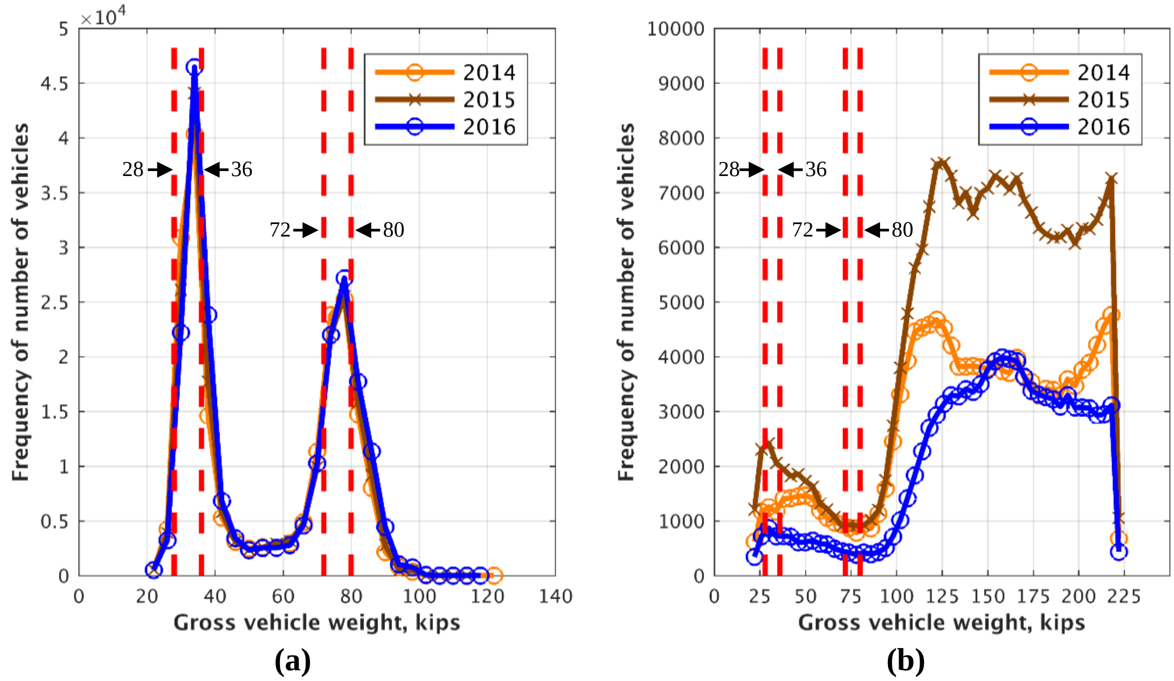


Figure 8. Histogram of gross vehicle weight of Class 9 vehicles for (a) WIM station 915 (b) WIM station 963

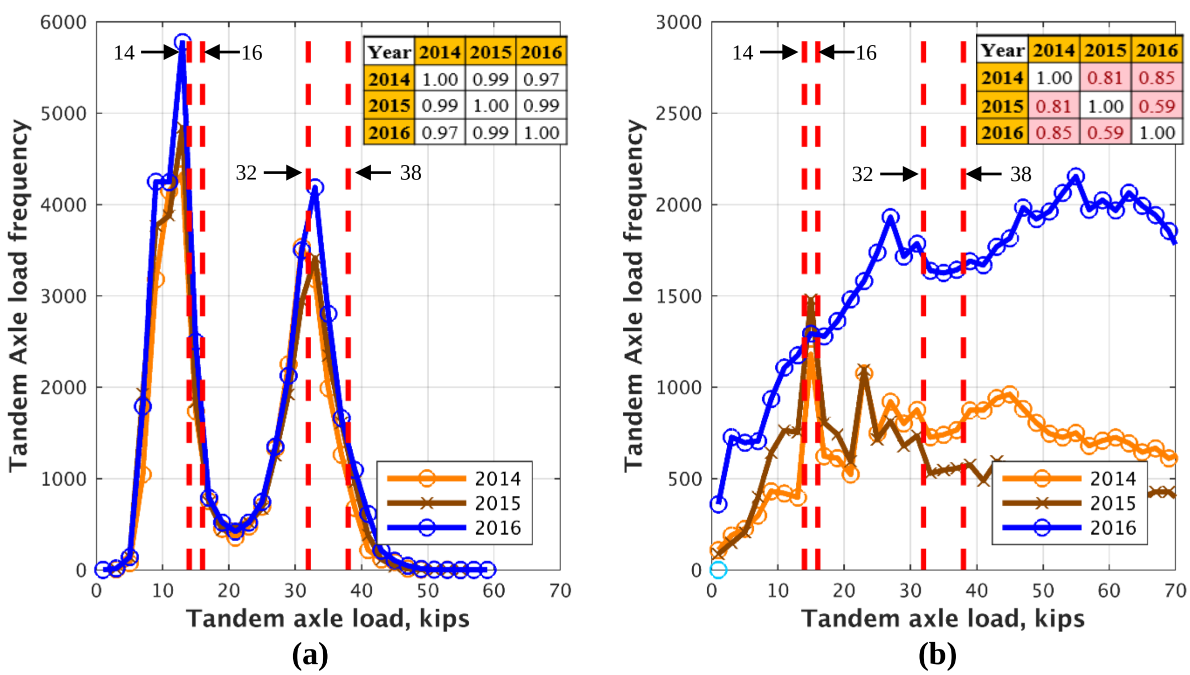


Figure 9. Histogram and Pearson correlation coefficients of tandem axle checks for January for (a) WIM station 931 (b) WIM station 963

3.4.1. Gross vehicle weight of all the WIM stations in Alabama after QC checks

The WIM data from all the stations after filtered through the QC procedure are shown in the form of cumulative distribution function (CDF) plots in Figure 10 to Figure 12. The variation in traffic from each year at the WIM stations can be seen.

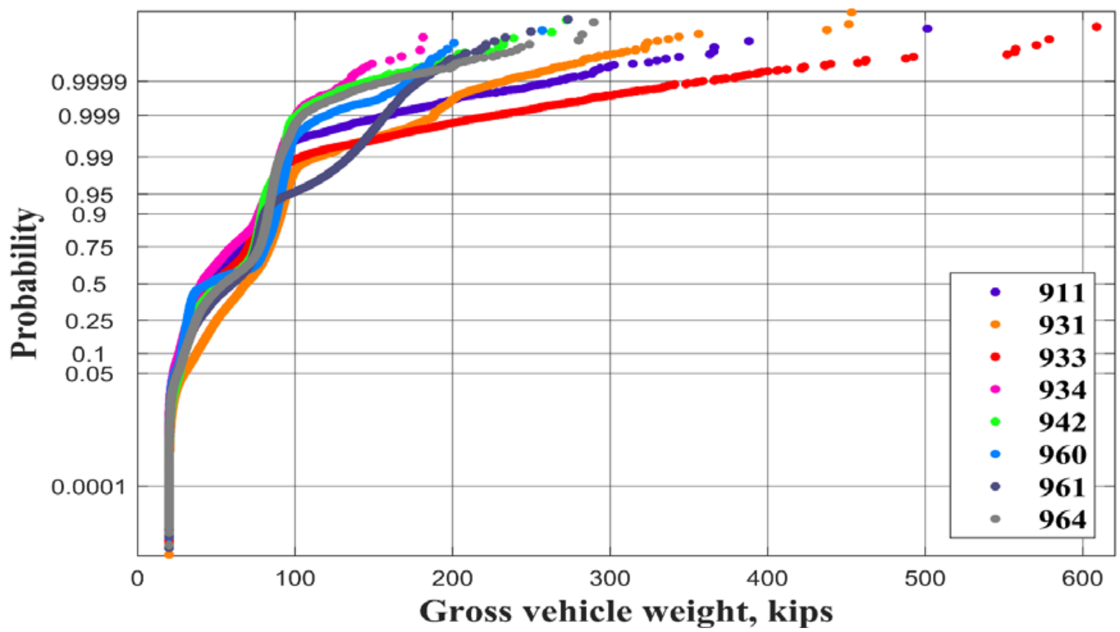


Figure 10. Cumulative Distribution Function plot for GVW of the WIM records of all WIM stations in Alabama for the year 2014

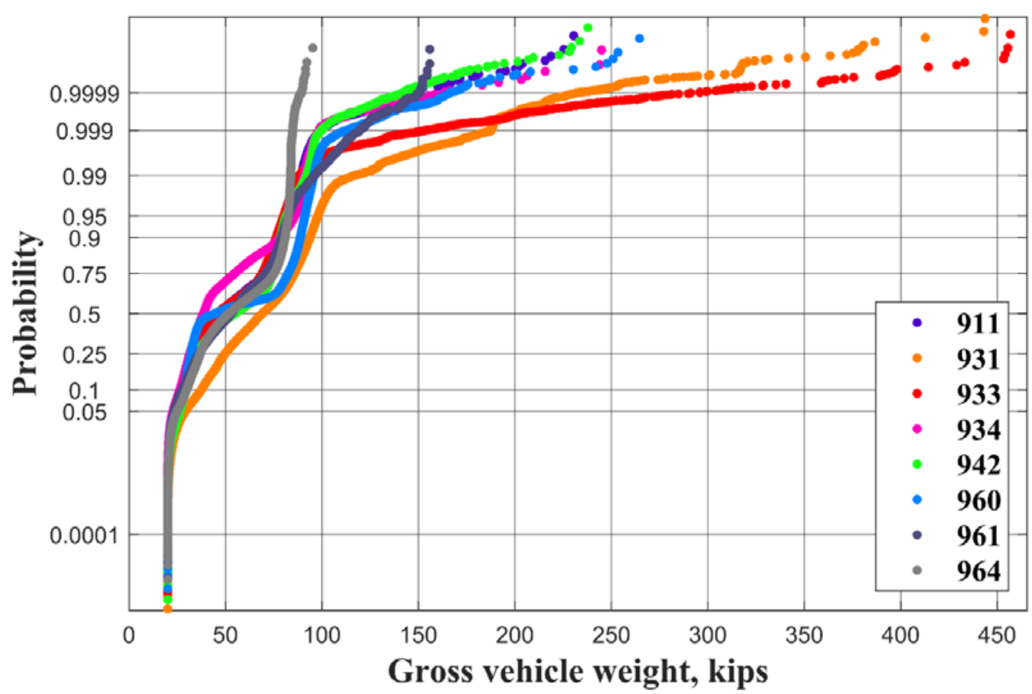


Figure 11. Cumulative Distribution Function plot for GVW of the WIM records of all WIM stations in Alabama for the year 2015

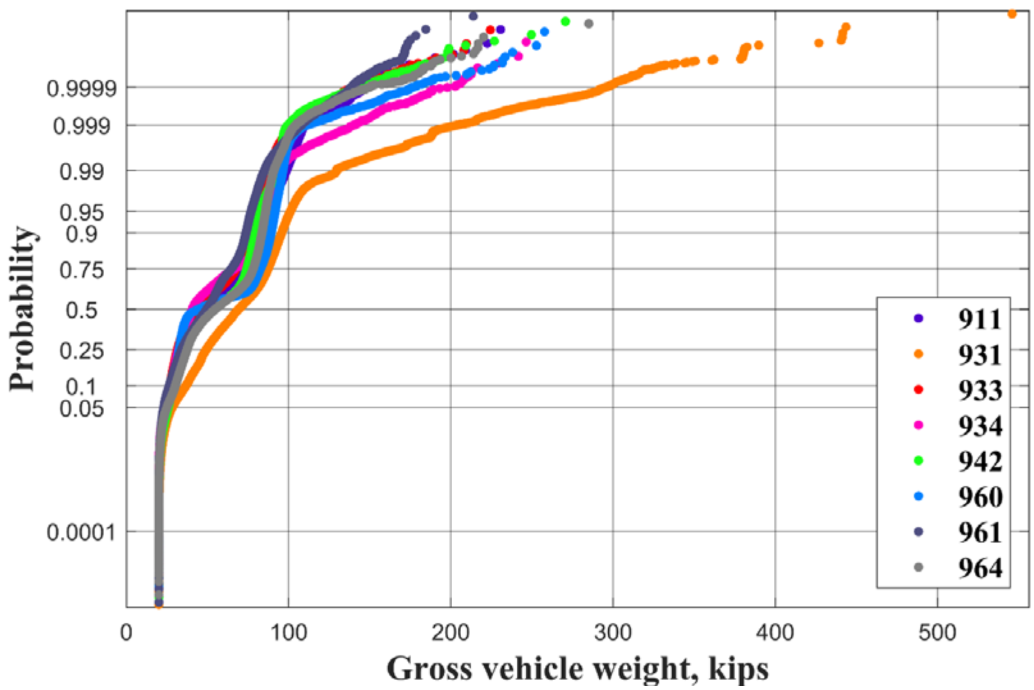


Figure 12. Cumulative Distribution Function plot for GVW of the WIM records of all WIM stations in Alabama for the year 2016

3.5. Computer app for evaluating the quality of WIM Data – ALDOT_WIM_QC v1.0

A computer app was developed and delivered to ALDOT so that the developed QC procedure can be implemented on a routine basis. The computer app can process the data collected over a one-month period. The user can visualize the results of the completeness check, logical checks, and statistical checks. Also, the results are saved in the form of images and can be assessed or shared by the user. A more detailed discussion of the ALDOT_WIN_QC v1.0 computer app is provided in Appendix E.

3.6. Summary

This chapter discusses a proposed procedure to check the quality of the traffic data and detect the root cause of questionable recorded traffic data. Inconsistency in recording due to communication failure, operational problems with the sensor and drift in calibration can be interpreted from this developed procedure. The proposed procedure consists of a completeness check, logical checks, and statistical checks. A review of the literature to identify the state-of-the-art was performed and a database of issued permits is used to establish limits for threshold parameters. The proposed QC procedure can verify the accuracy of unusual vehicle configurations that are categorized as "unclassified." Some of the results are shown for the WIM database for years 2014 to 2016, but a standalone application is developed so the

ALDOT can check the quality of WIM data on a monthly basis. Thus, the procedure can help ALDOT in monitoring the health of WIM systems by performing the checks periodically on accumulated data.

CHAPTER 4 IDENTIFICATION OF ISSUED PERMIT VEHICLES IN WIM TRAFFIC DATABASE

4.1. Introduction

Evaluation of existing bridges requires the assessment and prediction of the load carrying capacity and actual loads. Knowledge of the actual loads including illegally overloaded vehicles can help in day-to-day and planned maintenance procedures and law-enforcement effort. A major source of information about bridge live load is Weigh-in-Motion (WIM) database. Prediction of live load involves consideration of three groups of vehicles: legal, permit and illegally overloaded vehicles. Therefore, it is important to identify these three groups in the WIM data. It is easy to check if a recorded vehicle satisfies the requirements for legal vehicles. However, the major difficulty is to separate permit vehicles from the illegally overloaded ones.

4.2. Literature Review

Identification of illegally overloaded vehicles in traffic is trending popular topic in the transportation community. Nowadays, the traffic load monitoring systems are rapidly developing and are incorporated by State DOTs (Office of Freight Management and Operations 2017; *Traffic Monitoring Guide* 2016). The effects caused by legal vehicles and permit vehicles can be assessed, but it is more important to evaluate the damage caused by illegally overloaded vehicles.

The problem of illegal overloading the trucks goes far beyond the safety of the roads and bridges. The violators create a high competition in the transportation service market, where the operators that follow the permit limits stay at a disadvantage. Most states follow the federal weight limits to protect the roads and bridges from progressive damage. However, requests to increase axle load limits to reduce transporttion costs are reported (Luskin and Walton 2001; Stith 2006). A Texas Department of Transportation (TxDOT) study reported the consequences of a legal limit change to transportation infrastructure in the state of Texas are quite dramatic: $10 and $510 million for the replacement and repair of pavements and bridges, respectively. Moreover the estimated annual savings on transportation costs from a repeal of the gross vehicle weight (GVW) limit of 355kN (80,000lb) in the state of Texas exceeds $2 billion (Luskin and Walton 2001).

Permit regulations and monitoring procedures were developed to provide the safe operation of the transportation structures. However, the problem of controlling the haulers violating the law remains unsolved, as well as the question: to what extend the vehicles can be overloaded? Several sources reported about the relative proportion of illegal vs. law-abiding haulers (Enright et al. 2016; Fiorillo and Ghosn 2014; Luskin and Walton 2001; Stith 2006; Taylor et al. 2000)

There is no exact method to distinguish permit and illegal vehicles in the collected WIM dataset (Enright et al. 2016). However, WIM records have been used to develop models of permit trucks for bridge rating and design. The benefits of separating the data and analyzing are shown in Caprani et al. (Caprani et al. 2008). In Wisconsin, individual vehicle records were used to evaluate the state-specific standard permit vehicles based on a statistical analysis of the load effects caused by the heaviest 5% of trucks in each class (Jian Zhao and Habib Tabatabai 2012). Similarly, both European and US WIM databases were analyzed to identify permit vehicles based on the state regulations and to produce an equivalent permit truck traffic using Monte-Carlo simulation (Enright et al. 2016). Fiorillo and Ghosn proposed a sorting procedure to define the proportions of illegally overloaded and permitted traffic based on WIM data collected by New York DOT (Fiorillo and Ghosn 2014).

4.3. Truck Size and weight regulations

In the United States, vehicles are allowed to operate without any permit and are considered as legal, as long as they satisfy the weight guidelines of Federal Bridge Formula Weights (Formula B) (Equation 4.1) ("Bridge Formula Weights- FHWA Freight Management and Operations" n.d.). The primary purpose for the formula is to reduce the risk of damage to highway bridges by the adequately distributed load by determining the optimum axle configuration and axle load distribution.

$$W=500\left[\frac{LN}{N-1}+12N+36\right] \qquad (4.1)$$

Where:

W – Gross vehicle weight of a group of axles under consideration, lbs

L – The distance between the outer axles of any group of two consecutive axles, ft

N – The number of axles in the considered group

However, this is applicable only on the Interstate network. For the state and local highway systems, each state has its set of weight guidelines. Many vehicles that do not obey the Federal Bridge Formula B but do obey the state's legal weight guidelines are commonly referred to as vehicles exempt with "grandfather rights" (Moses 2001). Weight limits that are in use now along with Formula B and state-specific "grandfather" exceptions were established in mid-1970s (Federal Highway Administration and U.S. Department of Transportation 2015).

Figure 13 shows a graphical representation for sorting vehicles in traffic into different categories based on weights. Vehicles that are under legal weight limits in the jurisdiction and that satisfy Federal legal weight limit and "grandfathered rights" are considered as "Legal loads." Otherwise, they require permits, either annual, single trip or super load permit. Vehicles that require a permit but do not have it are considered as "Illegal Trucks." Overloaded vehicles are those that require permits to travel. Database of permit and illegal vehicles together is overloaded vehicles.

According to *AASHTO LRFD Bridge design specifications* (AASHTO 2017), the normal vehicular live load for bridges (Strength I limit state) includes all legal trucks, "grandfathered" exceptions and vehicles permitted by routine permits. Illegally overloaded vehicles without permits belong to an unanalyzed portion of bridge live load that is more likely to create an extreme lifetime stress condition.

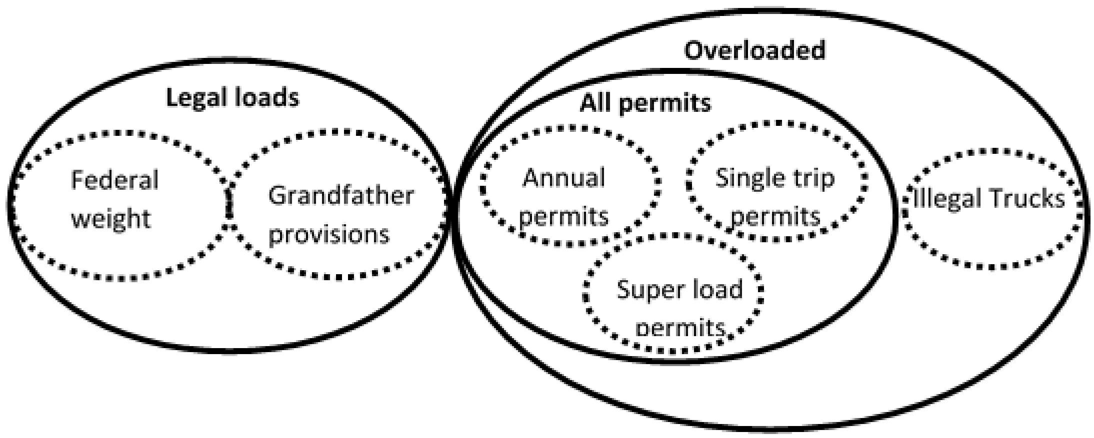


Figure 13. Vehicle categories

Each state has specific permit regulations for transportation of certain goods through the state. Truck weight regulations under Alabama jurisdiction ("Alabama Code Title 32. Motor Vehicles and Traffic" n.d.) are presented in Figure 14. Vehicles that satisfy Federal legal weight limit and "grandfathered rights" in Figure 14 are considered as "Legal loads." Otherwise, they require permits, either annual, single trip or super load permit. Vehicles that require a permit but do not have it are considered as "Illegal Trucks." Also, permits are issued for either overweight or oversize or both combined.

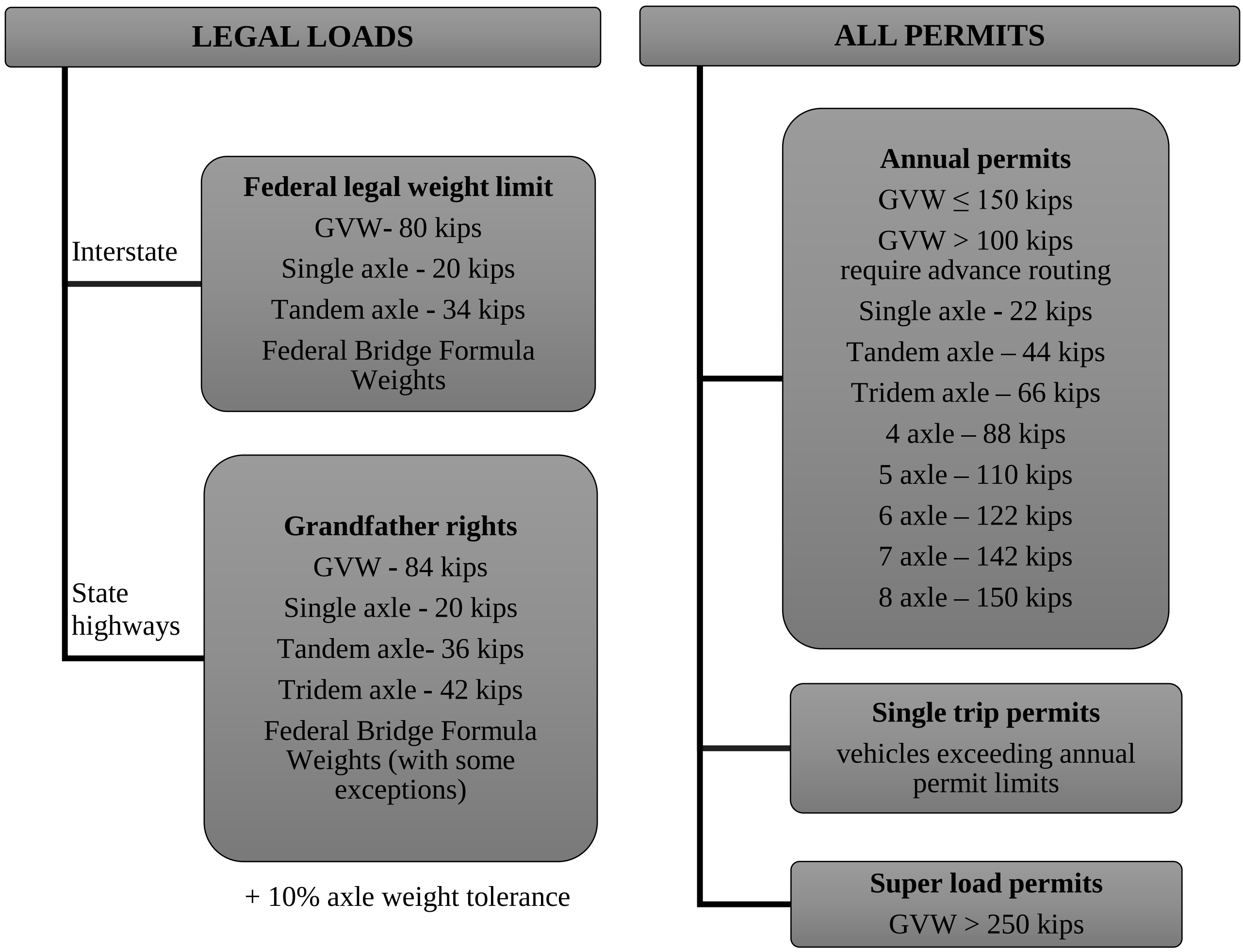


Figure 14. Truck weight regulations in the state of Alabama.

4.4. Permit Data filtering

The total number of permits issued by the Maintenance Bureau is 123,602 for 2014 and 122,539 for 2015. ALDOT issues about 500-600 permits per day. Around 200 of them are permits issued for overweight. The permit data was provided for this project for the years 2014 and 2015. The permit data were in the form of tables in Excel format for each year. The data consisted of permit ID, the validity of the permit, original and final destination, authorized roads, GVW, axle load and axle spacing. The data also includes information about the size of the vehicle (e.g., abnormal width, length or length). The data for Annual permits were included in the dataset; also multiple trips of the vehicles that had annual permits are included in the database.

Initial analysis of data indicated some inconsistency in issued permit records. Also, the data contained all kinds of permits (Oversize/Overweight/Both combined). Since analyzing the oversize permits are beyond the scope of this project, those were eliminated from the analysis. However, issued permits which had both oversize and overweight were retained along only overweight permits. WIM systems used in the state of Alabama can record up to 14 axle vehicles only. So, permits issued to vehicles with more than 14 axles were excluded from the analysis. To eliminate oversize, annual trip permits and vehicles with more than 14 axles from the issued permit data, the following criteria were developed for filtering the data:

- GVW column is "0" or "LEGAL"
- "Number of axles" column is marked as "LEGAL" or blank "Axle Load" columns
- Number of Axles >14 (number of axles limit in WIM data)

The results of issued permit data filtering are summarized in Table 10.

Table 10. Summary of a database of issued permits

		Year	
		2014	**2015**
	Total records	123602	122539
Filtering criteria	GVW = "LEGAL" and "0"	75833	75954
	Number of axle = "LEGAL" or "0"	6	15
	Number of axle > 14	28	18
	Data eliminated	75867	75987
	Data left after filtering	47735	46552
	% of data left after filtering	39%	38%

4.4.1. Vehicles that require permits in WIM database

To identify permitted trucks, the first step is the separation of legal traffic in the WIM traffic database so that the remaining database includes only permit vehicles and illegal traffic, i.e., overloaded trucks. Based on the truck weight regulations for the state of Alabama that are shown in Figure 14, the traffic was sorted into legal and overloaded trucks.

Table 11 and Table 12 shows the summary of the WIM records that require permits for the year 2014 and 2015. Also, the WIM records that require permits are categorized further into the different kinds of permits required.

Table 11. Vehicles that require permits in WIM database for the year 2014

Year - 2014	WIM Location							
	911	931	933	934	942	960	961	964
Total records	**357,854**	**1,584,347**	**427,505**	**169,407**	**787,426**	**305,565**	**851,184**	**642,336**
GVW limit	1,553	30,388	4,850	192	862	1,039	37,986	1,109
Single Axle limit	7,068	297,041	9,695	9,910	13,372	15,432	62,848	10,886
Tandem Limit	5,599	296,030	4,621	6,512	9,526	28,093	43,538	9,622
Tridem Limit	576	-	346	760	4,353	1,492	-	1,791
Bridge Formula Weights	8,249	3,554	6,067	3,106	10,888	22,537	24,601	32,607
Permit/ Illegally overloaded	**23,045**	**627,013**	**25,579**	**20,480**	**39,001**	**68,593**	**168,973**	**56,015**
	6%	**40%**	**6%**	**12%**	**5%**	**22%**	**20%**	**9%**

Table 12. Vehicles that require permits in WIM database for the year 2015

Year - 2015	WIM Location							
	911	931	933	934	942	960	961	964
Total records	**350,493**	**1548620**	**411,725**	**112,120**	**689,126**	**282311**	**115,364**	**135,825**
GVW limit	320	53168	1,558	88	664	713	410	239
Single Axle limit	5,665	350002	7,437	6,094	11,746	13689	2,625	862
Tandem Limit	6,582	240637	3,319	4,766	8,968	30497	6,187	475
Tridem Limit	494	0	511	328	3,550	1062	-	299
Bridge Formula Weights	5,563	1965	4,611	2,516	9,174	23032	356	1,019
Permit/ Illegally overloaded	**18,624**	**645,772**	**17,436**	**13,792**	**34,102**	**68,993**	**9,578**	**2,894**
	5%	**42%**	**4%**	**12%**	**5%**	**24%**	**8%**	**2%**

4.5. Identification of permit vehicles in WIM data

In the previous section, a summary of the vehicles that are overloaded (permit / illegally overloaded) in the WIM data database was presented. The main challenge is to determine if a vehicle with a permit passed a specific WIM station and was recorded by the WIM sensor. Each vehicle in the database of issued permits by ALDOT has a detailed description of a route, including “original destination,” “final destination” and an “authorized routes.” Using this information, it is possible to visualize the route of each trip on a web mapping service and check whether permit vehicles that pass one or more WIM stations. However, ALDOT issues around 120,000 permits annually and it is difficult to track each permitted vehicle manually.

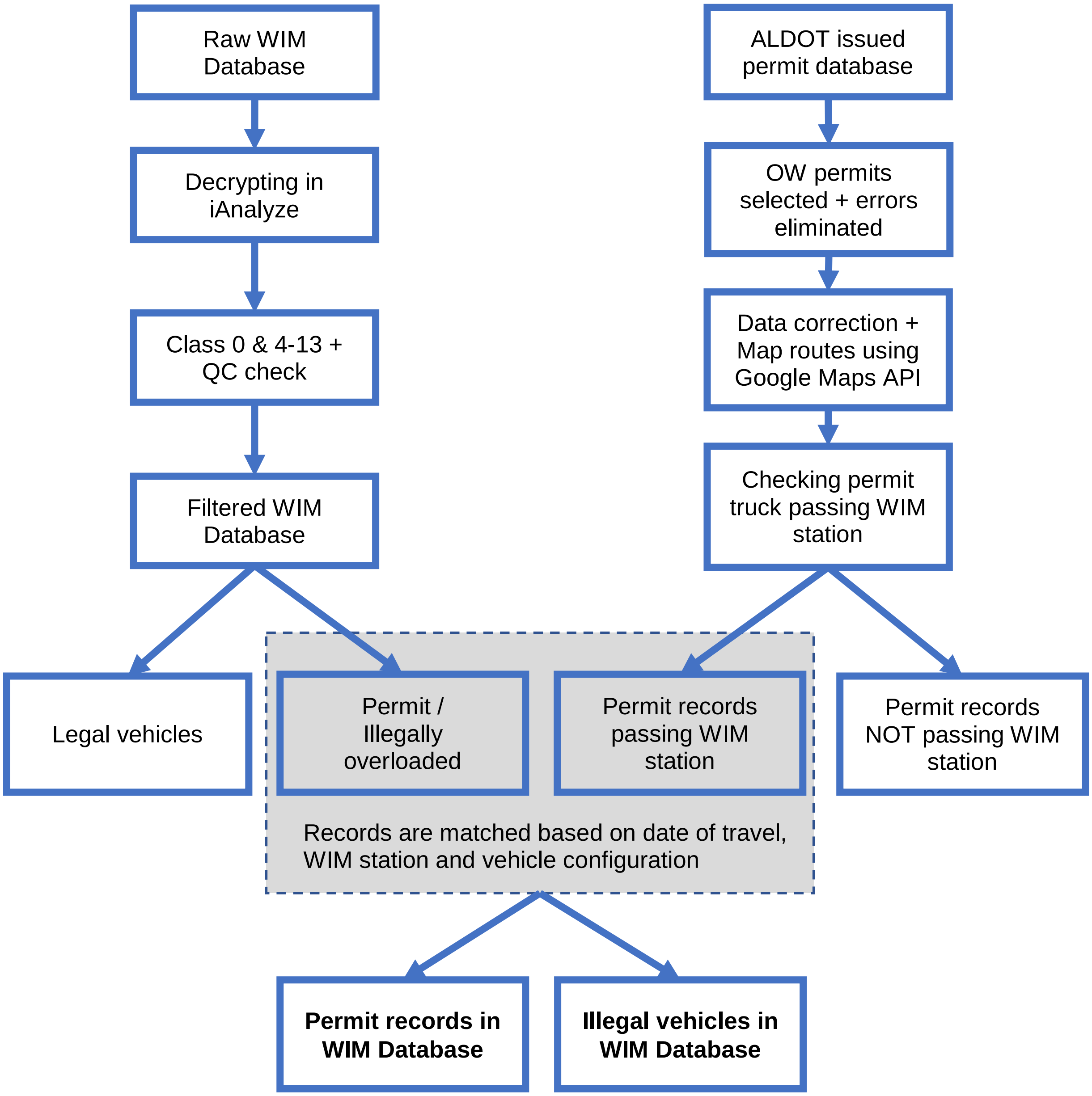
In this section, the procedure to detect permit vehicles passing WIM station is presented. An automated code was developed to analyze every trip route made by the vehicle in the permit database and identify the trip paths, and corresponding WIM stations passed. The algorithm is presented as a flowchart and is shown in Figure 15.

As shown in Figure 15, there are two databases used to sort permit vehicles in the WIM database. One is the WIM database, and other is issued permits database by ALDOT. Firstly, the WIM database is processed as shown in the left side of the flowchart by starting from decrypting in iAnalyze (Figure 4). Then, the Class 0 & 4-13 is selected, and QC checks are done to eliminate errors and determine the validity of the data (Figure 5). Later the filtered data is sorted into a legal vehicle group and permit/illegally overloaded group using Alabama weight regulations (Figure 14).

Next, the issued permits database by ALDOT is processed. On an everyday basis, each permit application is processed by ALDOT using Bentley software, where the trip route is entered manually by the hauler, and authorized routes are approved by ALDOT. So, in the provided accumulated permit database, there are permits issued for Oversize (OS) as well as Overweight (OW). The database of OW permits is extracted and further filtered to eliminate errors caused by manual entry. There are many possible ways the routes can be entered manually, and there are some routes that may not be recognized by Google Maps API. Therefore, some of these names and route descriptions must be manually corrected for more accurate mapping in Google Maps API.

Route mapping process is illustrated below:

- Asking Google Maps API for directions on the possible routes between the source and destination.
- Comparing the route descriptions produced by Google Maps API to the authorized route description, and select the best match.
- Encoding coordinates from the Google Maps API path description string for the selected route.
- Building a string line base on the above-encoded path coordinates.
- Finding WIM station in a buffer zone round the string line (WIM station coordinates are mapped at first).
- Storing results in database and KML for future review.



**WIM – Weigh-in-Motion; QC – Quality Control; OW – Overweight; API – Application Programming Interface

Figure 15. The algorithm to sort permit and Illegal vehicles in WIM database

The routes specified in the authorized route description of each permit application were matched with one of the possible routes of Google Maps API. All the routes of individual overweight permit vehicles are shown in Figure 16. As a result of this procedure, each record of the permit database is marked with the corresponding WIM station it passed. Then there is a set of permit records that pass-through WIM stations and others that do not pass. Lastly, the permit/illegally overloaded dataset from WIM database and a dataset of permit records that pass-through WIM station is matched based on the date of travel, WIM station, and vehicle configurations. By this matching process, the permit and illegally overloaded vehicles can be identified at each WIM station. Some of the permit vehicle routes go through more than one WIM station. Therefore, the same permit is compared with the WIM records collected from several WIM sites. The summary of the permit vehicles identified at all WIM sites is shown in Table 13. Also in Table 13, the summary of a number of records that passed through a WIM station and number of records that passed through WIM station and were matched with one of the Overloaded WIM records is shown.

A comparison of the permits identified in the traffic stream (Table 13) to the vehicles that require permits (Table 11 and Table 12) for the respective WIM stations is possible. In the year 2014 and 2015 there were 1,028,699 and 811,191 vehicles that require permits, out of which 3,734 and 2,951 vehicles operated with a permit, respectively. These numbers indicate that less than 0.5% of overweight vehicles operate with a permit. The total number of WIM overloaded vehicles requiring permits of all the WIM locations is substantially higher than the number of permits that were issued even though the permit trucks often pass more than one WIM locations.

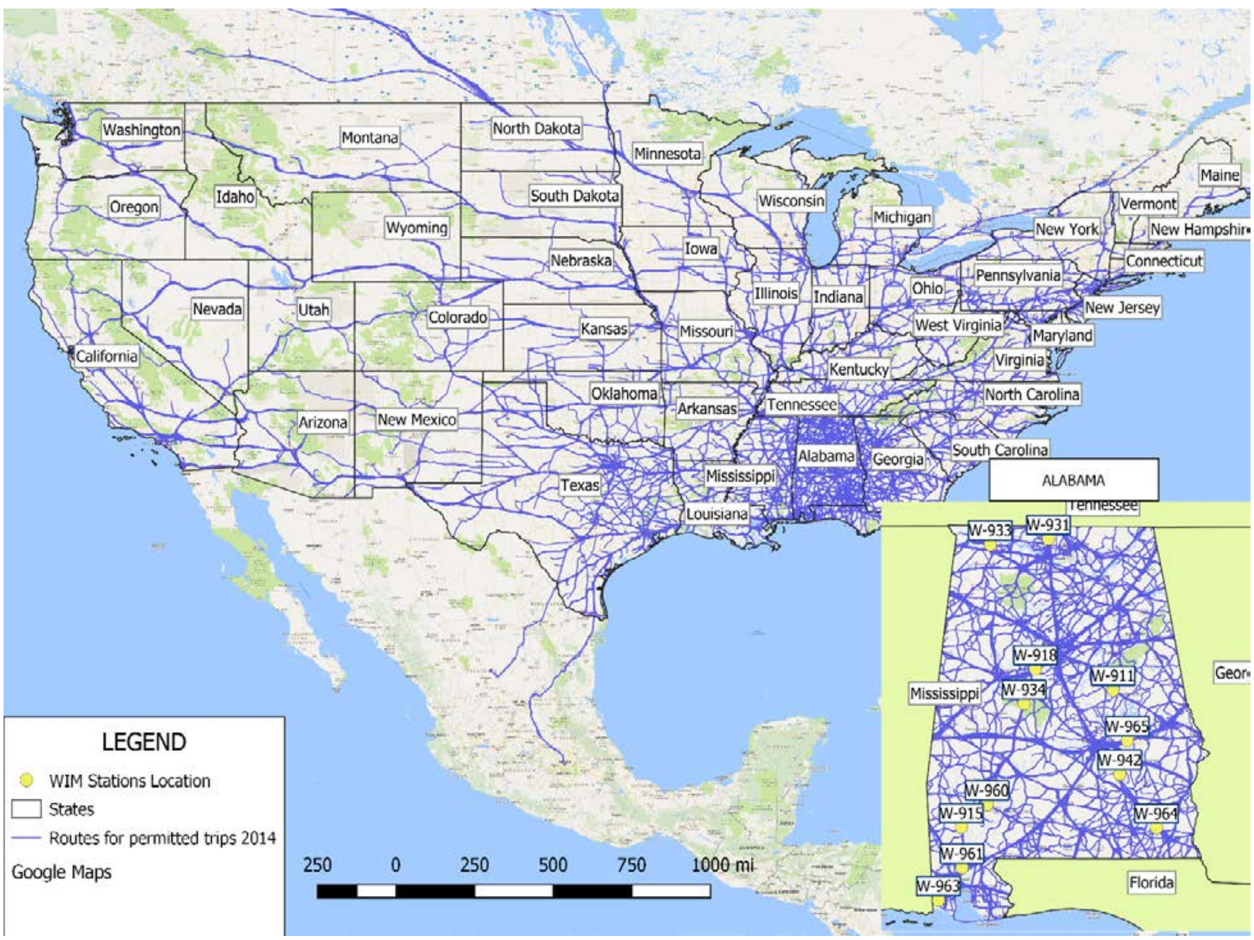


Figure 16. Routes of individual overweight permits issued by ALDOT for the Year 2014

Table 13. Summary of ALDOT issued permits that passed through WIM stations and that issued permits that passed WIM stations and matched with Overloded WIM records

Station code	**Issued permits that passed through WIM stations**		**Issued permits that passed through WIM stations and matched with one of Overloaded WIM records**	
	Year 2014	**Year 2015**	**Year 2014**	**Year 2015**
911 (US280)	575	448	225	165
915 (US43)	556	899	N/A	N/A
918 (I20)	8086	6963	N/A	N/A
931 (I65)	2634	2479	1000	934
933 (AL157)	200	216	69	73
934 (US78)	228	211	86	76
942 (US231)	526	530	206	193
960 (US84)	885	489	339	192
961 (I65)	4381	3055	1696	1193
963 (I10)	3899	4292	N/A	N/A
964 (US231)	282	349	113	125
965 (I85)	2827	3748	N/A	N/A
Total	25079	23679	3734	2951

4.6. Summary

This chapter discusses a procedure to identify the permit vehicles in the WIM data. The first step is the separation of legal traffic so that the remaining file includes only permit vehicles and illegal traffic. Then WIM data without legal vehicles are sorted out using the parameters of issued permits to identify vehicles that have a permit. The remaining vehicles can be considered as illegal traffic. The procedure is illustrated for the traffic data for the years 2014 and 2015. Less than 0.5% of overweight vehicles operate with a permit. The developed procedure depends primarily on the authorized routes of issued permit vehicles and the accuracy of WIM measurements. The soundness of the procedure can be improved if authorized routes of issued permit vehicles were available in the form of geo coordinates. This procedure is not practical for implementation by ALDOT at this stage due to complexity in the technology used in the devloped procedure and inadequate information of issued permit data.

CHAPTER 5 BRIDGE DAMAGE ACCUMULATION

5.1. Introduction

The service life of a bridge is affected by many factors such as but not limited to, traffic loads, natural hazards, defects in material production. Traffic-induced loads may cause damage to a bridge by fatigue and/or overload. Steel bridges are more prone to fatigue cracking compared to other types of bridges, so steel bridges are the focus of this research. Every passage of a truck across a bridge creates one or more stress cycles in the structural components which results in the accumulation of fatigue damage over time. A steel bridge located on a busy highway experiences millions of cycles of fatigue loading by heavily loaded trucks. If these stress cycles are of sufficient magnitude and number, they will result in fatigue cracking. The entire fatigue process in a member includes the formation of a fatigue crack, crack growth, and final failure (Fisher et al. 1998). The number of stress cycles required for the formation of a fatigue crack is typically much larger than the number of cycles required to grow a crack to a size that will cause failure. After formation, if a fatigue crack is not detected and properly repaired, it may lead to failure of the member. So, in broad terms, the passage of each heavy truck uses a tiny amount of the fatigue life of a bridge. In this chapter, the goal is to quantify the damage produced by an individual truck and the accumulated damage resulting from many trucks.

AASHTO LRFD Bridge design specifications (AASHTO 2017) have a design approach for fatigue. The stress range calculated for a code-specified fatigue design truck is limited to avoid fatigue cracking caused by the accumulation of damage from repetitive truck loading. The AASHTO fatigue design truck is intended to represent truck traffic. However, in the service life of a bridge, there is the uncertainty of the traffic loads that the bridge experiences. This chapter addresses the fatigue damage accumulated by bridges as a result of actual heavy truck traffic recorded at WIM sites. Background information is provided along with a review of the state-of-the-art from literature and the practices in the other states. Further, the methodology used in this report and the implementation of the developed procedures are discussed.

5.2. Literature Review

The study of the impacts of vehicular traffic on infrastructure has been conducted in many states. The earliest study dates back to the 1970s. Many states have sponsored studies to develop methodologies to quantify damage and do the cost analysis based on assumed cost models. The cost impact study for Indiana DOT was done in 1979 by Yoder et al. 1979 to study the impact on bridges and pavements due to a GVW limit increase from 73.28 kips to 80 kips. A study for New York State DOT was conducted in 1987 by BTML Division of Wilbur Smith Associates 1987 on the effect of permit truck weights on bridges. In 1991 the Minnesota DOT (Minnesota DOT 1991) conducted a study in response to TRB

Special report 225 (Board et al. 1990) to investigate bridge related impacts. A study for Illinois DOT (Illinois Department of Transportation, 1992) was conducted to study the impact on bridges due to a weight limit change. Also in 1992, Sorensen and Robledo, 1992 conducted a study for Washington State DOT to estimate the impact of the Turner trucks on the state's bridges. A study for Ohio DOT by Moses, 1992 was done to develop a permit fee system based on bridge damage costs.

Beginning the 21st century, many states sponsored a study on overweight load study. In 2004, Culmo et al. 2004 did a study on the behavior of steel bridges under specific permit trucks for Connecticut. Reisert and Bowman conducted a study on the fatigue of older steel bridges to overweight and oversized loads in Indiana in 2005. Also, in 2005 a study for Louisiana was done by F. L. Roberts et al. 2005 on effects of specific commodities transporting vehicles on Louisiana infrastructure. Later in 2012, a multi-phase study in Wisconsin was done by (H. Bae and M. Oliva 2009, 2012) where the impact of overweight vehicles was studied. Laboratory tests and numerical simulation were performed for deck deterioration as part of the study.

Almost all state DOT's have sponsored studies to determine the impact of overweight traffic on infrastructure. However, the recent studies done in Texas, South Carolina, New York, and New Jersey give more insight into the modern approach and use of state-of-art-practice. Also, the study sponsored by FHWA on the effect of truck weight on bridge network costs uses an innovative approach to envelope all states. These five sources are described in the following sections.

Effect of Truck Weight on Bridge Network Costs (Gongkang Fu et al. 2003)

This study was sponsored by AASHTO and FHWA with an objective to develop a methodology to estimate bridge network cost due to changes in truck weight limits. Based on the state of the practice literature review four-cost impact categories such as fatigue of existing steel bridges, decks, and deficiency due to overstressing. Also, deficiency due to overstress of new bridges was considered. Level I and Level II analyses were proposed based on the extent of data availability.

Oversize/Overweight Vehicle Permit Fee Study (Prozzi et al. 2012)

This study was done for the State of Texas and was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration. The objective of this study was to conduct a study of infrastructure damage caused by oversized and overweight vehicles (OS/OW) and to provide recommendations for permit fee adjustments if required. The methodology to quantify the pavement and bridge consumption rate per mile was developed as part of the project. Also, the new fee schedule was developed to account for the costs associated with OS/OW vehicles. Also, a revenue analysis was conducted to compare the revenue generated from permit sales and the revenue estimates from the new permit fee structure. It was concluded that from the permit sales of the financial year 2011 the revenue collected was $111.4 million compared to the estimated revenue of $671.4 million from the revenue estimates based on the new permit fee structure.

The rate of Deterioration of Bridges and Pavements as Affected by Trucks (Chowdhury et al. 2013)
This study was done for South Carolina DOT to analyze the impact of heavy vehicle traffic on infrastructure and develop policy recommendations. Several alternative fee structures were proposed, such as axle-based system and flat fee. Stake holder interviews were done as part of the study.

Effects of Overweight Vehicles on NYSDOT Infrastructure (Ghosn et al. 2015)
This study was focused on the development of a methodology for estimating effects caused by heavy trucks on New York State infrastructure sponsored by New York State Department of Transportation (NYSDOT). In modeling the effects of overweight trucks on bridges, the overweight WIM traffic data was categorized to probable divisible permits, special hauling permits, and Illegals. The structural response to overweight vehicles in the traffic data was considered using overstress of main bridge members and cyclic fatigue accumulation. For estimating the effects on pavements, an incremental cost approach was used to compare the options of using an increase in design thickness of pavement layers and a possible increase in the maintenance schedule. The cost effect was calculated considering the bridge material and construction. The cost effect was studied on a representative sample of 22 bridges along the I-88 corridor in New York State. Based on a cost allocation study it was found that the total cost for entire New York state infrastructure is $240 million per year, with $95 million per year for bridge network and $145 million per year for pavements.

Impact of Freight on Highway Infrastructure in New Jersey (Nassif et al. 2015)
This study was conducted with an objective to quantify the effects of overweight vehicles on the New Jersey Infrastructure sponsored by the New Jersey Department of Transportation (NJDOT). A model was proposed based on a literature review of the effects of overweight vehicles from other states and deterioration models. A tool ASSISTME-WIM software was developed to estimate the actual damage cost on NJ highways due to overweight trucks. The Life Cycle Cost performance Analysis (LCCA) was done, and it was estimated that average cost of moving one ton of load by an overweight truck per mile in NJ is about $0.33, where 40% of damage is attributed to bridges and 60% to pavements.

5.3. Background and Methodology

Fatigue cracks tend to form at discontinuities or changes in geometry or cross section. Welded attachments such as web stiffeners or the end of a flange coverplate are considered fatigue prone details, or potential locations for the formation of fatigue cracks. Since a steel bridge experiences repeated cyclic stress, a suitable model of fatigue resistance is needed to evaluate the cyclic performance of the fatigue prone details (referred to herein simply as details). The nominal-stress life approach is used in *AASHTO LRFD Bridge design specifications* (AASHTO 2017).

Fatigue behavior of a material and connection detail is usually presented with an S-N curve similar to one shown in Figure 17 (black line). These curves are established by fatigue testing and are available in the *AASHTO LRFD Bridge design specifications* (AASHTO 2017) for various categories of fatigue details that are commonly used in bridge design. In Figure 17, the resistance relates the magnitude of the applied constant-amplitude stress range (S) to the corresponding number (N) of cycles to failure of the detail.

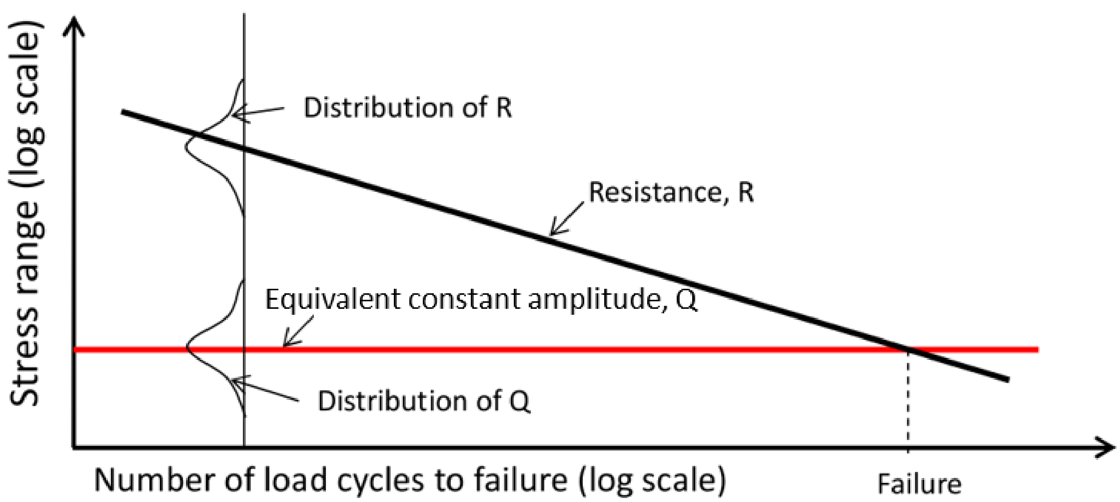


Figure 17. Fatigue failure on S-N curve (SHRP 2 Research Reports 2015)

A family of similar S-N curves for different detail categories were established by extensive laboratory testing and are included in the *AASHTO LRFD Bridge Design Specifications* (AASHTO 2017). These S-N relationships are shown in Figure 18. The stress range and fatigue life relationship is:

$$N = AS^{-m} \tag{5.2}$$

Where:

- m – slope constant (3 for steel)
- S – nominal stress range
- N – number of cycles to failure
- A – constant for a given detail

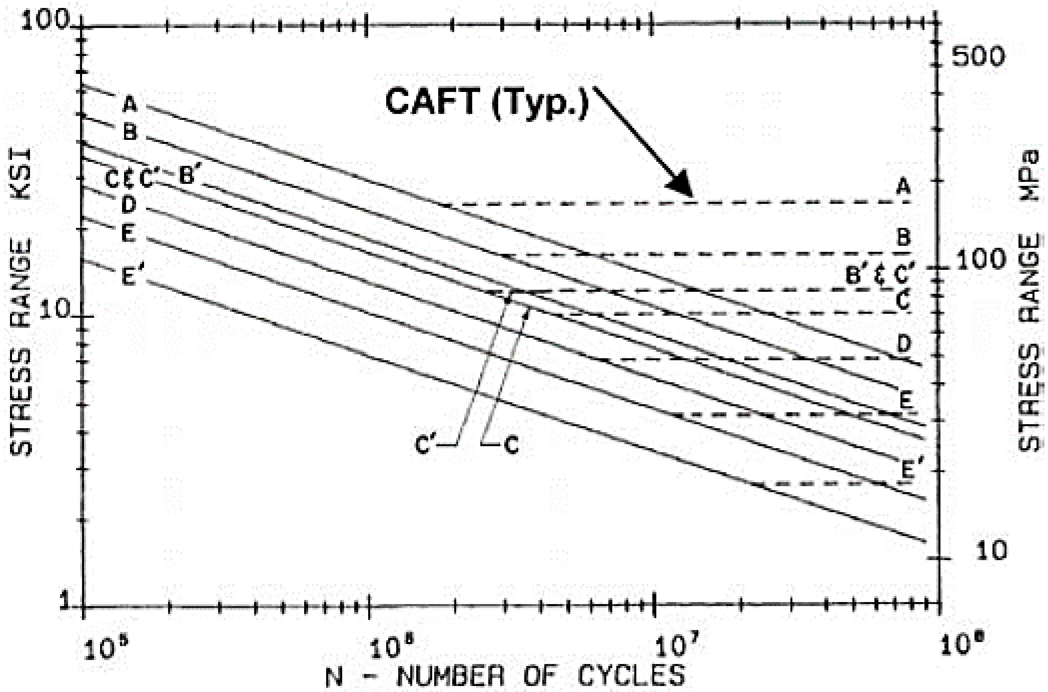


Figure 18. Stress Range versus Number of Cycles (S-N) curves (AASHTO 2017)

As illustrated by the categories in Figure 18, different details in a steel bridge have different lives, and as a result of the overall bridge geometry, individual details experience traffic-induced stress ranges of various magnitudes. So, some details accumulate fatigue damage faster, and their fatigue life is expended faster. (Franklin 2000) performed an evaluation of a large number of steel bridge spans in Birmingham that are typical of the steel bridges on Alabama highways and interstates. Based on that study (Franklin 2000), the base metal at the end of the bottom flange cover plates was identified as the most fatigue prone detail of steel girder bridges. These are Category E’ details and have the lowest fatigue resistance, and they also have relatively high applied stress ranges. In this chapter, much attention will be focused on the damage accumulated at the ends of the bottom flange cover plates on simple span girders. Traffic-induced stress ranges and damage accumulation at the upstream end of the cover plate is higher, so that the end receives more attention. Also, for comparisons with past research and more generic comparisons, such as comparisons of damage from different classes of trucks, damage accumulation at midspan is considered. The most critical detail likely to be present at midspan would be a transverse stiffener-to-web fillet weld, or perhaps a transverse stiffener-to-flange weld in a newer bridge. These would be Category C’ details as defined in *AASHTO LRFD Bridge Design Specifications* (AASHTO 2017).

An important question that must be addressed in the discussion of fatigue damage accumulation is: do all traffic-induced stress cycles to contribute to the accumulation of damage and potential formation of a fatigue crack? Current U.S. practice is that all stress cycles are considered if even only a small percentage

(Fisher et al. 1983) of the traffic-induced stress ranges are above the constant amplitude fatigue limit (CAFT) (see horizontal dashed lines in Figure 18). Pearson (2002) reported field measurements of stress ranges at cover plate ends of bridges in Birmingham that clearly show a sufficient number of stress cycles above the CAFT to cause fatigue cracking. It is assumed here that those bridges where the field measurements were made are representative of the steel bridges across the state, and all stress ranges at cover plate ends should be considered. But, it is also common practice in the analysis of WIM data to omit light vehicles. In the work reported here, vehicles with gross vehicle weight less than 20 kips were omitted from the analyses. For simplicity, since all trucks heavier than 20 kips were considered in the damage accumulation calculations at cover plate ends, they were also considered at midspan locations.

AASHTO fatigue design truck is used in design to envelop the current traffic at the given bridge site. The first proposed fatigue truck dates to 1978 (Schilling, C. G. and Klippstein, K. H. 1978) which was proposed based on FHWA's loadometer survey (Fisher, J. W. 1974) measured in 1970. It was a 3-axle truck with 14 ft and 30 ft axle spacing's and a GVW of 50 kips distributed at 0.122, 0.444 and 0.444 of GVW for axles 1, 2 and 3 respectively. Later in 1987 in NCHRP 299 (Moses et al. 1987) based on 27,000 WIM measurements from 30 sites nationwide (California, Oregon, Michigan & New York), the GVW was modified to 54 kips without and modification to axle configurations. So, the current fatigue truck was developed in 1978, but it was validated in 2012 by WIM data from 7 states (California, Florida, Idaho, New York, Michigan, Texas & Vermont) (Bowman et al. 2012). However, in all the reports mentioned above where fatigue truck is validated/updated only the GVW was calculated using Equation 5.3 but the vehicle configuration was not modified. Equation 5.3 is the way to calculate an effective truck weight for fatigue truck if the data from WIM study is available for a particular bridge site. The truck traffic excluding panel, pickup, and other 2-axle/4-wheel trucks are considered for calculating effective GVW. Truck traffic from Class 6-13 is considered for calculating effective truck weight.

$$W = \left(\sum \frac{1}{T} * W_i^3\right)^{\frac{1}{3}} \tag{5.3}$$

Where:

W = gross weight of fatigue truck

T = total number of trucks

W_i = gross weight at mid-width of interval i

The S-N curves for different detail categories are shown in Figure 18 (Figure C6.6.1.2.5-1 of (AASHTO 2017)). The S-N curves are similar to the S-N curve in Figure 17 and were developed using constant-amplitude stress range test data. However, bridges are subjected to variable amplitude stress cycles. A cumulative damage theory is used to calculate an effective stress range from variable amplitude stress cycles. The Palmgren-Miner (Miner 1945) rule provides a rational means to account for this cumulative damage for variable amplitude stress ranges as follows.

$$\frac{n_1}{N_1}+\frac{n_2}{N_2}+\frac{n_3}{N_3}+\cdots+\frac{n_n}{N_n}=\sum\frac{n_i}{N_i}=1 \tag{5.4}$$

Where, $\frac{n_i}{N_i}$ is the incremental damage that results from the stress range cycles with magnitude S_i that occur n_i times, and N_i is the number of cycles to failure at the constant amplitude stress range S_i. Some trucks in the WIM database create more than one cycle of loading as they cross a bridge. Processing of large amounts of WIM data is simplified by representing the fatigue damage produced by these multiple cycles of loading from a single truck as an equivalent single cycle of loading. In terms of stresses, the equivalent single cycle stress range S_{eff} for the set of truck is:

$$S_{eff}=\left[\sum\frac{n_i}{N}S_i^m\right]^{1/m} \tag{5.5}$$

Where:

m – slope constant (3 for steel)

n_i – number of cycles at i^{th} stress range, S_i

N – total number of stress cycles

The fatigue damage is the result of tensile stress ranges resulting from bending moment. The stress formulation can be extended to bending moment as shown in Eq. (5.6).

$$M_{eff}=\left[\sum\frac{n_i}{N}M_i^m\right]^{1/m} \tag{5.6}$$

Where:

m – slope constant (3 for steel)

n_i – number of cycles at i^{th} moment range, M_i

N – total number of stress cycles

Each WIM record from the traffic database is run for different span lengths to obtain plots of bending moment versus time at a specific location as truck crosses along the span. Rainflow cycle counting

(ASTM E1049—85 (Reapproved 2017)) was used to determine the number and magnitudes of the individual stress cycles resulting from the truck crossing.

Various approaches were investigated for the calculation and reporting of fatigue damage accumulation so that the results would be useful for ALDOT in routine maintenance activities. Two approaches are used in this report to quantify the damage. One approach is a WIM site-specific damage ratio which is a relative measure of damage that can be generalized to any type of bridge. The other approach is specific to a particular bridge. Two approaches are discussed in detail in the next sections.

5.4. WIM Site-Specific Damage Ratio

This approach can help understand which WIM location experiences the most damaging traffic in the state of Alabama. Also, the damage caused by different groups of trucks in the traffic can be assessed. To provide comparisons using the largest amount of traffic data possible, the direction of traffic on both sides (Lane 1 & 2 and Lane 3 & 4) of WIM stations are combined. Each WIM record from the traffic database are run for 30, 60, 90, 120 and 200 ft span lengths to obtain plots of bending moment versus time at a specific location as truck crosses along the span. The specific location along the span length was limited to mid-span and upstream cover plate end along the span. The upstream cover plate end location rather than the downstream was used because the damage at the upstream cover plate end is higher. The amount of damage is calculated as shown in Equation 5.7 which is a modification of Equation 5.2.

$$\mathrm{D} = \mathrm{NM}_{\mathrm{eff}}^{\mathrm{m}} \tag{5.7}$$

Where:

D – amount of damage

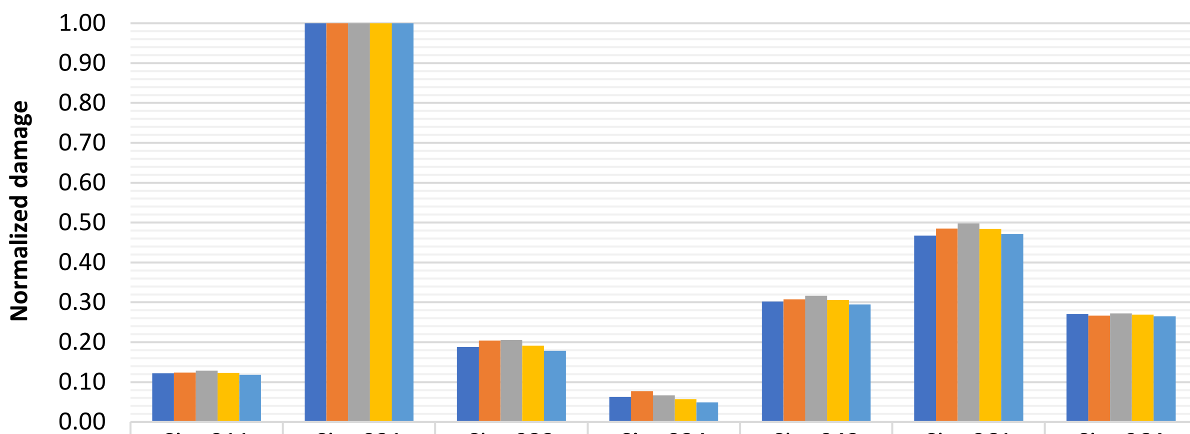
m – slope constant (3 for steel)

M_{eff} – effective moment calculated as shown in Eq. 5.6

N – number of cycles

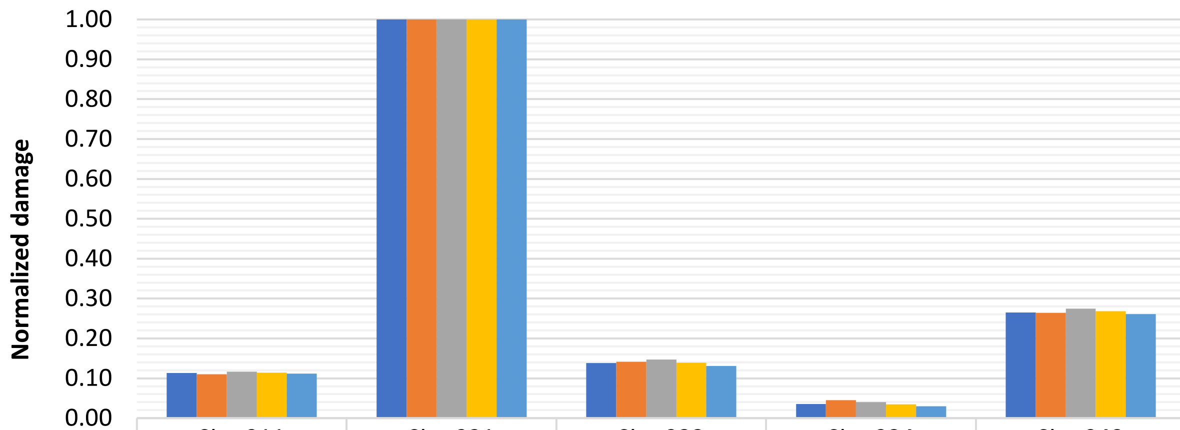
5.4.1. Comparison of damage of WIM sites

The amount of damage (NM_{eff}^3) was calculated for each WIM site (911-964) for both the directions combined and for years 2014-2015 for upstream cover plate end and mid-span. The resulting damage (NM_{eff}^3) for each WIM location is calculated for 30, 60, 90, 120 and 200 ft span lengths and normalized to the WIM location with most damaging traffic. In this case, WIM location 931 has the most damaging traffic. The results for the upstream cover plate end are shown in Figure 19 and Figure 20 and for mid-span are shown in Figure 21 and Figure 22. The numbers of WIM records are shown in Figure 23 and Figure 24. In Figure 19 and Figure 21, for the year 2014, the most damaging traffic is WIM location 931 followed by WIM location 961 and 942. The damage accumulated by considering different span lengths is almost the same. In Figure 20 and Figure 22, for the year 2015, the most damaging traffic is WIM location 931 followed by WIM location 942 and 933. The data from WIM location 961 and 964 are eliminated for the year 2015 as data was not available for the whole year. Also, data for WIM location 960 is eliminated for the year 2014 and 2015 since the data was available only for one direction. The only consistent pattern in the relative damage at the various sites is that the damage at site 931 is at least twice that at the other sites for both 2014 and 2015. The normalized accumulated damage is practically independent of the location along the girder and span length.



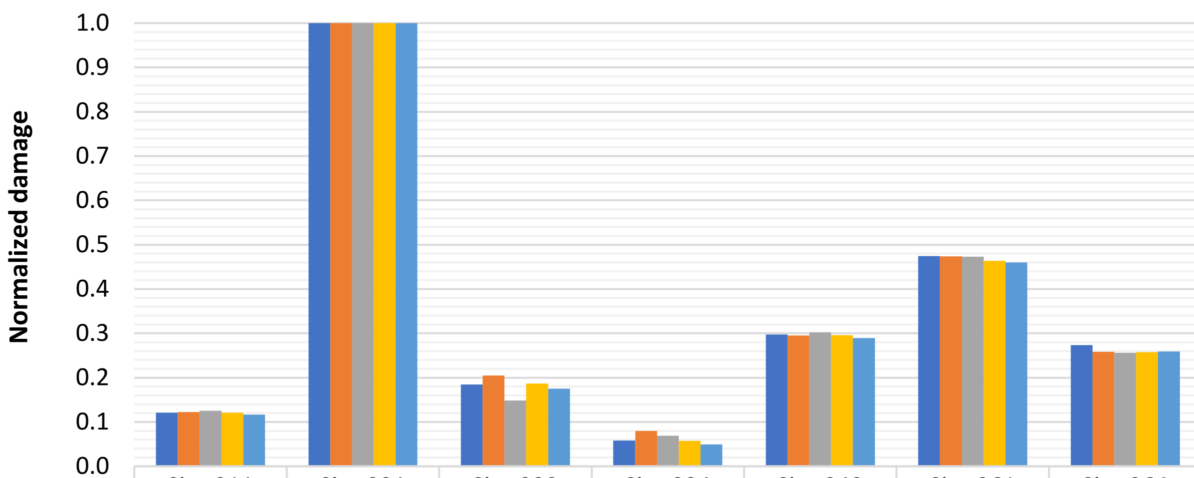
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 961	Site 964
30ft	0.12	1.00	0.19	0.06	0.30	0.47	0.27
60ft	0.12	1.00	0.20	0.08	0.31	0.48	0.27
90ft	0.13	1.00	0.21	0.07	0.32	0.50	0.27
120ft	0.12	1.00	0.19	0.06	0.31	0.48	0.27
200ft	0.12	1.00	0.18	0.05	0.29	0.47	0.27

Figure 19. Normalized accumulated damage in 2014 at the upstream cover plate end



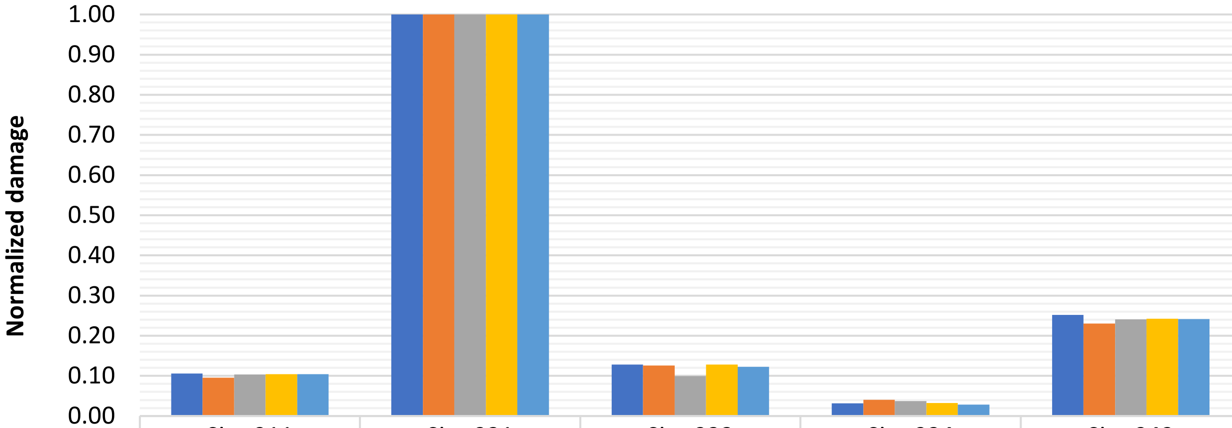
	Site 911	Site 931	Site 933	Site 934	Site 942
30ft	0.11	1.00	0.14	0.04	0.26
60ft	0.11	1.00	0.14	0.04	0.26
90ft	0.12	1.00	0.15	0.04	0.27
120ft	0.11	1.00	0.14	0.03	0.27
200ft	0.11	1.00	0.13	0.03	0.26

Figure 20. Normalized accumulated damage in 2015 at the upstream cover plate end



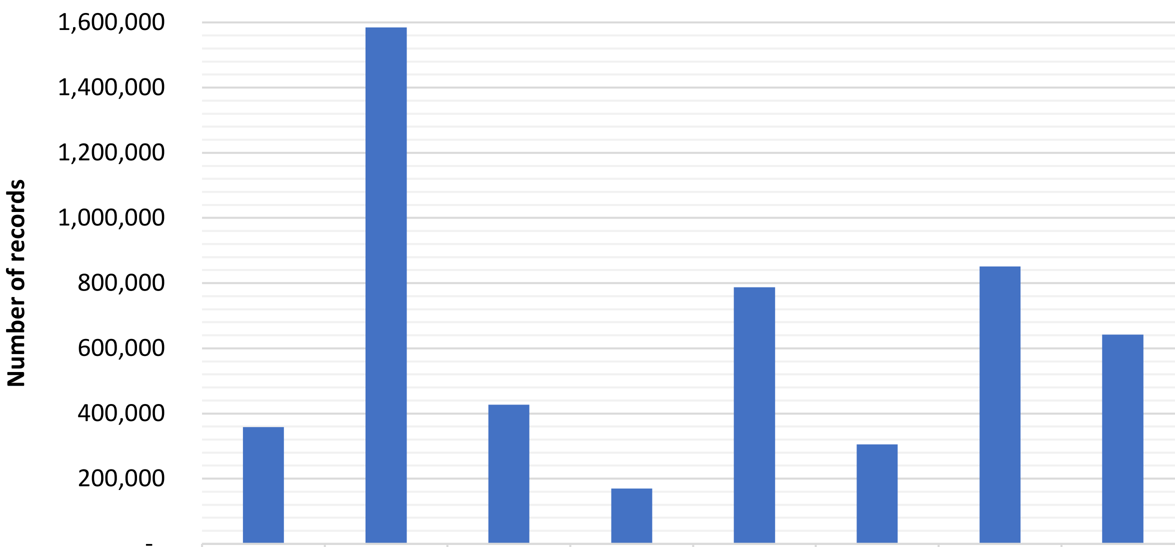
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 961	Site 964
30ft	0.12	1.00	0.18	0.06	0.30	0.47	0.27
60ft	0.12	1.00	0.21	0.08	0.30	0.47	0.26
90ft	0.13	1.00	0.15	0.07	0.30	0.47	0.26
120ft	0.12	1.00	0.19	0.06	0.30	0.46	0.26
200ft	0.12	1.00	0.18	0.05	0.29	0.46	0.26

Figure 21. Normalized accumulated damage in 2014 at mid-span



	Site 911	Site 931	Site 933	Site 934	Site 942
30ft	0.11	1.00	0.13	0.03	0.25
60ft	0.10	1.00	0.13	0.04	0.23
90ft	0.10	1.00	0.10	0.04	0.24
120ft	0.10	1.00	0.13	0.03	0.24
200ft	0.10	1.00	0.12	0.03	0.24

Figure 22. Normalized accumulated damage in 2015 at mid-span



	911	931	933	934	942	960	961	964
No. of records	357,854	1,584,34	427,505	169,407	787,426	305,566	851,213	642,337

Figure 23. The number of WM records collected in 2014

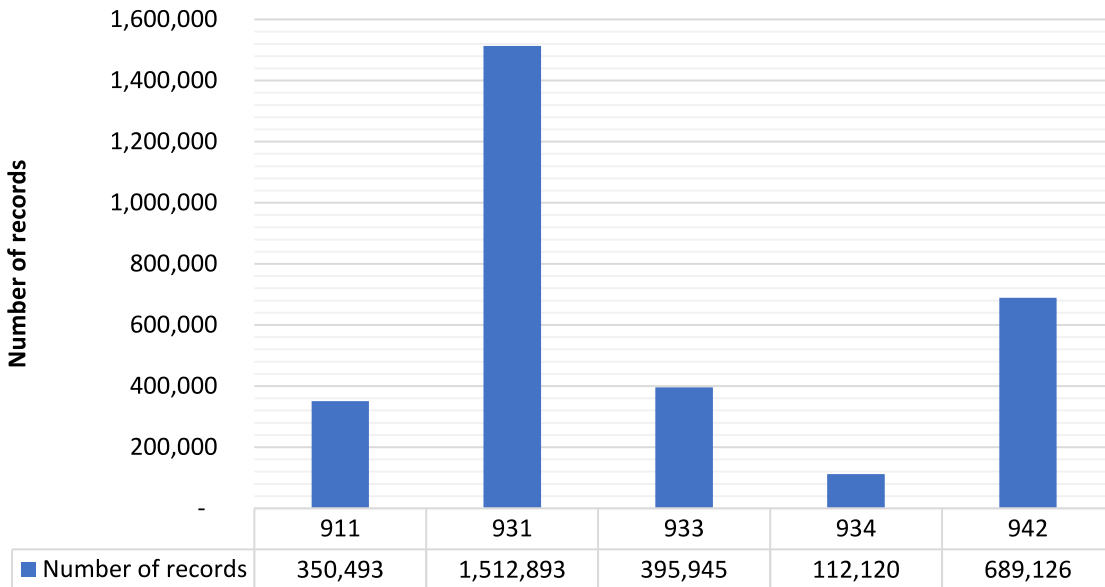
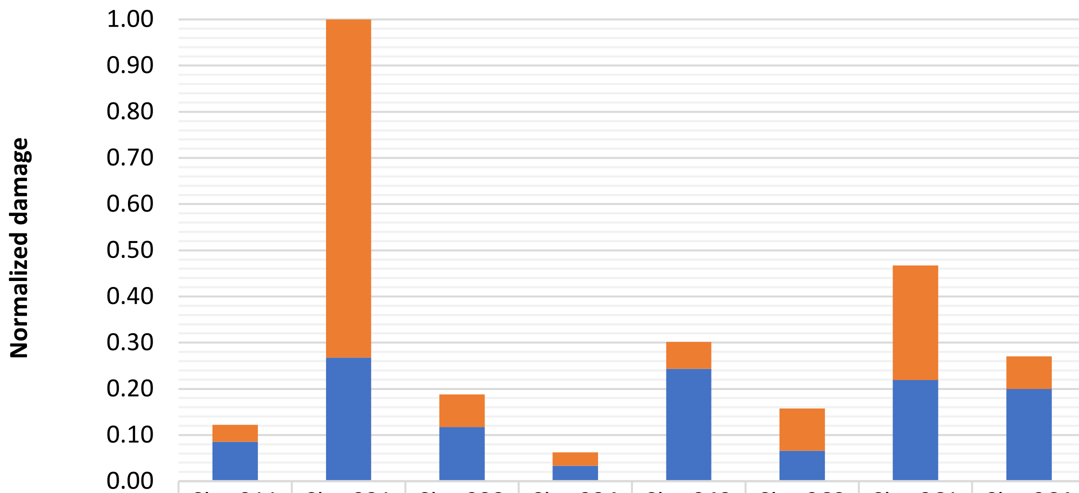


Figure 24. The number of WM records collected in 2015

5.4.2. The impact of overweight vehicles on damage accumulation

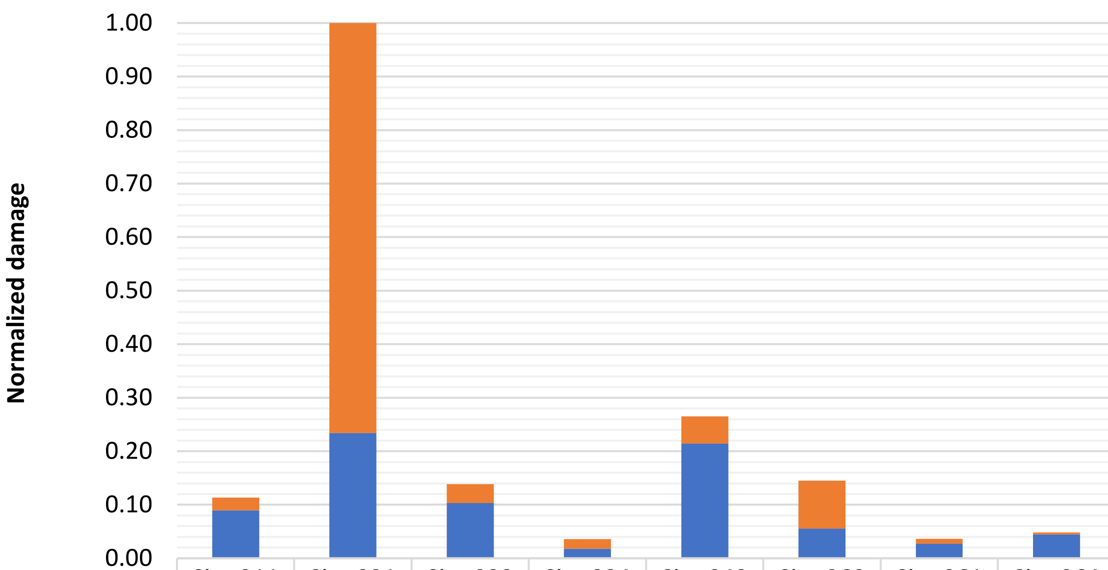
The truck traffic data was divided into two groups, legal and overweight, and the corresponding amount of damage (NM_{eff}^3) was computed for each group. Legal traffic includes vehicles that comply with Alabama's legal regulations, "grandfather exceptions" and annual permits that have GVW less than 100 kips. The overweight group covers vehicles that require an individual trip permit to travel legally due to its weight or axle load combination and annual permits that have GVW greater 100 kips. The proportion of the damage caused by these groups of vehicles (legal, overweight) is shown in Figure 25 and Figure 26 for the year 2014 and 2015. The corresponding number of legal and overloaded trucks are shown in Figure 27 and Figure 28. Results of the previous section show that the normalized fatigue damage is practically independent of the location along the girder and span length. Therefore, here and in further sections, the results are shown for the 30-ft span and upstream cover plate end only.

From Figure 25 and Figure 26, the amount of damage accumulated by overloaded traffic from WIM locations 931, 960, 961 is greater than for the legal traffic. However, at WIM location 961, the damage accumulated from overloaded traffic is greater than legal traffic only in the year 2015. It appears that damage caused by overweight vehicles is higher than legal vehicles when the number of overweight vehicles is greater than approximately 20% of all the vehicles. From Figure 29 and Figure 30 for the years 2014 and 2015, it can be concluded that the 20% of overloaded trucks create more than 50% of the total damage for the traffic combined from all the locations.



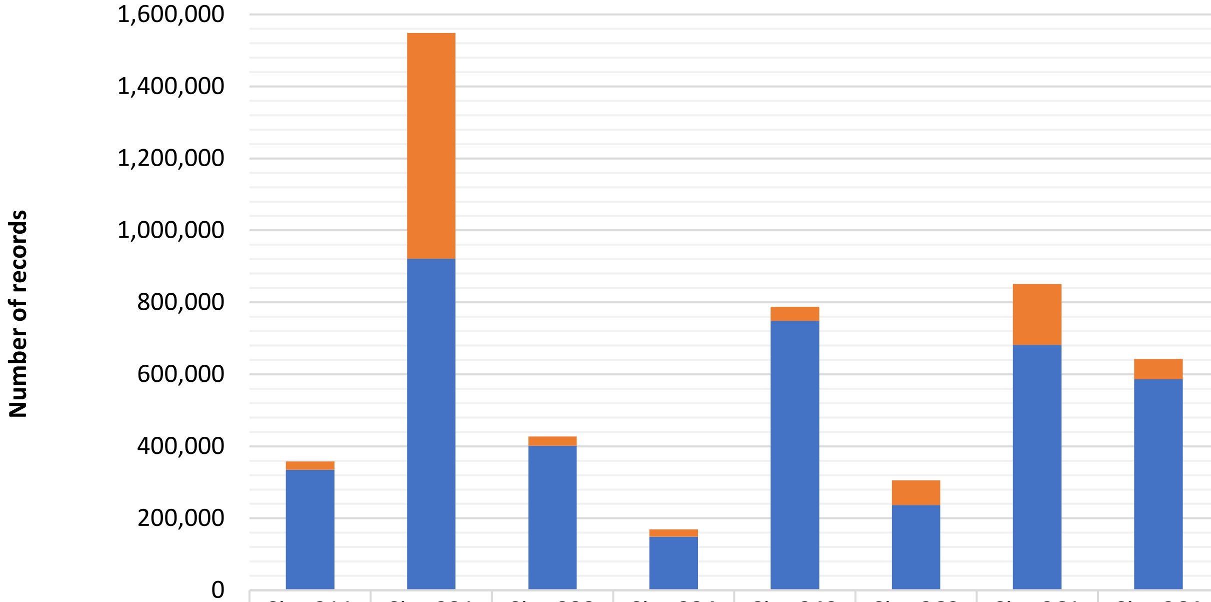
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
Overweight traffic	0.04	0.73	0.07	0.03	0.06	0.09	0.25	0.07
Legal traffic	0.09	0.27	0.12	0.03	0.24	0.07	0.22	0.20

Figure 25. Normalized accumulated damage in 2014 at the upstream cover plate end of a 30-ft span due to legal and overweight truck traffic



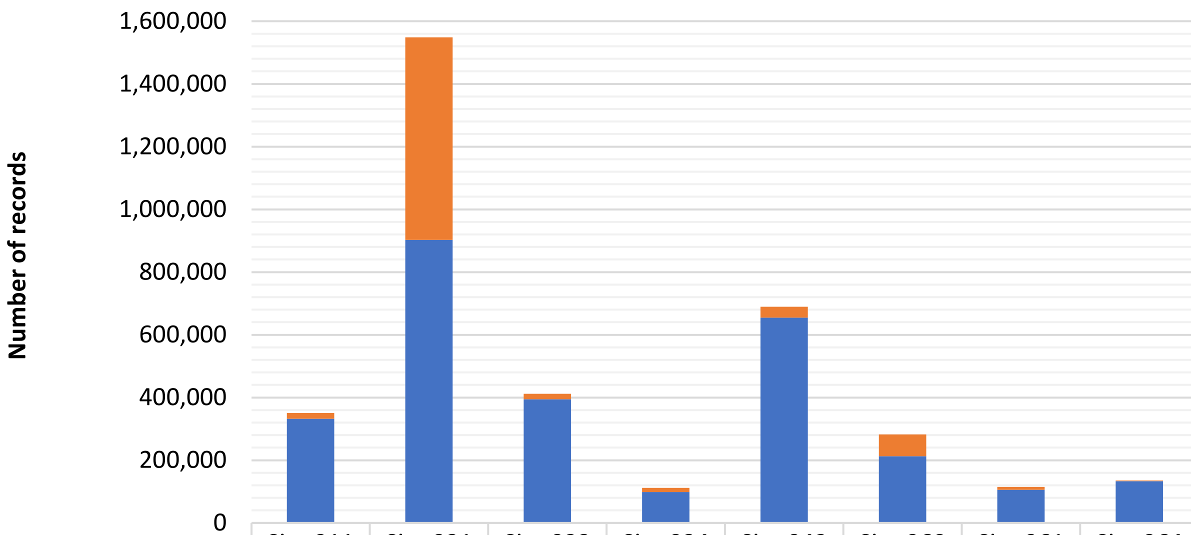
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
Overweight traffic	0.02	0.77	0.04	0.02	0.05	0.09	0.01	0.00
Legal traffic	0.09	0.23	0.10	0.02	0.21	0.06	0.03	0.04

Figure 26. Normalized accumulated damage in 2015 at the upstream cover plate end of a 30-ft span due to legal and overweight truck traffic.



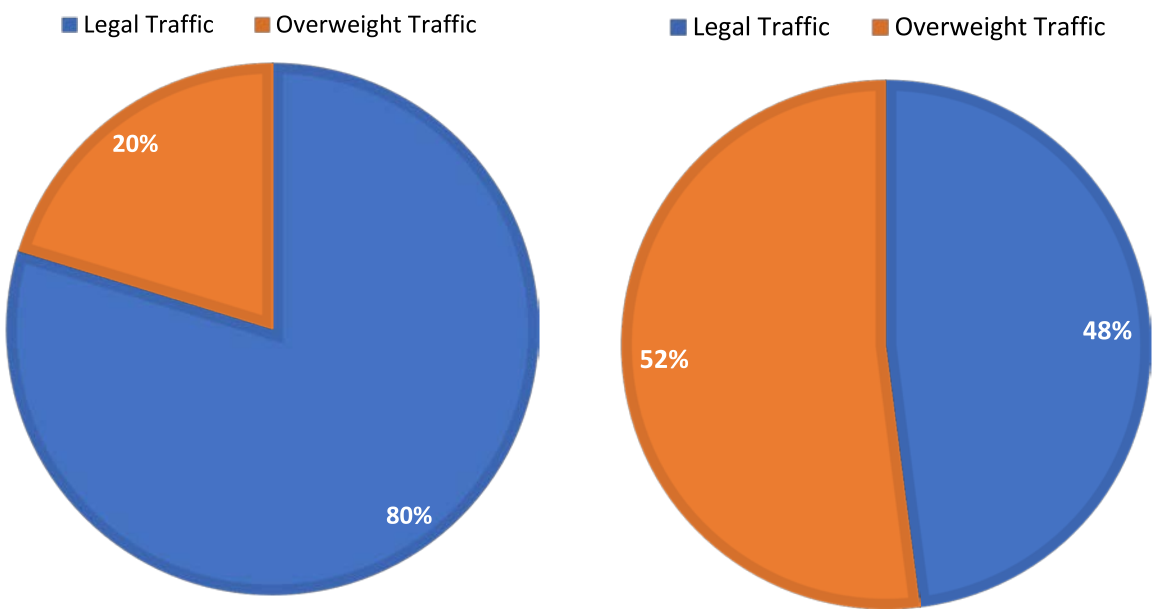
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
Overweight traffic	23,045	627,013	25,579	20,480	39,001	68,593	168,973	56,015
Legal traffic	334,809	921,334	401,926	148,927	748,425	236,972	682,211	586,321

Figure 27. The number of legal and overweight WIM records collected in 2014



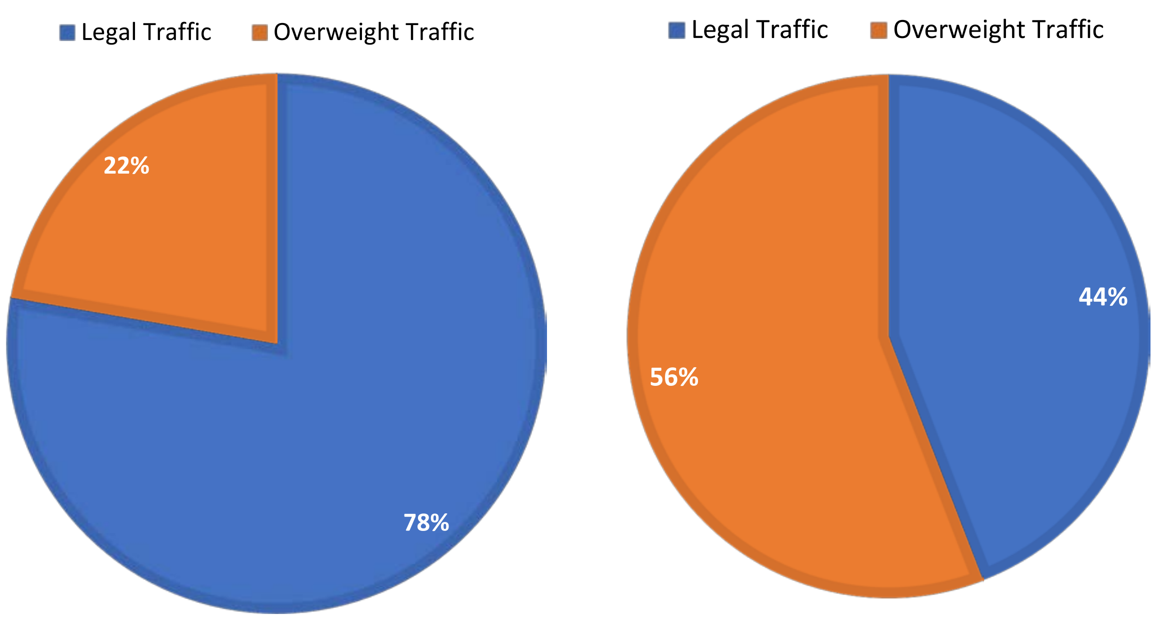
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
Overweight traffic	18,624	645,772	17,436	13,792	34,102	68,993	9,578	2,894
Legal traffic	331,869	902,848	394,289	98,328	655,024	213,318	105,786	132,931

Figure 28. The number of legal and overweight WIM records collected in 2015.



a) b)

Figure 29. Contribution of the legal and overweight traffic to (a) the total number of records, and (b) the total amount of fatigue damage for all WIM locations in 2014



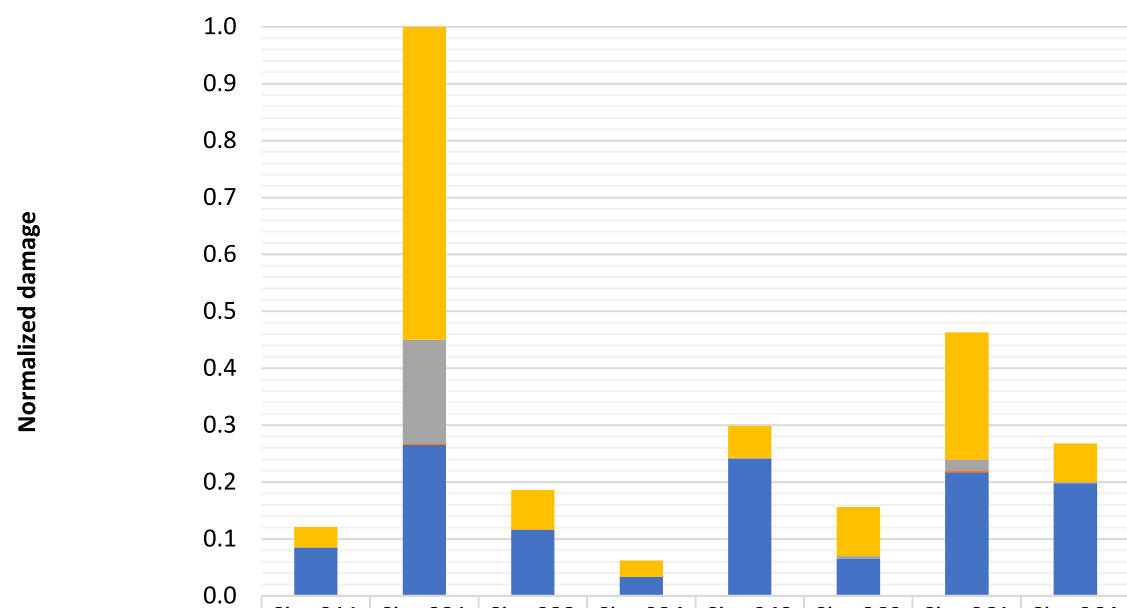
a) b)

Figure 30. Contribution of the legal and overweight traffic to (a) the total number of records, and (b) the total amount of fatigue damage for all WIM locations in 2015

5.4.3. The impact of vehicles with permits on damage accumulation

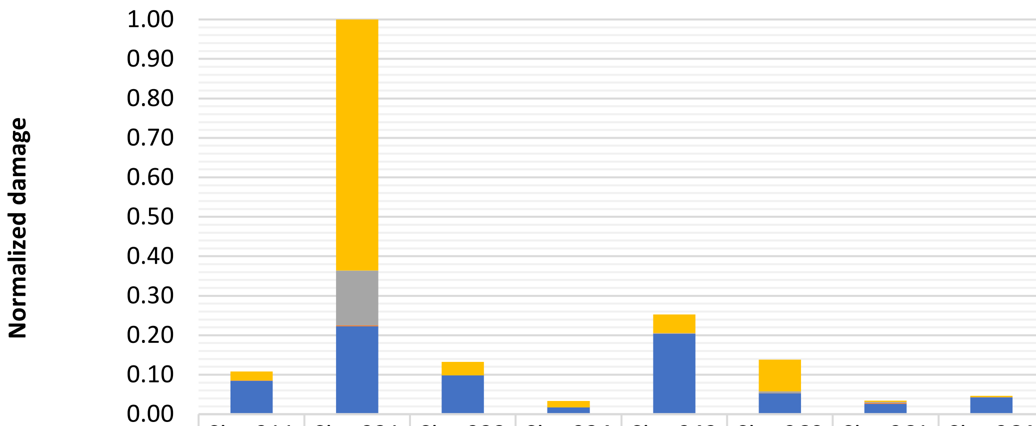
Some vehicles require an overweight permit to operate on a state or interstate roads. However, a number of them do not have permits and, therefore, operate illegally. Others have an axle weight distribution and axle configuration similar to ones listed in the database of permits issued by ALDOT. The number of such trucks operating on the highways is substantially higher than permitted by ALDOT, but they meet permit criteria. The proportion of the damage caused by these groups of vehicles (legal, ALDOT permitted, illegal and those that meet ALDOT permit criteria) is shown in Figure 31 and Figure 32 for the year 2014 and 2015. The corresponding numbers of WIM records are shown in Figure 33 and Figure 34.

The Illegal vehicles cause the most damage at the WIM site 931 and 960 for the years 2014 and 2015 and at WIM site 961 for the year 2014. Vehicles with a permit and those that meet permit criteria do less damage than illegal vehicles or legal. From Figure 35 and Figure 36 where the traffic from all locations is combined for years 2014 and 2015, it can be concluded that the 2.5% of trucks that are illegally overloaded create more than 40% of the total damage.



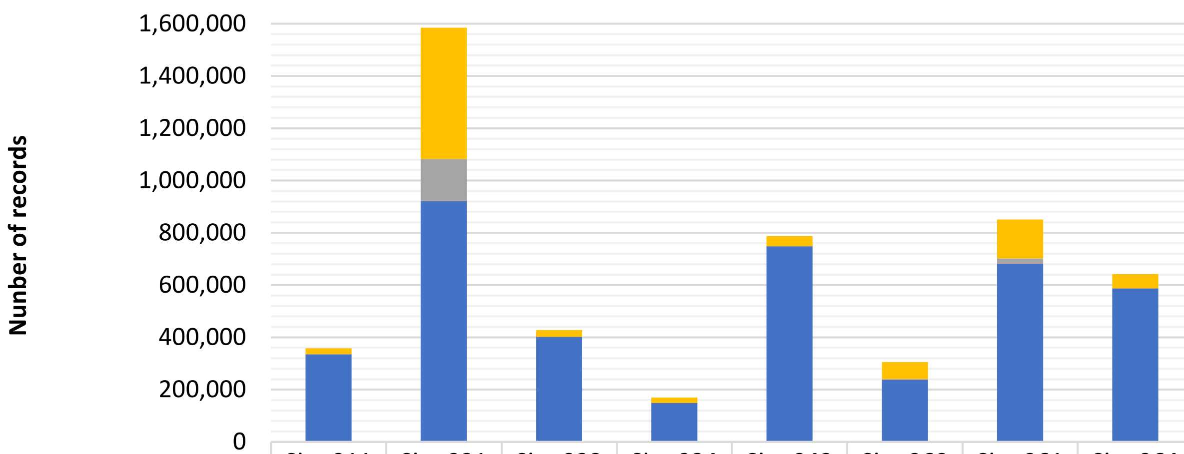
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
WIM Illegal traffic	0.04	0.55	0.07	0.03	0.06	0.09	0.22	0.07
Meet permit requirements	0.00	0.18	0.00	0.00	0.00	0.00	0.02	0.00
ALDOT Permits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Legal traffic	0.08	0.27	0.12	0.03	0.24	0.07	0.22	0.20

Figure 31. Amount of damage accumulated in 2014 at the upstream cover plate end due to legal, permitted, and illegal truck traffic that meets permit requirement



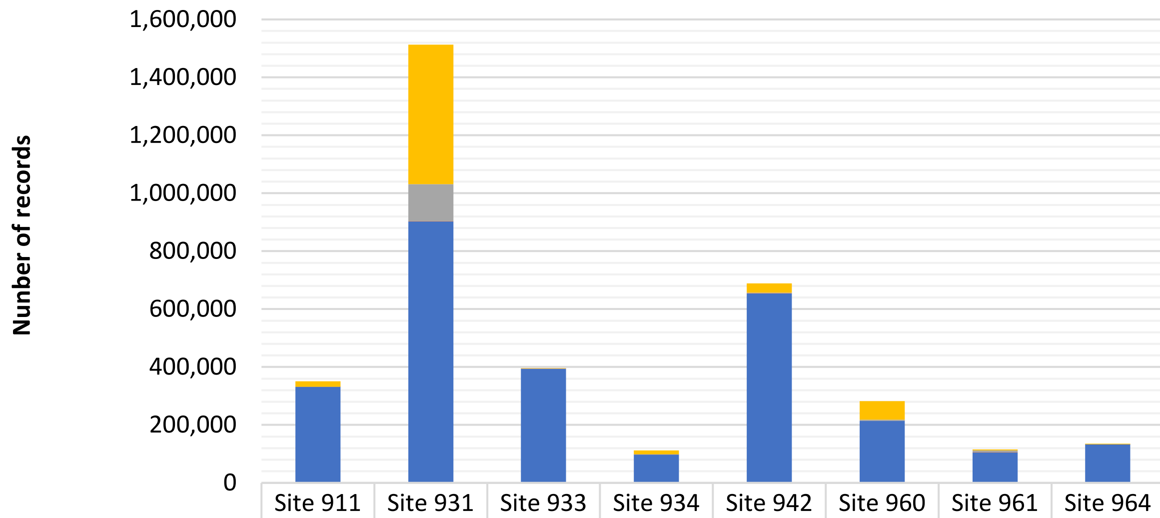
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
WIM Illegal traffic	0.02	0.64	0.03	0.02	0.05	0.08	0.00	0.00
Meet permit requirements	0.00	0.14	0.00	0.00	0.00	0.01	0.00	0.00
ALDOT Permits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Legal traffic	0.08	0.22	0.10	0.02	0.20	0.05	0.03	0.04

Figure 32. Amount of damage accumulated in 2015 at the upstream cover plate end due to legal, permitted, illegal and truck traffic that meet permit requirement



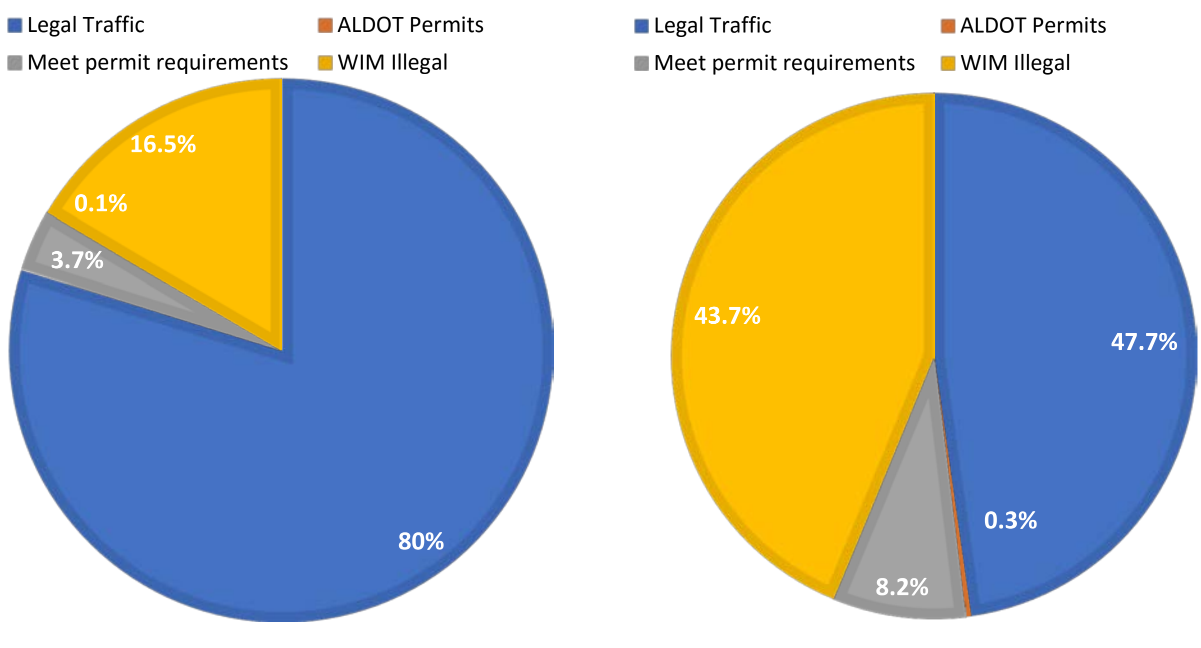
	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
WIM Illegal traffic	22,131	501,628	25,188	20,288	37,588	64,483	149,809	53,702
Meet permit requirements	689	160,385	322	106	1,207	3,772	17,497	2,201
ALDOT Permits	225	1,000	69	86	206	339	1,696	113
Legal traffic	334,809	921,334	401,926	148,927	748,425	236,972	682,211	586,321

Figure 33. The number of legal, permitted, and illegal trucks that meet ALDOT permit criteria collected in 2014



	Site 911	Site 931	Site 933	Site 934	Site 942	Site 960	Site 961	Site 964
WIM Illegal traffic	18,027	481,193	1,372	13,521	32,740	64,442	2,713	2,551
Meet permit requirements	432	127,918	211	195	1,169	4,359	5,673	219
ALDOT Permits	165	934	73	76	193	192	1,193	124
Legal traffic	331,869	902,848	394,289	98,328	655,024	213,318	105,786	132,931

Figure 34. The number of legal, ALDOT permitted, illegal and records that meet ALDOT permit criteria collected in 2015



a) b)

Figure 35. Contributions of the legal, permitted, illegal and trucks that meet permit criteria to (a) the total number of records, and (b) the total amount of fatigue damage for all WIM location in 2014

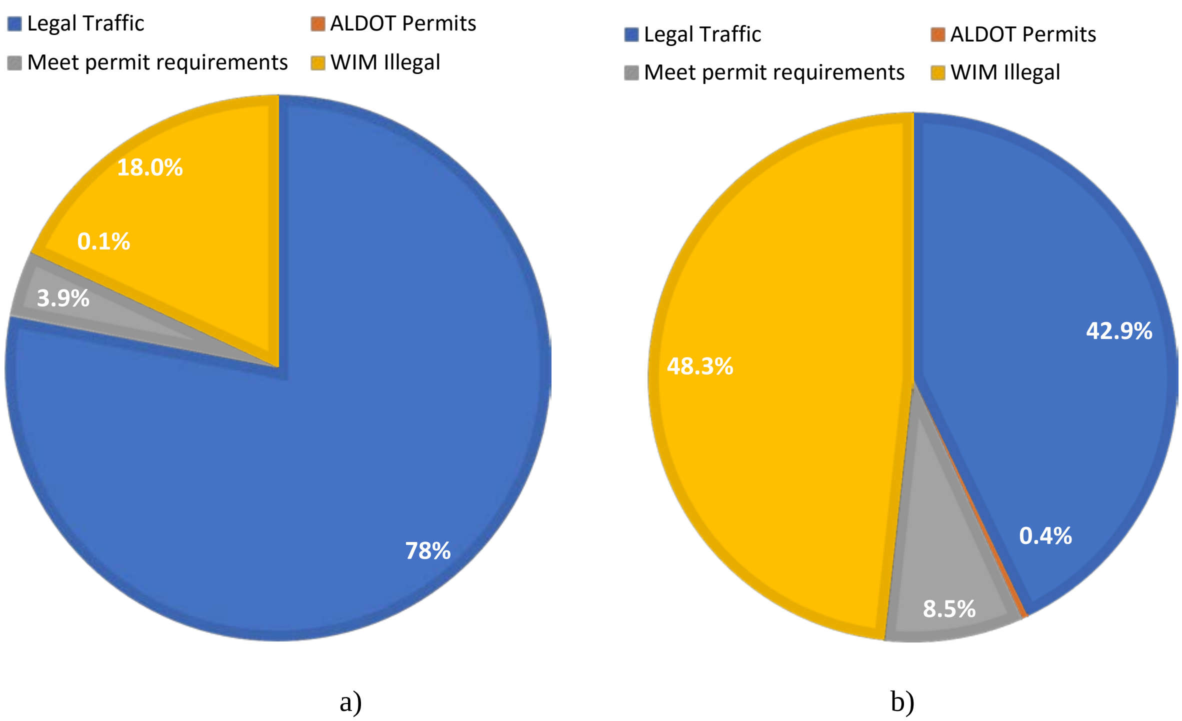


Figure 36. Contributions of the legal, permitted, illegal and trucks that meet permit criteria to (a) the total number of records, and (b) the total amount of fatigue damage for all WIM location in 2015

5.4.4. Comparison of damage from different FHWA vehicle classes

The total amount of accumulated damage strongly depends on the traffic mix, in particular on the dominating vehicle types. The contribution of damage by different vehicle classes is shown in Table 14 and Table 15 for WIM location 931 and 960. These locations were selected because these WIM sites have the most damaging traffic compare to other sites.

The results indicate that the Class 9 truck (5-axle, single trailer truck, see Table 14 and Table 15) contributes the most to the total amount of accumulated damage at WIM location 931 and 960. This is partly due to the high population of those vehicles. This type of vehicle is the most common in Alabama, as well as in the US. Above 70% of damage due to legal, permit and illegal vehicles are caused by 5-axle Class 9 trucks. At WIM location 960, other vehicle classes also contribute significantly to damage accumulation.

Table 14. Contribution to the total accumulated damage by different FHWA vehicle classes at WIM site 931 for the year 2014 and 2015

WIM location 931							
Year 2014				**Year 2015**			
Vehicle Class	Legal (%)	Permit (%)	Illegal (%)	Vehicle Class	Legal (%)	Permit (%)	Illegal (%)
VC 0	0.0	0.0	3.1	VC 0	0.0	0.0	8.5
VC 4	1.5	0.0	2.1	VC 4	1.6	0.0	2.4
VC 5	0.6	0.0	7.1	VC 5	1.4	0.0	6.5
VC 6	0.5	0.0	3.6	VC 6	0.6	0.0	3.4
VC 7	0.0	0.0	0.8	VC 7	0.0	0.0	1.2
VC 8	2.5	0.0	3.3	VC 8	3.0	0.0	4.1
VC 9	91.4	98.2	76.6	VC 9	89.9	97.6	70.2
VC 10	1.7	0.9	1.0	VC 10	1.7	0.8	0.9
VC 11	1.7	0.0	1.6	VC 11	1.7	0.0	1.9
VC 12	0.0	0.0	0.1	VC 12	0.0	0.0	0.2
VC 13	0.1	0.8	0.7	VC 13	0.1	1.4	0.5
Total	**100**	**100**	**100**		**100**	**100**	**100**

Table 15. Contribution to the total accumulated damage by different FHWA vehicle classes at WIM site 960 for year 2014 and 2015

WIM location 960							
Year 2014				**Year 2015**			
Vehicle Class	Legal (%)	Permit (%)	Illegal (%)	Vehicle Class	Legal (%)	Permit (%)	Illegal (%)
VC 0	0.0	0.0	0.2	VC 0	0.0	0.0	0.1
VC 4	0.7	0.0	0.2	VC 4	0.7	0.0	0.1
VC 5	0.8	0.0	0.1	VC 5	0.8	0.0	0.0
VC 6	8.1	0.0	4.2	VC 6	7.4	0.0	4.0
VC 7	0.3	0.0	9.7	VC 7	0.2	0.0	6.0
VC 8	0.9	2.3	0.0	VC 8	1.0	0.3	0.0
VC 9	84.6	69.8	67.1	VC 9	85.6	84.0	74.4
VC 10	4.3	27.2	15.0	VC 10	4.0	14.4	13.5
VC 11	0.0	0.0	0.0	VC 11	0.0	0.0	0.0
VC 12	0.1	0.0	1.9	VC 12	0.0	0.0	0.9
VC 13	0.3	0.8	1.6	VC 13	0.2	0.2	0.9
Total	**100**	**100**	**100**		**100**	**100**	**100**

5.5. Damage accumulation index to a specific bridge

The traffic carried by each bridge is different. Also, the bridges were built in different time periods and there is variation in the design of bridges. Additional assessments of damage can be calculated by considering a specific bridge and by knowing the traffic carried by that bridge. A procedure was developed to estimate the damage for a specific bridge. Fatigue crack initiation and propagation usually occur in a region of tensile stress at a welded attachment. Therefore, particular fatigue prone details are of interest in the damage assessment. Also, bridges are designed for fatigue assuming the AASHTO fatigue design truck encompasses the traffic carried by that bridge during its service life. A primary interest here is knowing how much damage is accumulating over the service life of the bridge. All the scenarios mentioned above are considered to develop a practical procedure.

5.5.1. Damage at a specific fatigue prone detail

Different details in a steel bridge experience stress ranges of various numbers and magnitudes and, therefore, some accumulate fatigue damage faster than others. Based on the study performed by Franklin (Franklin 2000), the base metal at the end of a bottom flange cover plate is considered here as the most fatigue prone detail in Alabama's steel girder bridges. The bottom flange of the girder at the upstream cover plate end is a Category E' detail, and the base metal adjacent to a transverse stiffener weld near the bottom flange at the mid-span may be a Category C' detail as defined in *AASHTO LRFD Bridge design specifications* (AASHTO 2017).

For a specific fatigue prone detail, an index of the fatigue damage accumulated by a bridge along a route due to the truck traffic recorded by a WIM station can be calculated using Eq. 5.8. D_m is a Miner's fraction determined by dividing the fatigue damage accumulated over a specified period of time by the mean value of fatigue damage defining failure. This fraction is also equal to the fatigue life expended divided by the mean fatigue life as follows:

$$D_m = \frac{p * N * S_{eff}^3}{R_R * A} \quad (5.8)$$

Where:

D_m – fraction of mean fatigue life expended at a specific fatigue prone detail

N – total number of cycles produced by truck traffic in a specific period of time (set of records in the WIM database) determined by counting bending moment cycles using rainflow counting

A – constant for a particular detail category (*AASHTO LRFD Bridge design specifications* Table 6.6.1.2.3.-1 (AASHTO 2017))

R_R – resistance factor for mean fatigue life (Manual for Bridge Evaluation (MBE), Table 7.2.5.1-1 (AASHTO 2018))

S_{eff} – effective stress range for a set of records in the WIM database determined based on Eq. 5.9

p – fraction of truck traffic in a single lane as specified in *AASHTO LRFD Bridge design specifications* Table 3.6.14.2.1, (Table 16 of this report)

Table 16. Fraction of truck traffic in a single lane, p (*AASHTO LRFD Bridge design specifications*, Table 3.6.1.4.2.1 (AASHTO 2017))

Number of lanes available to Trucks	p
1	1
2	0.85
3 or more	0.8

The variable 'p' in Equation 5.8 is used for a fraction of truck traffic in a single lane depending upon the number of lanes available to trucks. Effective stress range, S_{eff} for a set a WIM records is calculated based on Equation 5.9. The Equation 5.9 calculates stress range from the moment range created by the trucks in WIM records. All the vehicle records in WIM database contain the direction of travel and lane number information. The calculated S_{eff} for the set of WIM records is for the traffic in one direction and with traffic in all the lanes in that direction combined. The girder distribution factor (GDF) and dynamic load allowance (IM) are calculated according to *AASHTO LRFD Bridge design specifications*, section 4.6.2.2.2 and 3.6.2 respectively (AASHTO 2017). The variable 'P' is the ratio of measured to calculated stress range. A 'P' value of 0.6 is calculated by using the results from Pearson (2002) where the author had measurements of the stress range at cover plate ends of four typical steel girder bridges. The 'P' value is the ratio of stress range measured from the passage of a single truck of known weight and configuration to the stress range calculated by the simplified bridge analysis procedure of the *AASHTO LRFD Bridge design specifications.* The effective constant amplitude stress range at the detail is

$$S_{eff} = \frac{M_{eff} * GDF * (1+IM) * P * R_p}{S} \qquad (5.9)$$

Where:

M_{eff} – effective moment range for a set of WIM records calculated as shown in Eq. 5.6

GDF – girder distribution factor for a single loaded lane

IM – dynamic load allowance, 0.15 from *AASHTO LRFD Bridge design specifications*, Table 3.6.2.1-1 (AASHTO 2017)

P – ratio of measured to calculated stress range, 0.6 (determined based on the stress ranges measured by Pearson (Pearson 2002))

S – section modulus for the specific fatigue detail

R_p – multiple presence factor

The multiple presence factor as described in MBE Article 7.2.2.1 is given by

$$R_p = 0.988+6.87\text{x}10^{-5}\ (L) + 4.01\text{x}10^{-6}\ [ADTT]_{PRESENT} + \frac{0.0107}{n_L} \quad (5.10)$$

Where:

L = span length in feet

$[ADTT]_{PRESENT}$ = present average number of trucks per day for all directions of truck traffic including all lanes on the bridge

n_L = number of lanes

5.6. Damage accumulated from WIM traffic relative to AASHTO fatigue design truck and ALDOT rating vehicles

As mentioned in the previous section the AASHTO fatigue design truck is intended to capture the fatigue damage caused by the traffic on the highways. The current AASHTO fatigue design truck has a GVW of 57.6 kips and the configuration is the same as the HS truck shown in Figure 37; except, the spacing between the last two axles is a constant 30 ft (AASHTO 2017). A fraction called damage accumulation index, α, is introduced in Equation 5.11, which is the ratio of the damage caused by WIM truck traffic relative to an equal number of crossings of the AASHTO fatigue design truck. Equation 5.7 can be used for a set of WIM trucks or a single truck alone. Values of NM_{eff}^3 for a fatigue truck on various span lengths are shown in Appendix D. The damage accumulation index, α, is shown in the form of an equation as:

$$\alpha = \frac{D_{\text{due to WIM trucks}}}{D_{\text{due to fatigue design truck}}} \quad (5.11)$$

Further substituting Eq. 5.7 in Eq. 5.11, and if T is the number of trucks (WIM records) then the damage accumulation index is:

$$\alpha = \frac{(NM_{eff}^m)_{\text{due to WIM trucks}}}{T * (NM_{eff}^m)_{\text{due to fatigue design truck}}} \quad (5.12)$$

Similar to the relative damage calculated by using the AASHTO fatigue design truck, the relative damage of the ALDOT rating vehicles can be calculated. The ALDOT rating vehicles are shown in Figure 37. The corresponding ratios of D (using Equation 5.7) for a single passage of an ALDOT rating vehicle to a single passage of the AASHTO fatigue design truck for standard span lengths of 30, 60, 90, 120 and 200 ft are shown in Table 17 and Table 18.

Table 17. Ratios of D for ALDOT rating vehicles to AASHTO fatigue design truck for mid-span

Vehicle Type	Span length				
	30 ft	60 ft	90 ft	120 ft	200 ft
AASHTO Fatigue Truck	1	1	1	1	1
H Design	0.54	1.78	0.87	0.65	0.49
Two-Axle	0.85	4.30	2.33	1.84	1.44
Tri-Axle	2.54	10.22	5.23	4.03	3.08
Concrete	1.66	6.84	3.53	2.72	2.09
18 Wheeler 3S2	1.57	3.73	3.18	3.00	2.85
6 Axle	1.97	4.17	3.41	3.31	3.21
School Bus	0.13	0.25	0.15	0.12	0.10
Emergency Vehicle 2	0.77	3.94	2.14	1.69	1.33
Emergency Vehicle 3	3.16	14.28	7.52	5.87	4.56

Table 18. Ratios of D for ALDOT rating vehicles to AASHTO fatigue design truck for upstream cover plate end

Vehicle Type	Span length				
	30 ft	60 ft	90 ft	120 ft	200 ft
AASHTO Fatigue Truck	1	1	1	1	1
H Design	0.24	0.48	0.23	0.18	0.13
Two-Axle	0.72	1.29	0.64	0.49	0.39
Tri-Axle	0.86	2.86	1.40	1.05	0.81
Concrete	0.56	2.13	0.99	0.73	0.55
18 Wheeler 3S2	0.47	2.61	1.93	0.88	0.79
6 Axle	0.54	3.24	1.18	1.05	0.94
School Bus	0.05	0.21	0.05	0.04	0.03
Emergency Vehicle 2	0.58	1.10	0.61	0.49	0.38
Emergency Vehicle 3	2.52	4.18	2.03	1.55	1.22

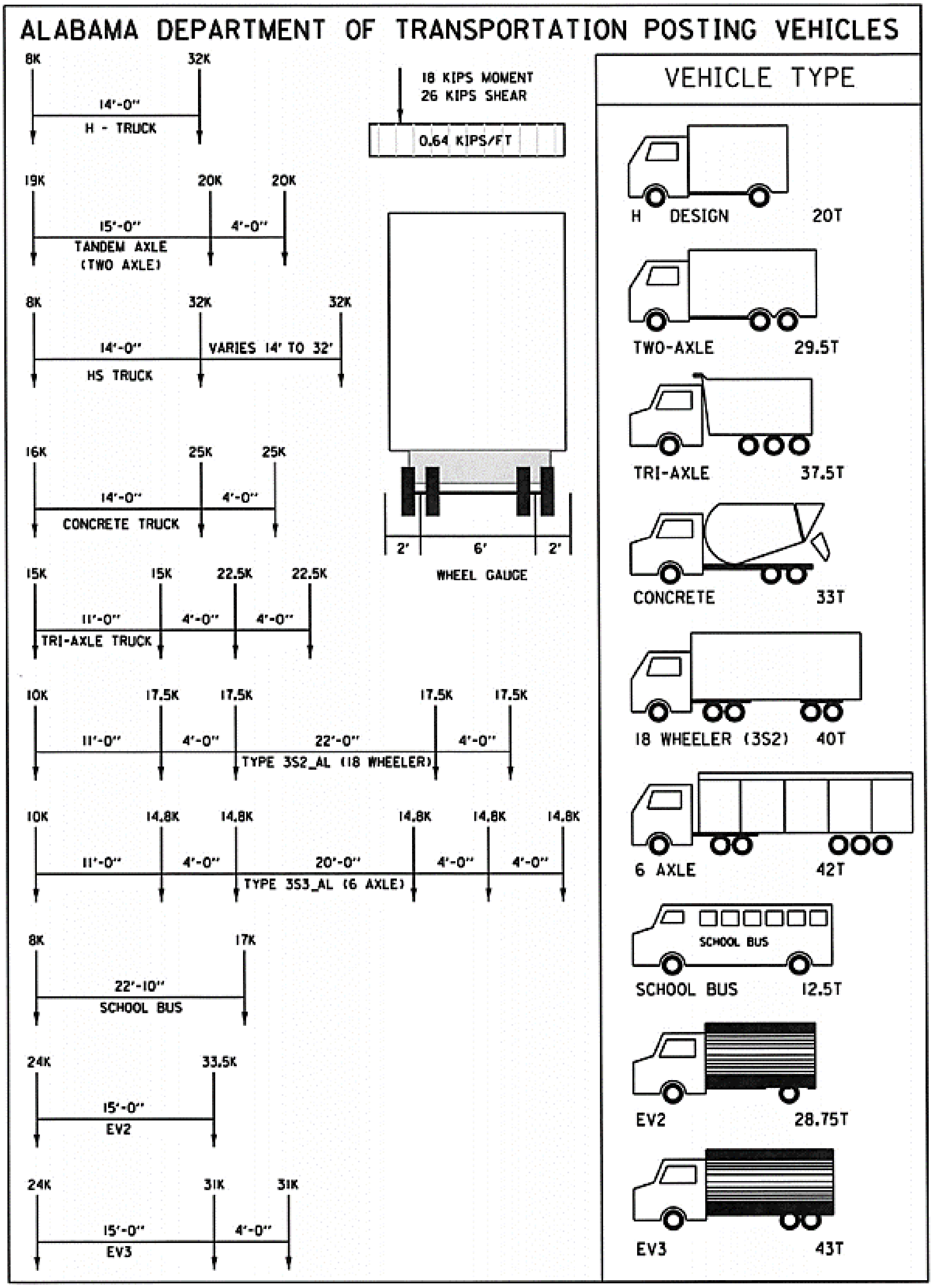


Figure 37. ALDOT rating vehicles

5.7. Evaluation of a specific bridge using traffic data from WIM site 931

A previous study funded by ALDOT and conducted by Auburn University Highway Research Center included evaluation and instrumentation of representative spans from among 58 simple-span rolled girder bridges, 18 continuous-span rolled-girder bridges and 6 plate-girder simple-span bridges in downtown Birmingham (Franklin 2000). Stress ranges were calculated at the following fatigue-prone details of the bridges: transverse diaphragm connections, longitudinal cover plate fillet weld connections, shear connectors, and cover plate ends at the upstream and downstream locations. The study concluded that the base metal at the end of the cover plate was identified as the most fatigue-detail of those steel girder bridges. The bottom flange of the girder at upstream cover plate end is detail category Type E' as defined in *AASHTO LRFD Bridge design specifications* (AASHTO 2017).

To demonstrate the procedures developed in this report, the damage accumulated at the specific fatigue prone detail, E,' i.e., cover plate end for the Span 86-W described by Franklin (2000) is selected. Plan view and cross section view of Span 86-W is shown in Figure 38 and Figure 39. This bridge is selected because it is a real bridge typical of steel girder bridges on Alabama highways. Also, as an example, WIM data from site 931 is used. Damage accumulated from the passage of traffic in one of the direction (lane 1 and 2) at WIM station 931 for the year 2014 on the upstream cover plate end is shown here.

Span 86-W consists of eight W36x150 rolled section girders spaced 8.71 ft. On average the total length of the beams is 66.30 ft, and the approximate of average span length is 60 ft. The cover plate size is 10" x 0-15/16" x 41"-6". Based on this information the bridge data inputs to estimate the damage accumulation are calculated and listed in Table 19.

Table 19. Bridge data inputs for Span 86-W Bridge on Interstate I-59/20 in Birmingham, Alabama

Section modulus (S)	701.98 in^3
Span length (L)	60 ft
Girder distribution factor (GDF)	0.51
Dynamic load allowance (IM)	0.15
Location of upstream cover plate end	11.04 ft
x/L of upstream cover plate end	0.2
Location of downstream cover plate end	53.57 ft
x/L of downstream cover plate end	0.2
Number of traffic lanes	4
Direction of traffic	One-direction only

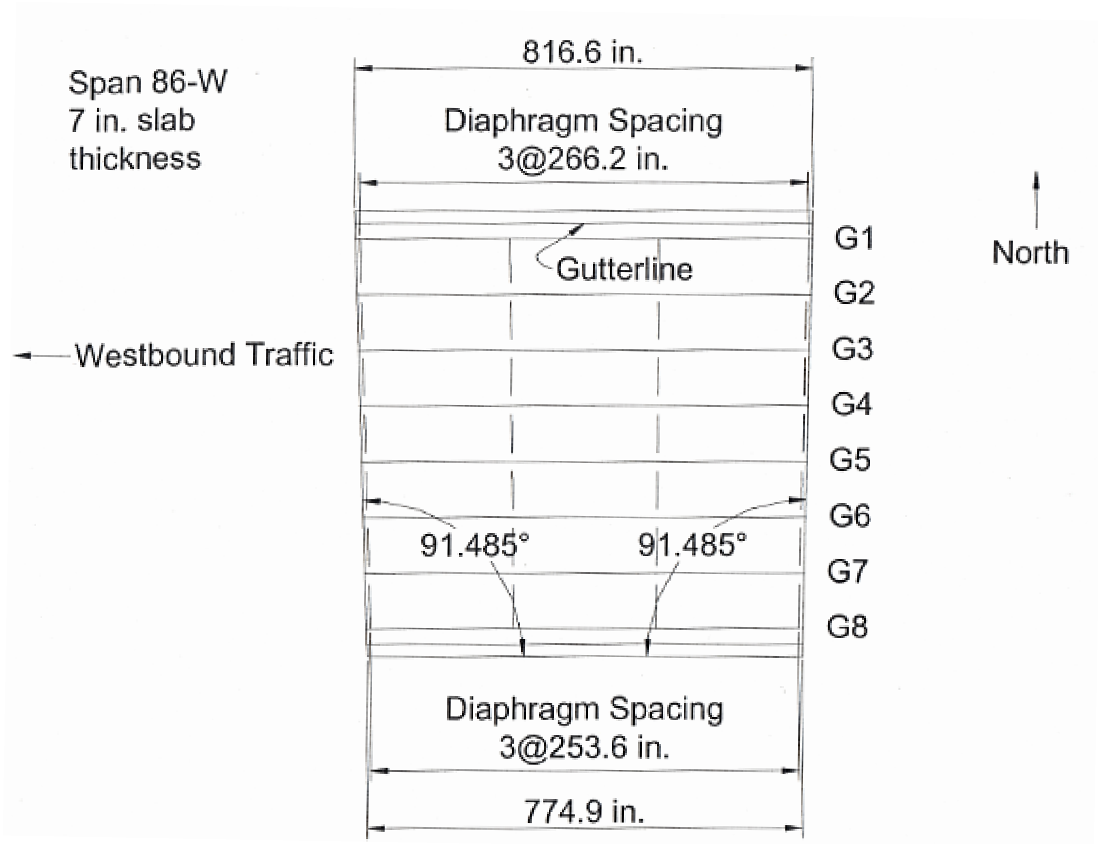


Figure 38. Plan View of Span 86-W

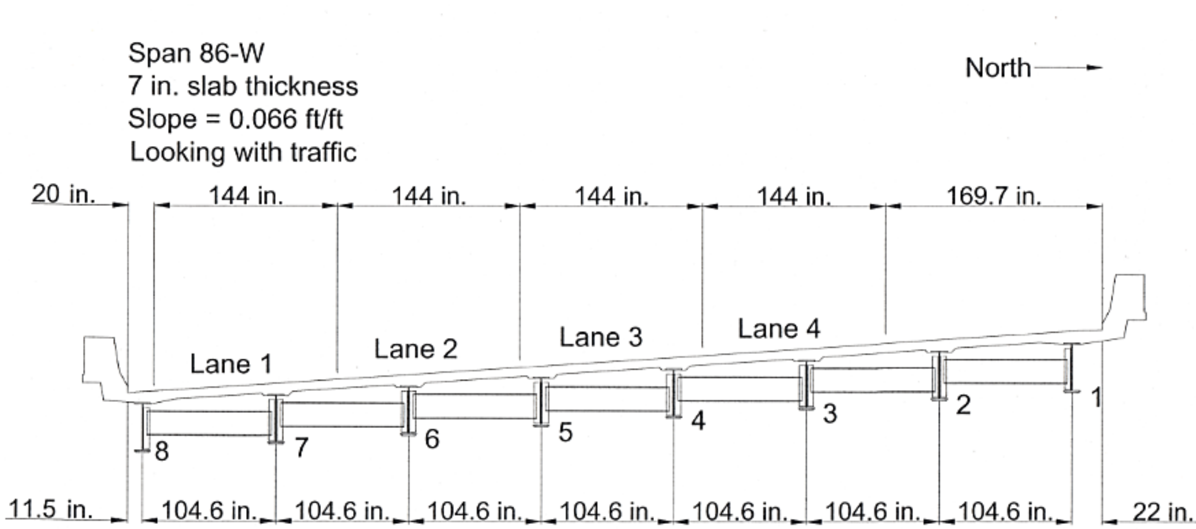


Figure 39. Cross Section View of Span 86-W

The traffic recorded at WIM site 931 is bi-directional with two lanes of traffic in each direction. Here fatigue damage is assumed to result only from traffic in one direction. N and M_{eff} for a span length of 60 ft and x/L location of 0.2 are calculated using the computer app - ALDOT_WIM_DAI v1.0 for each month of the year 2014. (A more detailed discussion of the ALDOT_WIM_DAI v1.0 computer app is shown in Appendix F). The output generated by the computer app by processing WIM station 931 traffic data is shown in Table 20. The table contains N, M_{eff} and D calculated for traffic in one of the direction (lane 1 and 2) for all the months in the year 2014.

Table 20. Output of ALDOT_WIM_DAI v1.0 for WIM station 931 and year 2014

Year 2014	**For L = 60 ft and x/L = 0.2 (upstream coverplate end)**			
Month	**No. of records**	**N (cycles)**	**M_{eff} (kip-ft)**	**$D=NM_{eff}^3$ (cycles(kip-ft)^3)**
Jan	66423	145916	257.64	2.50E+12
Feb	62731	137922	257.38	2.35E+12
Mar	71102	155941	260.24	2.75E+12
Apr	69661	153324	256.61	2.59E+12
May	73938	161858	266.31	3.06E+12
Jun	72429	154466	296.94	4.04E+12
Jul	73259	154400	315.29	4.84E+12
Aug	73270	157581	300.38	4.27E+12
Sep	67079	145985	272.55	2.96E+12
Oct	79038	167937	306.89	4.85E+12
Nov	66480	144871	268.98	2.82E+12
Dec	67562	145270	283.27	3.30E+12
	T = 842972			∑ D = 4.03E+13

Other variables used in equation 5.8 and 5.9 to calculate the fraction of mean fatigue life expended, D_m, are listed in Table 21.

Table 21. Variables for calculation of fraction of mean fatigue life expended at a specific fatigue prone detail, D_m

Fraction of truck traffic (p)	0.8
Resistance factor for mean fatigue life) for E' detail (R_R)	1.9
Ratio of measured to calculated stress range (P)	0.6
Multiple presence factor (R_p)	0.998005
Average daily truck traffic (ADTT)	2809
Number of lanes (n_L)	4

By substituting Eq. 5.9 in Eq. 5.8, the D_m results in:

$$D_m = \frac{p}{R_R * A} * \left(\frac{GDF*(1+IM)*P*R_p}{S}\right)^3 * NM_{eff}^{\ 3} \quad (5.13)$$

By substituting all the values from Table 19, Table 21 and ∑ D for (NM_{eff}^3) for the year 2014 from Table 20 in Eq. 5.13, the fraction of mean fatigue life expended, D_m, at the upstream cover plate end is 0.0099. The calculated D_m can be interpreted by comparing with a design life of the bridge to the estimated amount of damage it accumulated in a year. For instance, if a bridge is designed for 75 years, then 1/75 (which is 0.0133) is more than the calculated damage 0.0099 indicating the rate of damage accumulation is lesser than anticipated during the design.

Also, a demonstration of damage accumulated from WIM traffic relative to AASHTO fatigue design truck for WIM station 931 for the year 2014 is shown here. The damage accumulation index, α is calculated from Eq. 5.11 for a Span 86-W that has an approximate span length of 60 ft. ∑ D for the year 2014 and T are shown in Table 20. NM_{eff}^3 values for the fatigue truck for various span lengths are shown in Appendix D, and the one corresponding to 60 ft span length is 7.23E+07. By substituting all these values in Eq. 5.11, the damage accumulation index, α is 0.66. This indicates that the damage accumulated from the WIM trucks is 34% less than the damage accumulated from an equal number of crossings of the AASHTO fatigue design truck. So, the AASHTO fatigue design truck captures the fatigue damage caused by the traffic at WIM site 931. D_m and α for the traffic from other WIM stations for the year 2014 and for the same Span 86-W bridge are shown in Table 22.

Table 22. D_m and α for the traffic in all WIM Sites in the state of Alabama for the year 2014

WIM Site	No. records (T)	ADTT	R_p	$NMeff^3$ (cycles(kip-ft)^3)	D_m	α
911	181387	755	1.000	5.26E+12	0.0013	0.40
931	842972	2809	1.006	4.05E+13	0.0099	0.66
933	358308	1216	1.000	9.18E+12	0.0022	0.35
934	84034	2092	1.003	3.60E+12	0.0009	0.59
942	376148	1667	1.001	7.58E+12	0.0018	0.28
960	628916	787	1.000	1.21E+13	0.0029	0.27
961	306640	2862	1.006	1.80E+13	0.0044	0.81
964	304904	829	1.000	8.32E+12	0.0020	0.38

Also, the effective moment, M_{eff} and a number of cycles, N, for all the WIM locations for the years 2014 to 2016 are listed in Appendix C. The tables in Appendix C are separated based on directions (Lane 1 & 2 in one direction, Lane 3 & 4 in other direction) and results are calculated for standard span lengths of 30, 60, 90, 120 and 200 ft. Also, results for Class 0 vehicles are listed in separate tables.

5.9. Fraction of mean fatigue life expended at a specific fatigue prone detail (Dm) for AISI short span steel bridges

AISI Short-Span Steel Bridges (American Iron and Steel Institute 1995) has real-life bridge design examples of composite rolled beams with welded cover plates. To evaluate the fraction of mean fatigue life expended at a specific fatigue prone detail (D_m), analyses were performed for the bottom flange of the girder at the mid-span (transverse stiffener fillet welds, detail category Type C') and cover plate ends (detail category Type E') at the upstream and downstream locations for some of these example bridge designs. Span lengths of 60, 90 and 120 ft were selected. Descriptive information for the composite rolled beams with a welded cover plate for the selected bridge span lengths is shown in Table 23. More in-depth design details of each span length are in Appendix G.

Table 23. Composite rolled beams with a welded cover plate from AISI (American Iron and Steel Institute 1995)

		Cover plate		
Span (ft)	**Beam cross-section**	**Thickness x Width (in)**	**Location (in)**	**Girder spacing (ft)**
60	W 33x118	3/4 x 9 -1/2	5.5	10
90	W 40x183	1-1/2 x 10	9.5	10
120	W 36x300	2 x 14	14.5	10

Using the designs from AISI and WIM data for all the WIM stations, the mean fatigue life expended by a specific fatigue prone detail (D_m) is calculated using the procedure shown in section 5.5. The results are shown in Figure 40 to Figure 47 for the traffic in two different directions (Lane 1 & 2 in one direction, Lane 3 & 4 in other direction) for the bottom flange of the girder at the mid-span (transverse stiffener fillet welds, detail category Type C') and cover plate ends (detail category Type E') for the year 2014 and 2015.

In Figure 40 to Figure 47, the dashed red colored line at 0.0133 marks the fraction 1/75corresponding to one year of 75-year design life. If the calculated D_m is more than 0.0133, it indicates that the rate of damage accumulation is more than anticipated during the design. The plots show that the bridge design life is consumed up to four times faster than expected if the bridge experiences the truck traffic that was recorded at WIM site 931 (Athens). It is used up two times faster if the truck traffic is similar to WIM records collected at WIM sites 942 (Pine Level) and 961 (Mobile). For the traffic recorded at the other WIM sites, the fatigue life of the standard bridge details investigated is greater than 75 years.

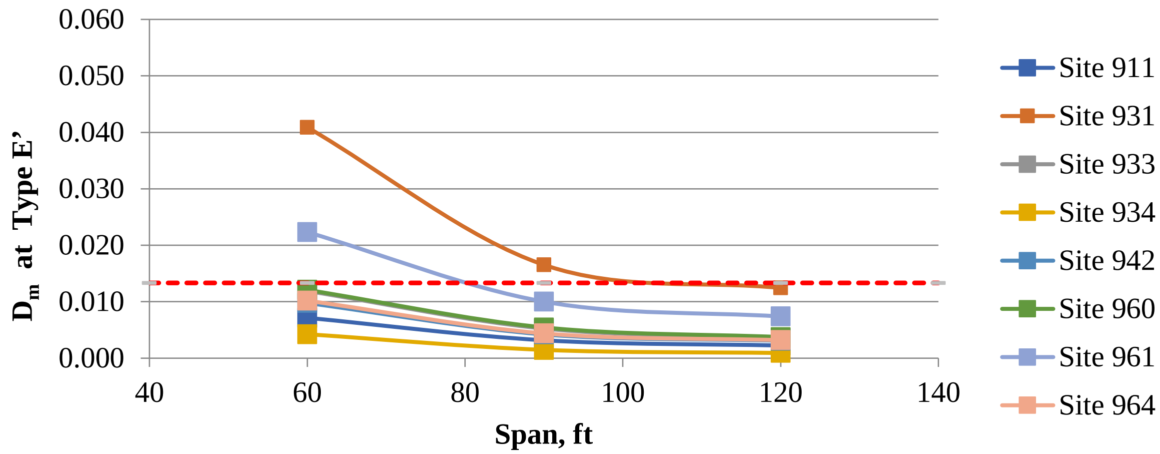


Figure 40. D_m at upstream cover plate end (Lane 1 & 2, year 2014)

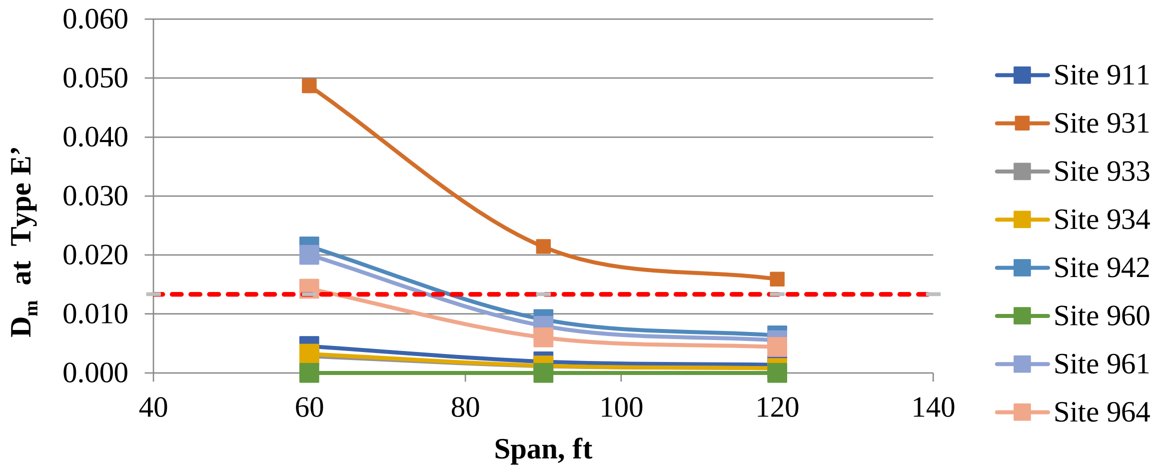


Figure 41. D_m at upstream cover plate end (Lane 3 & 4, year 2014)

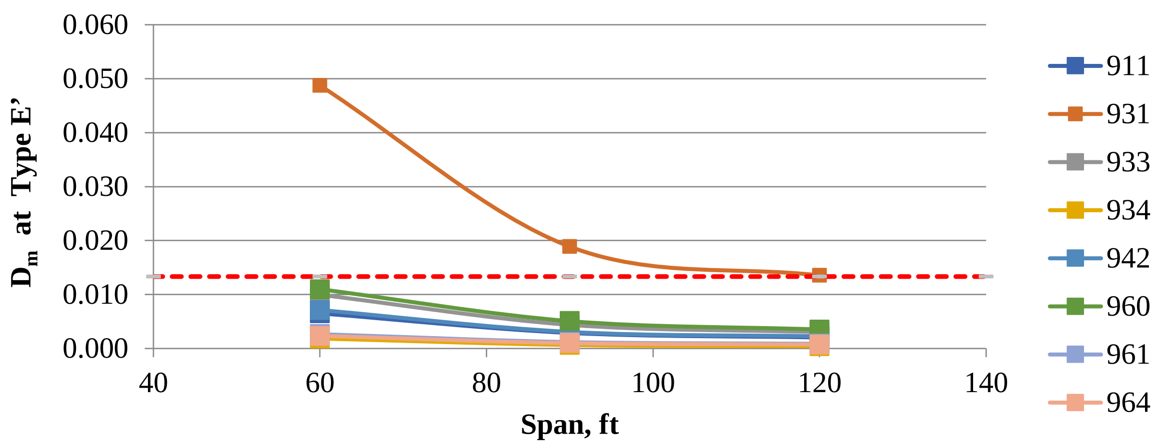


Figure 42. D_m at upstream cover plate end (Lane 1 & 2, year 2015)

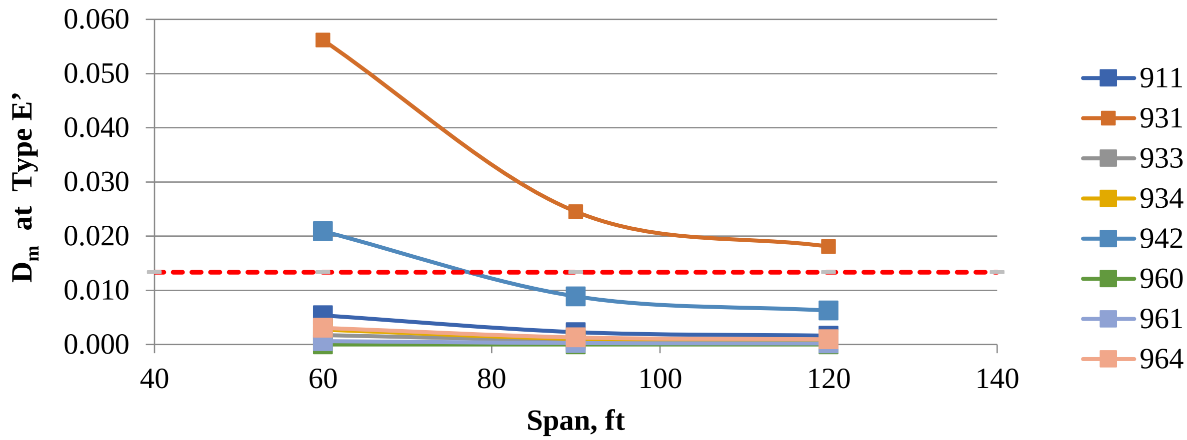


Figure 43. D_m at upstream cover plate end (Lane 3 & 4, year 2015)

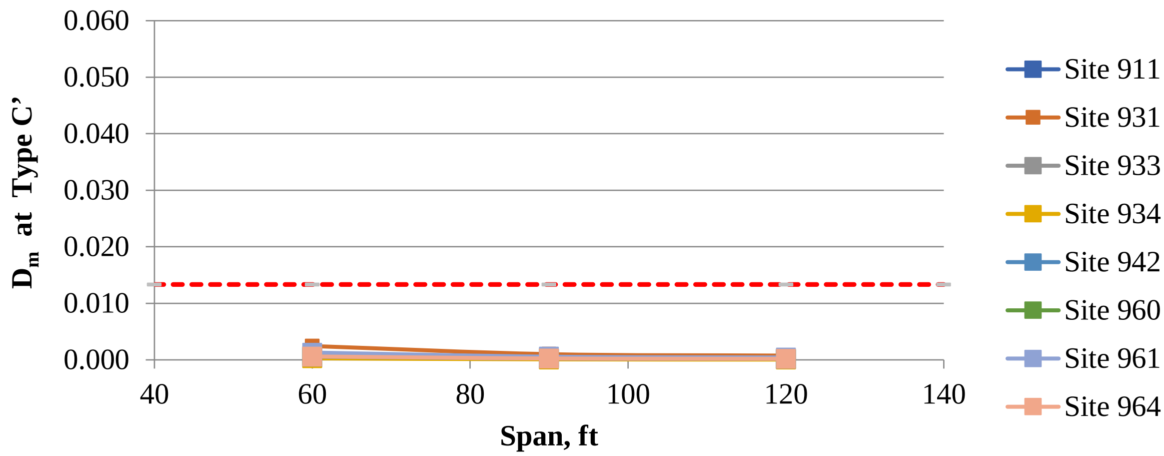


Figure 44. D_m at mid span (Lane 1 & 2, year 2014)

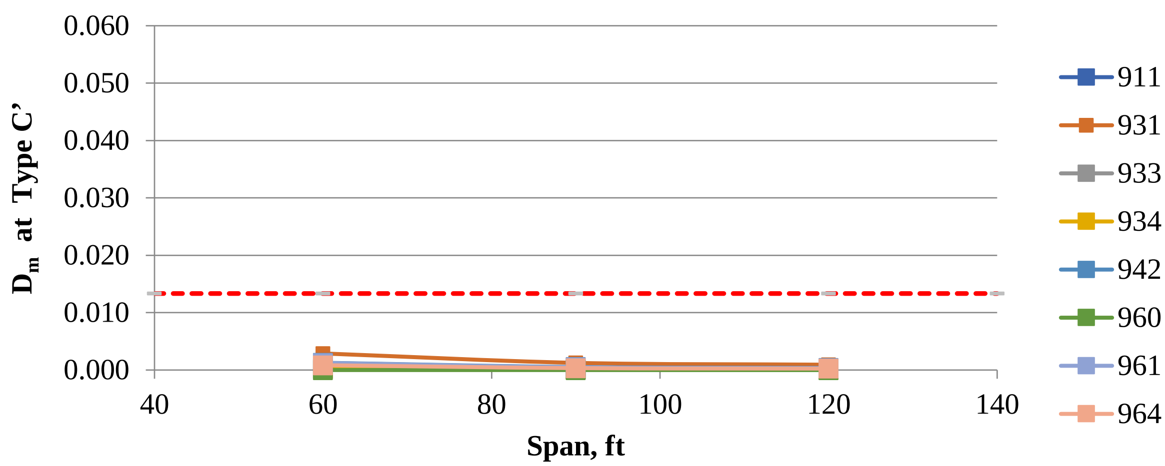


Figure 45. D_m at mid span (Lane 3 & 4, year 2014)

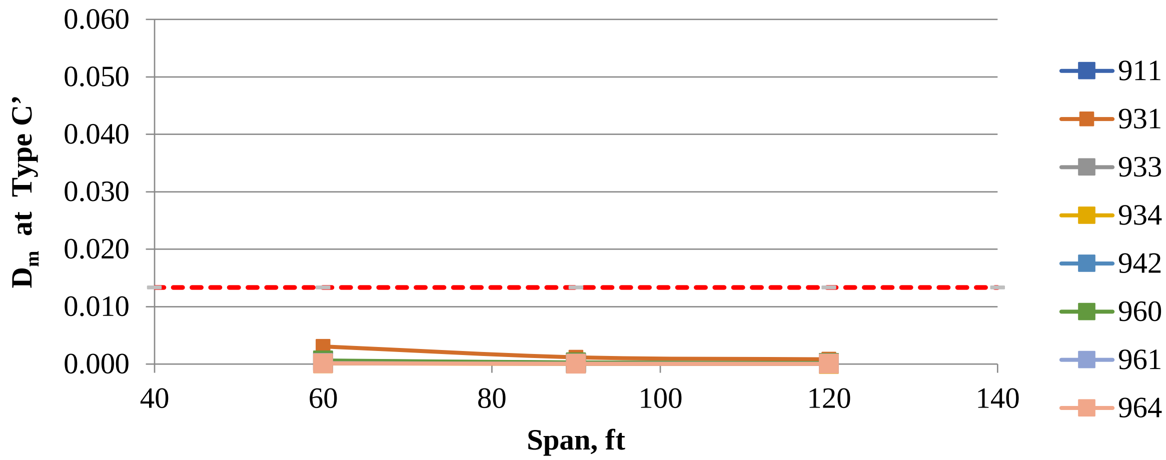


Figure 46. D_m at mid span (Lane 1 & 2, year 2015)

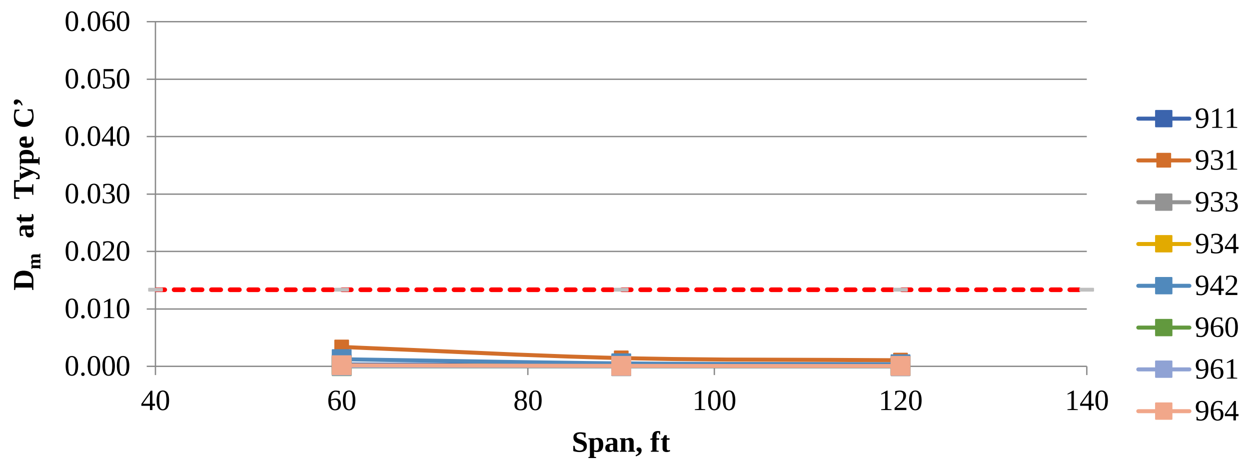


Figure 47. D_m at mid span (Lane 3 & 4, year 2015

5.10. Summary and Conclusions

A methodology was developed for using WIM data to calculate the amount of fatigue damage accumulated in steel girder bridges due to real traffic. Previous research has shown that steel girder bridges on Alabama highways experience stress ranges at bottom flange cover plate ends that are large enough to eventually cause fatigue cracking. So, cover plate ends were a focus of the work presented here.

The methodology is robust because it allows comparisons of the traffic at various locations, comparisons of real traffic to design assumptions, and comparisons of the damage caused by individual trucks. Results presented show that the traffic recorded at some sites are more damaging than assumed in design, especially at sites 931 and 961. Overloaded trucks are a significant source of the damage. Trucks with overweight permits do not contribute significantly to the total accumulated damage. At sites where 20%

or more of the trucks are overloaded, the overloaded trucks produce more fatigue damage than the legal traffic. Considering all data from all WIM sites for 2014 and 2015, 2.5% of the trucks are overloaded so that they do not meet ALDOT criteria for a permit, and those trucks produce more than 40% of the fatigue damage.

CHAPTER 6 IDENTIFYING PRIORITIES FOR WIM SITES UPGRADE

6.1. Introduction

Data collected from WIM sites in the state of Alabama are used for various purposes within the ALDOT. Identifying priorities for WIM sites upgrade or selection of new WM sites becomes challenging due to limited resources. A common rule adopted by many state agencies to prioritize WIM sites is by traffic volume at a particular route and economic activities. Montana Department of Transportation (MDT) uses a list of evaluation criteria such as traffic factor groups, roadway condition and enforcement activities to select a WIM and ATR station (Stephens et al. 2017).

By reviewing the available literature, there were no methodologies available to identify priorities of WIM sites other than the one used by MDT. The approach presented here is novel and it can aid ALODT in efficiently allocating funds. The sites selected here as priorities for upgrade are based on QC analysis of the WIM data, frequency of overloaded vehicles and damage caused by the overloaded vehicles. The candidate WIM sites selected here as priorities for an upgrade can be upgraded to virtual WIM stations, change in the type of WIM system or replacing the existing WIM system. Upgrading to virtual WIM stations can help ALDOT in effective enforcement. Some of the existing WIM systems can be upgraded to more robust and accurate WIM systems that are available in the market. The site selection for a new WIM station may affect the quality of WIM data being recorded. Factors to consider when selecting a new WIM location are discussed in *WIM Data Analyst Manual* (Quinley 2010a).

6.2. Critical WIM sited based on the QC analysis

Based on the quality control analysis (Chapter 3) the WIM location 918 and 963 data is poor quality. The QC procedure indicated the malfunctioning of those systems. Repair, replacement or upgrade of those systems is recommended. The QC procedure developed in this project can identify problems with the WIM systems that occur in the future. It is recommended that the QC procedure be used on a monthly basis using the standalone application ALDOT_WIM_QC v1.0.

6.3. Critical WIM sited based on the weight permit violation

The identification of issued permits in the WIM data was attempted for the years 2014 and 2015 using the procedures described in Chapter 4. The number of overloaded vehicles at WIM location 931 and 961 were higher compared to other location throughout the state. Also, the number of vehicles that obtained a permit when compared to the number of vehicles that required a permit was higher. Upgrading these WIM stations to Virtual Weigh stations can help in effective enforcement along those routes.

6.4. Critical WIM sited based on the damage accumulation index

The damage accumulation procedures developed in this project were applied to data from all the WIM locations. From the results shown in Chapter 5, the damage accumulated in bridges along the routes of WIM location 931 and 961 is higher compared to other locations within the state of Alabama. Additional WIM locations along near those locations and upgrading to Virtual Weigh stations can help in effective enforcement along those routes.

CHAPTER 7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1. Summary

Knowledge of current live loads helps in day-to-day planned maintenance of bridges and pavements and law enforcement efforts. Each heavy truck traveling across a bridge contributes to the accumulated damage, or expenditure of the life, of the bridge. WIM provides an excellent source to study truck loads and their effects on bridges.

The main objective of this project is to develop procedures to evaluate the traffic induced damage to bridges by the use of WIM data that can be implemented by ALDOT in day-to-day maintenance activities. The objectives also include the improvement of the procedures used to process raw WIM data, development of a procedure to evaluate the quality of the WIM data, development of a procedure to identify vehicles with permits issued by ALDOT in the WIM database, and development of procedures to convert the WIM measurements into an index of accumulated damage for bridges along the route. Also, the developed procedures are used to identify priorities for the upgrade of WIM stations to Virtual Weigh Stations.

WIM data from 12 WIM stations for the years 2014 to 2016 was provided to the research team by ALDOT. Also, issued permit data for the years 2014 and 2015 was provided. WIM data was encrypted and shared in raw format which was free from any pre-filtering and representing the whole traffic database at the respective WIM station. The WIM system vendor's iAnalyze software was used to decrypt the WIM data. The steps of WIM data conversion are shown in Figure 4.

The first step of WIM data analysis is to evaluate the quality of the WIM data. A quality control procedure was developed to check the quality of the traffic data and detect the root cause of questionable recorded traffic data. Inconsistency in recording due to communication failure, operational problems with the sensor and drift in calibration can be interpreted using the proposed procedure. The proposed procedure consists of a completeness check, logical checks, and statistical checks. A review of the literature to identify the state-of-the-art was performed, and the database of issued permits is used to establish limits for threshold parameters.

Issued permit data from ALDOT for the year 2014 and 2015 were reviewed. The data contained both overweight and over dimension permits. A filtering procedure was developed to filter over dimensional permits and retain only overweight permits. An analytical procedure to identify legal, permitted and illegal vehicles in the WIM records was developed.

Traffic-induced loads can cause damage to bridges by fatigue and overload. Steel bridges are more prone to fatigue compared to other types of bridges. A procedure to evaluate damage accumulation in steel bridges was developed. The procedure can be used to assess WIM site-specific damage or bridge specific damage. WIM site-specific damage was used to make comparisons such as which of the WIM sites has the most damaging traffic and what types of trucks cause the most fatigue damage. Bridge specific damage includes assessing the damage at a fatigue prone detail in a particular bridge, and quantifying the relative damage of specific trucks such as the ALDOT rating trucks with respect to the AASHTO fatigue design truck.

Two computer apps were developed for implementation by ALDOT of the developed procedures. The computer app, ALDOT_WIM_QC v1.0, can be used to evaluate the quality of the WIM data and maintain the "health" of WIM systems. Another application, ALDOT_WIM_DAI v1.0, can be used to evaluate the fatigue damage in a steel girder bridge due to the traffic recorded at the WIM site. The results of the fatigue damage calculations can be used to evaluate the significance of the truck traffic along various routes and the impact of the various FHWA Vehicle Classes on the total damage. The results of the fatigue damage accumulation calculations can also be used as a part of the evaluation of existing bridges.

7.2. Conclusions

Based on the results of analyses and procedures developed in this project, the following conclusions are made:

1. The developed QC procedures identified malfunctioning of two WIM stations, 918 (Bucksville) and 963 (Grand Bay), and these stations are recommended for repair or replacement.
2. The developed logical check was found to be an effective QC procedure. It identified the malfunctioning of WIM site 918 (Bucksville). WIM data recorded at station 918 was excluded from further analysis.
3. The developed statistical check was found to be an effective procedure. It identified the malfunctioning of the sensor at WIM station 963 (Grand Bay). Truck statistics for that site were significantly different from other locations. Thus, WIM data recorded at this station is questionable. WIM data recorded at station 963 was excluded from further analysis.
4. It was found that less than 0.5% of overweight vehicles operate with a permit based on the combined WIM and issued permit data for 2014 and 2015.
5. WIM location 931 (Athens) accumulated the most fatigue damage in 2014 and 2015 followed by 961 (Mobile) in 2014 and 942 (Pine Level) in 2015.

6. Based on the combined WIM data, 20% of the vehicles are overloaded, and they cause more than 50% of the total fatigue damage.
7. WIM sites 931(Athens), 960 (Whatley) and 961 (Mobile) have the highest percentage of overweight vehicles.
8. Vehicles with a permit and those that meet permit criteria do less fatigue damage than either legal or illegal vehicles.
9. The 16-18% of trucks that are illegally overloaded create more than 40% of the total damage.
10. 5-axle Class 9 trucks cause more than 70% of fatigue damage.
11. For traffic recorded at WIM site 931 (Athens), the fatigue life of steel girder bridges is consumed four times faster than expected for a design life of 75 years. For traffic recorded at WIM sites other than 931 (Athens), 942 (Pine Level) and 961 (Mobile), the fatigue life of steel girder bridges is consumed slower than expected for a design life of 75 years.
12. WIM station 931 (Athens) and 961 (Mobile) are recommended for an upgrade to Virtual Weigh stations because of the high number of illegal vehicles and bridge fatigue life is being expended faster than expected during design.

7.3. Recommendations

The main recommendation is to revise the current permit fees and structure, and license fees to assign fair costs for overweight transporters and to the public. The other recommendations based on the results presented in this report include:

1. It is recommended to do a monthly QC check of the WIM data using the computer app ALDOT_WIM_QC for timely identification of malfunctioning systems.
2. It is recommended to share images from virtual WIM station to further improve the soundness of the QC procedure.
3. ALDOT_WIM_DAI can provide significant information about the impact of traffic and damage accumulated on the bridge, so it is recommended to use on a routine basis.
4. It is recommended to perform an analysis similar to the evaluation of a Span 86-W bridge that is shown in the report can be done for the bridges along the route of WIM station locations.
5. The developed procedures can be used by ALDOT’s bridge analysis and management systems to provide a continuously updated accounting of the fatigue damage being accumulated in each of Alabama’s bridges for which fatigue failure is a significant concern.
6. It is recommended to install more WIM stations to effectively capture the traffic in every region throughout the state.

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APPENDIX A : VEHICLE CLASS DESCRIPTION OF STATE OF ALABAMA ON STATE HIGHWAYS

File: al_state Classification Table Printed on: 2018-02-21 09:48:05

Compliance data is available. Tandem spacing is 8.00 ft or less.
Tridem spacing is 11.00 ft or less with equal spacing tolerance less than 0.33 ft and equal weight tolerance n/a.
Quadrem spacing is unused.
Class table has classes 0-13 and 27 vehicle type definitions. Error vehicles are class 0.
Unclassified vehicles are 0.
Autocal vehicle definition is type 18.

Weights are in pounds and lengths are in feet.

Page 1

Axles / Axle	Class / Type	Cpl-Table / SpacingRange	Gross Weight / Axle Weight	Loop Detuning Groups	Overall length	Front overhang	Rear overhang
2	1	THE ACTUAL DAT	any	any	any	any	any
A1	x	NO	min-3500				
A2	x	min-5.84	any				
2	2		any	any	any	any	any
A1	s	NO	min-3500				
A2	s	5.84-10.00	any				
2	3		any	any	any	any	any
A1	s	NO	min-3500				
A2	s	10.00-20.00	any				
3	2		any	any	any	any	any
A1	s	NO	min-3500				
A2	s	min-10.00	any				
A3	s	min-20.00	any				
4	2		any	any	any	any	any
A1	s	NO	min-3500				
A2	s	min-10.00	any				
A3	d	min-20.00	any				
A4	d	min-4.00	any				
3	3		any	any	any	any	any
A1	s	NO	min-3500				
A2	s	10.00-max	any				
A3	s	min-20.00	any				
4	3		any	any	any	any	any
A1	s	NO	min-4409				
A2	s	10.00-max	any				
A3	d	min-20.00	any				
A4	d	min-4.00	any				
2	5		any	any	any	any	any
A1	s	YES/1	3500-max				
A2	s	min-20.00	any				
2	4		any	any	any	any	any
A1	s	YES/1	3500-max				
A2	s	20.00-max	any				
3	6		any	any	any	any	any
A1	s	YES/1	any				
A2	d	min-20.00	any				
A3	d	min-5.84	any				
3	8		any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-20.00	any				
A3	x	5.84-max	any				
3	4		any	any	any	any	any
A1	x	YES/1	any				
A2	x	20.00-max	any				
A3	x	any	any				

4	7		any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-9.84	any				
A4	x	min-5.84	any				

Axles	Class	Cpl-Table	Gross Weight	Loop Detuning	Overall length	Front overhang	Rear overhang
Axle	Type	SpacingRange	Axle Weight	Groups			
4	7		any	any	any	any	any
A1	d	YES/1	any				
A2	d	min-5.84	any				
A3	d	any	any				
A4	d	min-5.84	any				
5	7		any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-5.84	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
6	7		any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-5.84	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
A6	x	min-5.84	any				
4	8		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
5	9		any	any	any	any	any
A1	s	YES/1	any				
A2	d	any	any				
A3	d	min-5.84	any				
A4	x	any	any				
A5	x	min-11.68	any				
5	11 Auto		any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-14.17	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
5	9		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
6	10		any	any	any	any	any
A1	s	YES/1	any				
A2	d	any	any				
A3	d	min-5.84	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
6	10		any	any	any	any	any
A1	s	YES/1	any				
A2	s	any	any				
A3	x	any	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
A6	x	min-5.84	any				
6	12		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				

Axles Axle	Class Type	Cpl-Table SpacingRange	Gross Weight Axle Weight	Loop Detuning Groups	Overall length	Front overhang	Rear overhang
7	13		any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-14.17	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
7	13		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
8	13		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
A8	x	any	any				
9	13		any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
A8	x	any	any				
A9	x	any	any				

There are 8 subtables.

Weights are in pounds and lengths are in feet.

Distance	Single	Tandem	Tridem	Axle limit	Group limit

Table 1 is used 1 time and has 1 line
and is named 'Tandem Table - use 8ft value in 2 Axle table'

n/a	n/a	n/a	n/a	n/a	39600

Table 2 is used 1 time and has 1 line
and is named 'Tridem Table - use 11ft value in 3 axle table'

n/a	n/a	n/a	n/a	n/a	48400

Table 3 is used 1 time and has 1 line
and is named 'GVW Table'

n/a	n/a	n/a	n/a	n/a	92400

Table 4 is used 1 time and has 3 lines
and is named '2 Axle Table'

min-8.00	n/a	n/a	n/a	n/a	39600
8.00-9.00	n/a	n/a	n/a	n/a	41800
9.00-10.00	n/a	n/a	n/a	n/a	44000

Table 5 is used 1 time and has 22 lines
and is named '3 Axle Table'

min-8.00	n/a	n/a	n/a	n/a	46200
8.00-9.00	n/a	n/a	n/a	n/a	46748
9.00-10.00	n/a	n/a	n/a	n/a	47849
10.00-11.00	n/a	n/a	n/a	n/a	48400
11.00-12.00	n/a	n/a	n/a	n/a	49500
12.00-13.00	n/a	n/a	n/a	n/a	50049
13.00-14.00	n/a	n/a	n/a	n/a	51149
14.00-15.00	n/a	n/a	n/a	n/a	51700
15.00-16.00	n/a	n/a	n/a	n/a	52800
16.00-17.00	n/a	n/a	n/a	n/a	53349
17.00-18.00	n/a	n/a	n/a	n/a	54449
18.00-19.00	n/a	n/a	n/a	n/a	55000
19.00-20.00	n/a	n/a	n/a	n/a	56100
20.00-21.00	n/a	n/a	n/a	n/a	56649
21.00-22.00	n/a	n/a	n/a	n/a	57750
22.00-23.00	n/a	n/a	n/a	n/a	58300
23.00-24.00	n/a	n/a	n/a	n/a	59400
24.00-25.00	n/a	n/a	n/a	n/a	59950
25.00-26.00	n/a	n/a	n/a	n/a	61600
26.00-27.00	n/a	n/a	n/a	n/a	62700
27.00-28.00	n/a	n/a	n/a	n/a	64900
28.00-29.00	n/a	n/a	n/a	n/a	66000

Distance	Single	Tandem	Tridem	Axle limit	Group limit
Table 6 is used 1 time and has 37 lines and is named '4 Axle Table'					
min-8.00	n/a	n/a	n/a	n/a	46200
8.00-9.00	n/a	n/a	n/a	n/a	46748
9.00-10.00	n/a	n/a	n/a	n/a	47849
10.00-11.00	n/a	n/a	n/a	n/a	48400
11.00-12.00	n/a	n/a	n/a	n/a	55000
12.00-13.00	n/a	n/a	n/a	n/a	55549
13.00-14.00	n/a	n/a	n/a	n/a	56649
14.00-15.00	n/a	n/a	n/a	n/a	57200
15.00-16.00	n/a	n/a	n/a	n/a	57750
16.00-17.00	n/a	n/a	n/a	n/a	58850
17.00-18.00	n/a	n/a	n/a	n/a	59400
18.00-19.00	n/a	n/a	n/a	n/a	59950
19.00-20.00	n/a	n/a	n/a	n/a	61050
20.00-21.00	n/a	n/a	n/a	n/a	61600
21.00-22.00	n/a	n/a	n/a	n/a	62150
22.00-23.00	n/a	n/a	n/a	n/a	63250
23.00-24.00	n/a	n/a	n/a	n/a	63800
24.00-25.00	n/a	n/a	n/a	n/a	64350
25.00-26.00	n/a	n/a	n/a	n/a	65450
26.00-27.00	n/a	n/a	n/a	n/a	66000
27.00-28.00	n/a	n/a	n/a	n/a	66550
28.00-29.00	n/a	n/a	n/a	n/a	67650
29.00-30.00	n/a	n/a	n/a	n/a	68200
30.00-31.00	n/a	n/a	n/a	n/a	69848
31.00-32.00	n/a	n/a	n/a	n/a	70949
32.00-33.00	n/a	n/a	n/a	n/a	71500
33.00-34.00	n/a	n/a	n/a	n/a	72049
34.00-35.00	n/a	n/a	n/a	n/a	73149
35.00-36.00	n/a	n/a	n/a	n/a	73700
36.00-37.00	n/a	n/a	n/a	n/a	74800
37.00-38.00	n/a	n/a	n/a	n/a	75900
38.00-39.00	n/a	n/a	n/a	n/a	77000
39.00-40.00	n/a	n/a	n/a	n/a	78100
40.00-41.00	n/a	n/a	n/a	n/a	79200
41.00-42.00	n/a	n/a	n/a	n/a	80300
42.00-43.00	n/a	n/a	n/a	n/a	81400
43.00-44.00	n/a	n/a	n/a	n/a	82500
Table 7 is used 1 time and has 33 lines and is named '5 Axle Table'					
min-12.00	n/a	n/a	n/a	n/a	55000
12.00-13.00	n/a	n/a	n/a	n/a	55549
13.00-14.00	n/a	n/a	n/a	n/a	56649
14.00-15.00	n/a	n/a	n/a	n/a	57200
15.00-16.00	n/a	n/a	n/a	n/a	63800
16.00-17.00	n/a	n/a	n/a	n/a	64350
17.00-18.00	n/a	n/a	n/a	n/a	64900
18.00-19.00	n/a	n/a	n/a	n/a	66000
19.00-20.00	n/a	n/a	n/a	n/a	66550
20.00-21.00	n/a	n/a	n/a	n/a	67100
21.00-22.00	n/a	n/a	n/a	n/a	67650
22.00-23.00	n/a	n/a	n/a	n/a	68748
23.00-24.00	n/a	n/a	n/a	n/a	69300
24.00-25.00	n/a	n/a	n/a	n/a	69848
25.00-26.00	n/a	n/a	n/a	n/a	70400
26.00-27.00	n/a	n/a	n/a	n/a	71500
27.00-28.00	n/a	n/a	n/a	n/a	72049
28.00-29.00	n/a	n/a	n/a	n/a	72600
29.00-30.00	n/a	n/a	n/a	n/a	73149
30.00-31.00	n/a	n/a	n/a	n/a	73700
31.00-32.00	n/a	n/a	n/a	n/a	74800
32.00-33.00	n/a	n/a	n/a	n/a	75900
33.00-34.00	n/a	n/a	n/a	n/a	77000
34.00-35.00	n/a	n/a	n/a	n/a	78100
35.00-36.00	n/a	n/a	n/a	n/a	79200
36.00-37.00	n/a	n/a	n/a	n/a	80300
37.00-38.00	n/a	n/a	n/a	n/a	81400
38.00-39.00	n/a	n/a	n/a	n/a	82500
39.00-40.00	n/a	n/a	n/a	n/a	83600
40.00-41.00	n/a	n/a	n/a	n/a	84700
41.00-42.00	n/a	n/a	n/a	n/a	85800
42.00-43.00	n/a	n/a	n/a	n/a	86900
43.00-44.00	n/a	n/a	n/a	n/a	88000

Table 8 is used 1 time and has 29 lines
and is named '6 Axle Table'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
min-16.00	n/a	n/a	n/a	n/a	63800
16.00-17.00	n/a	n/a	n/a	n/a	64350
17.00-18.00	n/a	n/a	n/a	n/a	64900
18.00-19.00	n/a	n/a	n/a	n/a	66000
19.00-20.00	n/a	n/a	n/a	n/a	72600
20.00-21.00	n/a	n/a	n/a	n/a	73149
21.00-22.00	n/a	n/a	n/a	n/a	73700
22.00-23.00	n/a	n/a	n/a	n/a	74800
23.00-24.00	n/a	n/a	n/a	n/a	75349
24.00-25.00	n/a	n/a	n/a	n/a	75900
25.00-26.00	n/a	n/a	n/a	n/a	76449
26.00-27.00	n/a	n/a	n/a	n/a	77000
27.00-28.00	n/a	n/a	n/a	n/a	78100
28.00-29.00	n/a	n/a	n/a	n/a	78649
29.00-30.00	n/a	n/a	n/a	n/a	79200
30.00-31.00	n/a	n/a	n/a	n/a	79749
31.00-32.00	n/a	n/a	n/a	n/a	80850
32.00-33.00	n/a	n/a	n/a	n/a	81400
33.00-34.00	n/a	n/a	n/a	n/a	81950
34.00-35.00	n/a	n/a	n/a	n/a	82500
35.00-36.00	n/a	n/a	n/a	n/a	83600
36.00-37.00	n/a	n/a	n/a	n/a	84700
37.00-38.00	n/a	n/a	n/a	n/a	85800
38.00-39.00	n/a	n/a	n/a	n/a	86900
39.00-40.00	n/a	n/a	n/a	n/a	88000
40.00-41.00	n/a	n/a	n/a	n/a	89100
41.00-42.00	n/a	n/a	n/a	n/a	90200
42.00-43.00	n/a	n/a	n/a	n/a	91300
43.00-44.00	n/a	n/a	n/a	n/a	92400

==
There is 1 structure.

Weights are in pounds and lengths are in feet.

Table 1 is used 20 times
Named 'THE ACTUAL DATA IS STARTED HERE'
Steering axle maximum allowed weight of 22000 lb
Single axle maximum allowed weight of 22000 lb Maximum
vehicle length is unused.
Spacing tolerance of is unused. Maximum
kingpin distance is unused. Maximum
vehicle width is unused.

Tandem axle spacing type is 2 OUTER_AXLES_SPC_TYP
Tandem axle balance factor is unused.
Tandem axle spacing table is 1 "Tandem Table - use 8ft value in 2 Axle table"

Tridem axle spacing type is 2 OUTER_AXLES_SPC_TYP
Tridem axle balance factor is unused.
Tridem axle spacing table is 2 "Tridem Table - use 11ft value in 3 axle table" Quadrem

axle spacing type is 0 NO_SPC_TYP

Gross weight spacing type is 0 NO_SPC_TYP Gross
weight spacing table is 3 "GVW Table"

Axle grouping spacing type is 2 OUTER_AXLES_SPC_TYP Axle
grouping grouping type is 2 ADJ_AXLES_GRP_TYP Axle grouping
spacing table 3 axle is 4 "2 Axle Table" Axle grouping
spacing table 4 axle is 5 "3 Axle Table" Axle grouping
spacing table 5 axle is 6 "4 Axle Table" Axle grouping
spacing table 6 axle is 7 "5 Axle Table" Axle grouping
spacing table 7 axle is 8 "6 Axle Table"

APPENDIX B : VEHICLE CLASS DESCRIPTION OF STATE OF ALABAMA ON INTERSTATE

Compliance data is available. Tandem spacing is 8.00 ft or less.
Tridem spacing is 11.00 ft or less with equal spacing tolerance less than 0.33 ft and equal weight tolerance n/a.
Quadrem spacing is unused.
Class table has classes 0-13 and 27 vehicle type definitions. Error vehicles are class 0.
Unclassified vehicles are 0.
Autocal vehicle definition is type 18.

Weights are in pounds and lengths are in feet.

Axles / Axle	Class / Type	Cpl-Table / SpacingRange	Gross Weight / Axle Weight	Loop Detuning Groups	Overall length	Front overhang	Rear overhang
2	1	Type 1	any	any	any	any	any
A1	x	NO	min-3500				
A2	x	min-5.84	any				
2	2	Type 2	any	any	any	any	any
A1	s	NO	min-3500				
A2	s	5.84-10.00	any				
2	3	Type 3	any	any	any	any	any
A1	s	NO	min-3500				
A2	s	10.00-20.00	any				
3	2	Type 4	any	any	any	any	any
A1	s	NO	min-3500				
A2	s	min-10.00	any				
A3	s	min-20.00	any				
4	2	Type 5	any	any	any	any	any
A1	s	NO	min-3500				
A2	s	min-10.00	any				
A3	d	min-20.00	any				
A4	d	min-4.00	any				
3	3	Type 6	any	any	any	any	any
A1	s	NO	min-3500				
A2	s	10.00-max	any				
A3	s	min-20.00	any				
4	3	Type 7	any	any	any	any	any
A1	s	NO	min-4409				
A2	s	10.00-max	any				
A3	d	min-20.00	any				
A4	d	min-4.00	any				
2	5	Type 8	any	any	any	any	any
A1	s	YES/1	3500-max				
A2	s	min-20.00	any				
2	4	Type 9	any	any	any	any	any
A1	s	YES/1	3500-max				
A2	s	20.00-max	any				
3	6	Type 10	any	any	any	any	any
A1	s	YES/1	any				
A2	d	min-20.00	any				
A3	d	min-5.84	any				
3	8	Type 11	any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-20.00	any				
A3	x	5.84-max	any				
3	4	Type 12	any	any	any	any	any
A1	x	YES/1	any				
A2	x	20.00-max	any				
A3	x	any	any				

4	7	Type 13	any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-9.84	any				
A4	x	min-5.84	any				

Axles Axle	Class Type	Cpl-Table SpacingRange	Gross Weight Axle Weight	Loop Detuning Groups	Overall length	Front overhang	Rear overhang
4	7	Type 14	any	any	any	any	any
A1	d	YES/1	any				
A2	d	min-5.84	any				
A3	d	any	any				
A4	d	min-5.84	any				
5	7	Type 15	any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-5.84	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
6	7	Type 16	any	any	any	any	any
A1	s	YES/1	any				
A2	x	any	any				
A3	x	min-5.84	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
A6	x	min-5.84	any				
4	8	Type 17	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
5	9	Type 18	any	any	any	any	any
A1	s	YES/1	any				
A2	d	any	any				
A3	d	min-5.84	any				
A4	x	any	any				
A5	x	min-11.68	any				
5	11 Auto	Type 19	any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-14.17	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
5	9	Type 20	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
6	10	Type 21	any	any	any	any	any
A1	s	YES/1	any				
A2	d	any	any				
A3	d	min-5.84	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
6	10	Type 22	any	any	any	any	any
A1	s	YES/1	any				
A2	s	any	any				
A3	x	any	any				
A4	x	min-5.84	any				
A5	x	min-5.84	any				
A6	x	min-5.84	any				
6	12	Type 23	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				

Axles Axle	Class Type	Cpl-Table SpacingRange	Gross Weight Axle Weight	Loop Detuning Groups	Overall length	Front overhang	Rear overhang
7	13	Type 24	any	any	any	any	any
A1	x	YES/1	any				
A2	x	min-14.17	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
7	13	Type 25	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
8	13	Type 26	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
A8	x	any	any				
9	13	Type 27	any	any	any	any	any
A1	x	YES/1	any				
A2	x	any	any				
A3	x	any	any				
A4	x	any	any				
A5	x	any	any				
A6	x	any	any				
A7	x	any	any				
A8	x	any	any				
A9	x	any	any				

There are 9 subtables.

Weights are in pounds and lengths are in feet.

Distance	Single	Tandem	Tridem	Axle limit	Group limit

Table 1 is used 1 time and has 1 line
and is named 'Tandem table - Value based on 8ft Tandem definition from Randy Braden'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
n/a	n/a	n/a	n/a	n/a	34000

Table 2 is used 1 time and has 1 line
and is named 'Tridem Table - Value based on 11ft Tridem Definition from Randy Braden'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
n/a	n/a	n/a	n/a	n/a	44000

Table 3 is used 1 time and has 1 line
and is named 'GVW Table - Max GVW 80,000 lbs'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
n/a	n/a	n/a	n/a	n/a	80000

Table 4 is used 1 time and has 3 lines
and is named '2 axle group table'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
min-8.04	n/a	n/a	n/a	n/a	38000
8.04-9.00	n/a	n/a	n/a	n/a	39000
9.00-10.00	n/a	n/a	n/a	n/a	40000

Table 5 is used 1 time and has 26 lines
and is named '3 axle group table'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
min-8.00	n/a	n/a	n/a	n/a	34000
8.00-8.04	n/a	n/a	n/a	n/a	42000
8.04-9.00	n/a	n/a	n/a	n/a	42500
9.00-10.00	n/a	n/a	n/a	n/a	43500
10.00-11.00	n/a	n/a	n/a	n/a	44000
11.00-12.00	n/a	n/a	n/a	n/a	45000
12.00-13.00	n/a	n/a	n/a	n/a	45500
13.00-14.00	n/a	n/a	n/a	n/a	46500
14.00-15.00	n/a	n/a	n/a	n/a	47000
15.00-16.00	n/a	n/a	n/a	n/a	48000
16.00-17.00	n/a	n/a	n/a	n/a	48500
17.00-18.00	n/a	n/a	n/a	n/a	49500
18.00-19.00	n/a	n/a	n/a	n/a	50000
19.00-20.00	n/a	n/a	n/a	n/a	51000
20.00-21.00	n/a	n/a	n/a	n/a	51500
21.00-22.00	n/a	n/a	n/a	n/a	52500
22.00-23.00	n/a	n/a	n/a	n/a	53000
23.00-24.00	n/a	n/a	n/a	n/a	54000
24.00-25.00	n/a	n/a	n/a	n/a	54500
25.00-26.00	n/a	n/a	n/a	n/a	55500
26.00-27.00	n/a	n/a	n/a	n/a	56000
27.00-28.00	n/a	n/a	n/a	n/a	57000
28.00-29.00	n/a	n/a	n/a	n/a	57500
29.00-30.00	n/a	n/a	n/a	n/a	58500
30.00-31.00	n/a	n/a	n/a	n/a	59000
31.00-32.00	n/a	n/a	n/a	n/a	60000

Table 6 is used 1 time and has 46 lines
and is named '4 axle group table'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
min-12.00	n/a	n/a	n/a	n/a	50000
12.00-13.00	n/a	n/a	n/a	n/a	50500
13.00-14.00	n/a	n/a	n/a	n/a	51500
14.00-15.00	n/a	n/a	n/a	n/a	52000
15.00-16.00	n/a	n/a	n/a	n/a	52500
16.00-17.00	n/a	n/a	n/a	n/a	53500
17.00-18.00	n/a	n/a	n/a	n/a	54000
18.00-19.00	n/a	n/a	n/a	n/a	54500
19.00-20.00	n/a	n/a	n/a	n/a	55500
20.00-21.00	n/a	n/a	n/a	n/a	56000
21.00-22.00	n/a	n/a	n/a	n/a	56500
22.00-23.00	n/a	n/a	n/a	n/a	57500
23.00-24.00	n/a	n/a	n/a	n/a	58000
24.00-25.00	n/a	n/a	n/a	n/a	58500
25.00-26.00	n/a	n/a	n/a	n/a	59500
26.00-27.00	n/a	n/a	n/a	n/a	60000
27.00-28.00	n/a	n/a	n/a	n/a	60500
28.00-29.00	n/a	n/a	n/a	n/a	61500
29.00-30.00	n/a	n/a	n/a	n/a	62000
30.00-31.00	n/a	n/a	n/a	n/a	62500
31.00-32.00	n/a	n/a	n/a	n/a	63500
32.00-33.00	n/a	n/a	n/a	n/a	64000
33.00-34.00	n/a	n/a	n/a	n/a	64500
34.00-35.00	n/a	n/a	n/a	n/a	65500
35.00-36.00	n/a	n/a	n/a	n/a	66000
36.00-37.00	n/a	n/a	n/a	n/a	66500
37.00-38.00	n/a	n/a	n/a	n/a	67500
38.00-39.00	n/a	n/a	n/a	n/a	68000
39.00-40.00	n/a	n/a	n/a	n/a	68500
40.00-41.00	n/a	n/a	n/a	n/a	69500
41.00-42.00	n/a	n/a	n/a	n/a	70000
42.00-43.00	n/a	n/a	n/a	n/a	70500
43.00-44.00	n/a	n/a	n/a	n/a	71500
44.00-45.00	n/a	n/a	n/a	n/a	72000
45.00-46.00	n/a	n/a	n/a	n/a	72500
46.00-47.00	n/a	n/a	n/a	n/a	73500
47.00-48.00	n/a	n/a	n/a	n/a	74000
48.00-49.00	n/a	n/a	n/a	n/a	74500
49.00-50.00	n/a	n/a	n/a	n/a	75500
50.00-51.00	n/a	n/a	n/a	n/a	76000
51.00-52.00	n/a	n/a	n/a	n/a	76500
52.00-53.00	n/a	n/a	n/a	n/a	77500
53.00-54.00	n/a	n/a	n/a	n/a	78000
54.00-55.00	n/a	n/a	n/a	n/a	78500
55.00-56.00	n/a	n/a	n/a	n/a	79500
56.00-57.00	n/a	n/a	n/a	n/a	80000

Table 7 is used 1 time and has 36 lines
and is named '5 axle table'

min-16.00	n/a	n/a	n/a	n/a	58000
16.00-17.00	n/a	n/a	n/a	n/a	58500
17.00-18.00	n/a	n/a	n/a	n/a	59000
18.00-19.00	n/a	n/a	n/a	n/a	60000
19.00-20.00	n/a	n/a	n/a	n/a	60500
20.00-21.00	n/a	n/a	n/a	n/a	61000
21.00-22.00	n/a	n/a	n/a	n/a	61500
22.00-23.00	n/a	n/a	n/a	n/a	62500
23.00-24.00	n/a	n/a	n/a	n/a	63000
24.00-25.00	n/a	n/a	n/a	n/a	63500
25.00-26.00	n/a	n/a	n/a	n/a	64000
26.00-27.00	n/a	n/a	n/a	n/a	65000
27.00-28.00	n/a	n/a	n/a	n/a	65500
28.00-29.00	n/a	n/a	n/a	n/a	66000
29.00-30.00	n/a	n/a	n/a	n/a	66500
30.00-31.00	n/a	n/a	n/a	n/a	67500
31.00-32.00	n/a	n/a	n/a	n/a	68000
32.00-33.00	n/a	n/a	n/a	n/a	68500
33.00-34.00	n/a	n/a	n/a	n/a	69000
34.00-35.00	n/a	n/a	n/a	n/a	70000
35.00-36.00	n/a	n/a	n/a	n/a	70500
36.00-37.00	n/a	n/a	n/a	n/a	71000
37.00-38.00	n/a	n/a	n/a	n/a	71500
38.00-39.00	n/a	n/a	n/a	n/a	72500
39.00-40.00	n/a	n/a	n/a	n/a	73000
40.00-41.00	n/a	n/a	n/a	n/a	73500
41.00-42.00	n/a	n/a	n/a	n/a	74000
42.00-43.00	n/a	n/a	n/a	n/a	75000
43.00-44.00	n/a	n/a	n/a	n/a	75500
44.00-45.00	n/a	n/a	n/a	n/a	76000
45.00-46.00	n/a	n/a	n/a	n/a	76500
46.00-47.00	n/a	n/a	n/a	n/a	77500
47.00-48.00	n/a	n/a	n/a	n/a	78000
48.00-49.00	n/a	n/a	n/a	n/a	78500
49.00-50.00	n/a	n/a	n/a	n/a	79000
50.00-51.00	n/a	n/a	n/a	n/a	80000

Table 8 is used 1 time and has 24 lines
and is named '6 axle table'

min-20.00	n/a	n/a	n/a	n/a	66000
20.00-21.00	n/a	n/a	n/a	n/a	66500
21.00-22.00	n/a	n/a	n/a	n/a	67000
22.00-23.00	n/a	n/a	n/a	n/a	68000
23.00-24.00	n/a	n/a	n/a	n/a	68500
24.00-25.00	n/a	n/a	n/a	n/a	69000
25.00-26.00	n/a	n/a	n/a	n/a	69500
26.00-27.00	n/a	n/a	n/a	n/a	70000
27.00-28.00	n/a	n/a	n/a	n/a	71000
28.00-29.00	n/a	n/a	n/a	n/a	71500
29.00-30.00	n/a	n/a	n/a	n/a	72000
30.00-31.00	n/a	n/a	n/a	n/a	72500
31.00-32.00	n/a	n/a	n/a	n/a	73000
32.00-33.00	n/a	n/a	n/a	n/a	74000
33.00-34.00	n/a	n/a	n/a	n/a	74500
34.00-35.00	n/a	n/a	n/a	n/a	75000
35.00-36.00	n/a	n/a	n/a	n/a	75500
36.00-37.00	n/a	n/a	n/a	n/a	76000
37.00-38.00	n/a	n/a	n/a	n/a	77000
38.00-39.00	n/a	n/a	n/a	n/a	77500
39.00-40.00	n/a	n/a	n/a	n/a	78000
40.00-41.00	n/a	n/a	n/a	n/a	78500
41.00-42.00	n/a	n/a	n/a	n/a	79000
42.00-43.00	n/a	n/a	n/a	n/a	80000

Table 9 is used 1 time and has 11 lines
and is named '7 axle table'

Distance	Single	Tandem	Tridem	Axle limit	Group limit
min-24.00	n/a	n/a	n/a	n/a	74000
24.00-25.00	n/a	n/a	n/a	n/a	74500
25.00-26.00	n/a	n/a	n/a	n/a	75000
26.00-27.00	n/a	n/a	n/a	n/a	75500
27.00-28.00	n/a	n/a	n/a	n/a	76500
28.00-29.00	n/a	n/a	n/a	n/a	77000
29.00-30.00	n/a	n/a	n/a	n/a	77500
30.00-31.00	n/a	n/a	n/a	n/a	78000
31.00-32.00	n/a	n/a	n/a	n/a	78500
32.00-33.00	n/a	n/a	n/a	n/a	79000
33.00-34.00	n/a	n/a	n/a	n/a	80000

===

There is 1 structure.

Weights are in pounds and lengths are in feet.

Table 1 is used 20 times
Named 'THE ACTUAL DATA IS STARTED HERE'
Steering axle maximum allowed weight of 20000 lb
Single axle maximum allowed weight of 20000 lb
Maximum vehicle length is unused.
Spacing tolerance of is unused. Maximum
kingpin distance is unused. Maximum
vehicle width is unused.

Tandem axle spacing type is 2 OUTER_AXLES_SPC_TYP
Tandem axle balance factor is unused.
Tandem axle spacing table is 1 "Tandem table - Value based on 8ft Tandem definition from Randy Braden"

Tridem axle spacing type is 2 OUTER_AXLES_SPC_TYP
Tridem axle balance factor is unused.
Tridem axle spacing table is 2 "Tridem Table - Value based on 11ft Tridem Definition from Randy Braden"

Quadrem axle spacing type is 0 NO_SPC_TYP

Gross weight spacing type is 0 NO_SPC_TYP
Gross weight spacing table is 3 "GVW Table - Max GVW 80,000 lbs"

Axle grouping spacing type is 2 OUTER_AXLES_SPC_TYP Axle
grouping grouping type is 2 ADJ_AXLES_GRP_TYP
Axle grouping spacing table 3 axle is 4 "2 axle group table"
Axle grouping spacing table 4 axle is 5 "3 axle group table"
Axle grouping spacing table 5 axle is 6 "4 axle group table"
Axle grouping spacing table 6 axle is 7 "5 axle table"
Axle grouping spacing table 7 axle is 8 "6 axle table"

APPENDIX C : EFFECTIVE MOMENT AND NUMBER OF CYCLES FOR THE WIM STATIONS IN ALABAMA FOR THE YEAR 2014-2016

The effective moment (M_{eff}), kip-ft and number of cycles (N) at mid-span and cover plate end created by the traffic from the WIM stations in the state of Alabama are listed in this appendix. The M_{eff} and N are separated per direction. Lane 1 & 2 is one direction and Lane 3 & 4 is in other direction are listed for Class 4-13. Class 0 data is listed separately as lane and direction information is not available. Also, the M_{eff} and N are calculated for standard span lengths 30, 60, 90, 120 and 200 ft.

Table C-24. Number of cycles at mid-span for Lane 1 & 2 (Class 4-13)

Station code	Name	Location	Span, ft	Number of cycles (N), cycles			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	467,752	436,478	534,408	479,546
			60ft	332,033	310,030	375,315	339,126
			90ft	223,331	208,225	251,787	227,781
			120ft	181,515	169,576	207,773	186,288
			200ft	181,392	169,445	207,693	186,177
931	Athens	I65 Limestone Co.	30ft	2,286,106	1,962,140	1,620,244	1,956,163
			60ft	1,588,547	1,372,996	1,135,427	1,365,657
			90ft	1,057,172	927,143	782,738	922,351
			120ft	845,437	749,451	632,166	742,351
			200ft	843,014	744,517	625,253	737,595
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	898,813	885,405	846,717	876,978
			60ft	627,384	616,157	586,846	610,129
			90ft	434,334	423,975	402,340	420,216
			120ft	358,364	352,948	333,173	348,162
			200ft	358,308	352,888	333,093	348,096
934	Sumiton	US78 Walker Co.	30ft	186,779	76,982	117,924	127,228
			60ft	121,570	49,813	76,248	82,544
			90ft	94,269	38,464	58,655	63,796
			120ft	84,412	34,667	53,615	57,565
			200ft	84,169	34,649	53,571	57,463
942	Pine Level	US231 Montgomery Co.	30ft	1,039,188	730,094	753,761	841,014
			60ft	700,418	494,329	511,221	568,656
			90ft	474,271	339,196	360,320	391,262
			120ft	376,514	263,972	272,811	304,432
			200ft	376,243	263,811	272,607	304,220
960	Whatley	US84 Clark Co.	30ft	753,280	704,162	752,137	736,526
			60ft	518,186	481,924	512,209	504,106
			90ft	345,929	319,969	340,754	335,551
			120ft	305,711	282,387	302,203	296,767
			200ft	305,486	282,267	301,892	296,548
961	Mobile	I65 Mobile Co.	30ft	1,733,947	191,857	1,747,517	1,224,440
			60ft	1,178,581	131,306	1,184,616	831,501
			90ft	826,662	92,933	826,088	581,894
			120ft	629,633	70,228	634,264	444,708
			200ft	628,916	70,175	633,339	444,143
964	Ozark	US231 Dothan Co.	30ft	825,688	190,024	743,080	586,264
			60ft	561,416	129,713	504,760	398,630
			90ft	387,611	88,461	342,444	272,839
			120ft	307,010	69,722	273,831	216,854
			200ft	306,642	69,631	273,419	216,564

Table C-25. Effective moment at mid-span for Lane 1 & 2 (Class 4-13)

Station code	Name	Location	Span, ft	Effective moment (M_{eff}), kip-ft			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	149	149	156	151
			60ft	355	354	372	360
			90ft	761	760	801	774
			120ft	1,266	1,263	1,328	1,286
			200ft	2,477	2,471	2,600	2,516
931	Athens	I65 Limestone Co.	30ft	171	176	184	177
			60ft	424	447	472	448
			90ft	875	907	944	909
			120ft	1,463	1,495	1,546	1,502
			200ft	2,872	2,917	3,009	2,933
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	142	139	136	139
			60ft	343	341	335	340
			90ft	741	729	719	730
			120ft	1,217	1,192	1,180	1,196
			200ft	2,363	2,309	2,291	2,321
934	Sumiton	US78 Walker Co.	30ft	162	163	174	166
			60ft	457	458	496	470
			90ft	854	865	945	888
			120ft	1,289	1,306	1,416	1,337
			200ft	2,381	2,418	2,613	2,470
942	Pine Level	US231 Montgomery Co.	30ft	130	130	126	129
			60ft	316	315	306	312
			90ft	667	662	637	655
			120ft	1,134	1,134	1,102	1,123
			200ft	2,243	2,243	2,182	2,223
960	Whatley	US84 Clark Co.	30ft	167	166	167	167
			60ft	404	401	405	403
			90ft	868	871	879	873
			120ft	1,386	1,395	1,404	1,395
			200ft	2,680	2,702	2,717	2,700
961	Mobile	I65 Mobile Co.	30ft	148	154	143	148
			60ft	351	362	341	351
			90ft	742	761	720	741
			120ft	1,278	1,313	1,235	1,275
			200ft	2,526	2,592	2,441	2,520
964	Ozark	US231 Dothan Co.	30ft	146	146	146	146
			60ft	350	348	351	350
			90ft	731	724	732	729
			120ft	1,241	1,239	1,243	1,241
			200ft	2,452	2,461	2,464	2,459

Table C-26. Number of cycles at mid-span for Lane 3 & 4 (Class 4-13)

Station code	Name	Location	Span, ft	Number of cycles (N), cycles			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	451,386	465,366	394,620	437,124
			60ft	318,730	322,260	269,301	303,430
			90ft	215,286	214,309	177,282	202,292
			120ft	177,176	181,108	154,030	170,771
			200ft	176,328	181,012	153,957	170,432
931	Athens	I65 Limestone Co.	30ft	2,015,074	2,087,000	1,953,681	2,018,585
			60ft	1,397,383	1,445,883	1,352,618	1,398,628
			90ft	1,035,292	1,069,849	1,006,747	1,037,296
			120ft	741,967	767,814	724,370	744,717
			200ft	740,688	766,772	722,292	743,251
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	163,037	105,119	41,943	103,366
			60ft	116,261	74,928	30,209	73,799
			90ft	80,097	50,525	19,621	50,081
			120ft	71,755	43,896	16,969	44,207
			200ft	68,735	42,825	16,964	42,841
934	Sumiton	US78 Walker Co.	30ft	197,628	177,690	187,492	187,603
			60ft	125,315	108,081	116,010	116,469
			90ft	97,186	85,592	91,945	91,574
			120ft	85,249	77,472	83,135	81,952
			200ft	85,202	77,432	82,110	81,581
942	Pine Level	US231 Montgomery Co.	30ft	1,081,652	1,125,704	1,168,382	1,125,246
			60ft	759,243	790,499	821,780	790,507
			90ft	527,995	548,212	571,376	549,194
			120ft	411,505	425,601	441,363	426,156
			200ft	411,116	425,261	441,061	425,813
960	Whatley	US84 Clark Co.	30ft	-	-	-	-
			60ft	-	-	-	-
			90ft	-	-	-	-
			120ft	-	-	-	-
			200ft	-	-	-	-
961	Mobile	I65 Mobile Co.	30ft	446,085	126,545	1,324,514	632,381
			60ft	317,625	86,946	908,147	437,573
			90ft	256,600	62,250	659,698	326,183
			120ft	202,922	45,080	469,896	239,299
			200ft	199,207	44,942	468,230	237,460
964	Ozark	US231 Dothan Co.	30ft	901,839	202,088	776,834	626,920
			60ft	623,047	139,235	535,174	432,485
			90ft	436,570	97,111	374,423	302,701
			120ft	335,181	74,642	288,163	232,662
			200ft	334,379	74,509	287,483	232,124

Table C-27. Effective moment at mid-span for Lane 3 & 4 (Class 4-13)

Station code	Name	Location	Span, ft	Effective moment (M_{eff}), kip-ft			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	138	134	136	136
			60ft	344	333	342	340
			90ft	711	711	736	719
			120ft	1,163	1,164	1,191	1,172
			200ft	2,258	2,270	2,316	2,281
931	Athens	I65 Limestone Co.	30ft	178	180	186	181
			60ft	427	431	447	435
			90ft	885	893	915	898
			120ft	1,558	1,574	1,603	1,578
			200ft	3,087	3,121	3,173	3,127
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	201	179	156	178
			60ft	510	451	380	447
			90ft	997	906	827	910
			120ft	1,528	1,418	1,337	1,428
			200ft	2,956	2,730	2,593	2,760
934	Sumiton	US78 Walker Co.	30ft	141	135	158	145
			60ft	387	384	445	405
			90ft	753	743	864	787
			120ft	1,177	1,141	1,321	1,213
			200ft	2,232	2,150	2,498	2,294
942	Pine Level	US231 Montgomery Co.	30ft	162	159	159	160
			60ft	398	389	392	393
			90ft	828	810	815	818
			120ft	1,385	1,360	1,370	1,372
			200ft	2,690	2,646	2,666	2,667
960	Whatley	US84 Clark Co.	30ft	-	-	-	-
			60ft	-	-	-	-
			90ft	-	-	-	-
			120ft	-	-	-	-
			200ft	-	-	-	-
961	Mobile	I65 Mobile Co.	30ft	211	109	109	143
			60ft	531	263	259	351
			90ft	1,024	546	535	702
			120ft	1,695	958	947	1,200
			200ft	3,326	1,901	1,884	2,370
964	Ozark	US231 Dothan Co.	30ft	157	156	157	157
			60ft	379	372	378	376
			90ft	779	768	780	776
			120ft	1,336	1,322	1,339	1,332
			200ft	2,644	2,624	2,653	2,641

Table C-28. Number of cycles at mid-span for Class 0

Station code	Name	Location	Span, ft	Number of cycles (N), cycles			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	434	190	163	262
			60ft	292	107	86	162
			90ft	235	90	75	133
			120ft	222	85	68	125
			200ft	195	52	39	95
931	Athens	I65 Limestone Co.	30ft	1,966	3,586	6,719	4,090
			60ft	1,287	2,611	4,882	2,927
			90ft	1,151	2,358	4,262	2,590
			120ft	1,052	2,271	3,693	2,339
			200ft	807	2,091	3,510	2,136
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	1,410	638	121	723
			60ft	961	432	63	485
			90ft	785	379	60	408
			120ft	673	338	46	352
			200ft	568	271	29	289
934	Sumiton	US78 Walker Co.	30ft	202	190	295	229
			60ft	104	83	203	130
			90ft	87	78	183	116
			120ft	97	98	181	125
			200ft	53	39	146	79
942	Pine Level	US231 Montgomery Co.	30ft	308	250	199	252
			60ft	151	120	98	123
			90ft	145	111	90	115
			120ft	130	105	84	106
			200ft	69	58	47	58
960	Whatley	US84 Clark Co.	30ft	275	173	173	207
			60ft	168	98	95	120
			90ft	154	86	88	109
			120ft	115	75	77	89
			200ft	80	46	41	56
961	Mobile	I65 Mobile Co.	30ft	763	50	273	362
			60ft	486	34	145	222
			90ft	357	24	137	173
			120ft	316	22	131	156
			200ft	256	17	69	114
964	Ozark	US231 Dothan Co.	30ft	230	44	73,586	24,620
			60ft	121	20	50,167	16,769
			90ft	108	18	34,910	11,679
			120ft	107	20	27,042	9,056
			200ft	55	10	26,959	9,008

Table C-29. Effective moment at mid-span for Class 0

Station code	Name	Location	Span, ft	Effective moment (M_{eff}), kip-ft			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	502	203	150	285
			60ft	1,616	647	501	921
			90ft	3,121	1,197	953	1,757
			120ft	4,678	1,825	1,503	2,669
			200ft	9,160	4,602	4,232	5,998
931	Athens	I65 Limestone Co.	30ft	588	719	673	660
			60ft	1,715	2,281	2,054	2,017
			90ft	3,003	4,152	3,795	3,650
			120ft	4,473	6,079	5,822	5,458
			200ft	9,182	11,477	11,032	10,564
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	628	566	193	463
			60ft	2,005	1,818	619	1,481
			90ft	3,802	3,376	1,098	2,759
			120ft	5,872	5,124	1,902	4,300
			200ft	11,741	10,295	5,241	9,093
934	Sumiton	US78 Walker Co.	30ft	136	166	343	215
			60ft	463	547	1,068	693
			90ft	888	1,006	1,991	1,295
			120ft	1,283	1,451	2,961	1,898
			200ft	3,283	4,714	6,133	4,710
942	Pine Level	US231 Montgomery Co.	30ft	205	179	210	198
			60ft	673	584	688	649
			90ft	1,173	1,044	1,205	1,141
			120ft	1,926	1,645	1,902	1,824
			200ft	5,588	4,755	5,432	5,258
960	Whatley	US84 Clark Co.	30ft	259	232	245	245
			60ft	725	720	753	733
			90ft	1,274	1,302	1,334	1,304
			120ft	2,213	2,097	2,195	2,168
			200ft	5,451	5,498	6,179	5,709
961	Mobile	I65 Mobile Co.	30ft	224	106	167	165
			60ft	630	275	522	476
			90ft	1,285	586	915	929
			120ft	2,097	941	1,441	1,493
			200ft	4,609	2,163	4,185	3,652
964	Ozark	US231 Dothan Co.	30ft	293	160	152	202
			60ft	868	521	366	585
			90ft	1,534	978	755	1,089
			120ft	2,347	1,457	1,295	1,700
			200ft	6,498	4,356	2,573	4,476

Table C-30. Number of cycles at cover plate end for Lane 1 & 2 (Class 4-13)

Station code	Name	Location	Span, ft	Number of cycles (N), cycles			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	498,063	466,062	567,539	510,555
			60ft	375,824	351,282	428,317	385,141
			90ft	341,068	318,285	385,533	348,295
			120ft	328,463	305,785	371,237	335,162
			200ft	181,793	169,799	208,061	186,551
931	Athens	I65 Limestone Co.	30ft	2,411,960	2,074,272	1,717,320	2,067,851
			60ft	1,825,471	1,576,870	1,310,930	1,571,090
			90ft	1,609,157	1,392,089	1,151,846	1,384,364
			120ft	1,565,208	1,351,366	1,117,065	1,344,546
			200ft	847,826	752,881	636,467	745,725
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	974,421	958,386	908,780	947,196
			60ft	725,354	711,906	674,564	703,941
			90ft	672,263	660,306	623,283	651,951
			120ft	650,941	640,471	606,564	632,659
			200ft	358,553	353,134	333,443	348,377
934	Sumiton	US78 Walker Co.	30ft	201,114	82,519	126,292	136,642
			60ft	152,267	62,824	98,193	104,428
			90ft	128,650	52,524	81,183	87,452
			120ft	120,884	49,471	73,583	81,313
			200ft	84,622	34,721	53,683	57,675
942	Pine Level	US231 Montgomery Co.	30ft	1,089,886	764,923	791,234	882,014
			60ft	807,038	567,147	589,213	654,466
			90ft	721,439	506,416	522,842	583,566
			120ft	696,149	490,042	504,850	563,680
			200ft	377,490	264,890	273,904	305,428
960	Whatley	US84 Clark Co.	30ft	832,892	781,263	837,210	817,122
			60ft	606,754	567,514	604,305	592,858
			90ft	564,281	526,337	561,457	550,692
			120ft	552,979	517,831	552,118	540,976
			200ft	306,689	283,161	303,045	297,632
961	Mobile	I65 Mobile Co.	30ft	1,825,851	202,847	1,839,279	1,289,326
			60ft	1,335,050	147,876	1,339,453	940,793
			90ft	1,211,801	134,917	1,218,232	854,983
			120ft	1,173,173	130,861	1,181,595	828,543
			200ft	630,751	70,408	635,508	445,556
964	Ozark	US231 Dothan Co.	30ft	871,283	198,734	777,980	615,999
			60ft	649,683	149,887	588,690	462,753
			90ft	575,050	131,291	511,852	406,064
			120ft	554,345	126,820	494,026	391,730
			200ft	307,826	70,094	275,388	217,769

Table C-31. Effective moment at cover plate end for Lane 1 & 2 (Class 4-13)

Station code	**Name**	**Location**	**Span, ft**	**Effective moment (M_{eff}), kip-ft**			**Average**
				2014	**2015**	**2016**	
911	Alex City	US280 Cosa Co.	30ft	96	96	100	97
			60ft	241	241	253	245
			90ft	458	457	482	466
			120ft	697	697	734	709
			200ft	1,623	1,619	1,703	1,648
931	Athens	I65 Limestone Co.	30ft	110	113	118	114
			60ft	281	293	308	294
			90ft	515	533	558	535
			120ft	787	809	843	813
			200ft	1,864	1,888	1,945	1,899
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	92	90	88	90
			60ft	233	230	226	230
			90ft	442	433	426	434
			120ft	669	654	645	656
			200ft	1,549	1,512	1,497	1,520
934	Sumiton	US78 Walker Co.	30ft	106	106	114	109
			60ft	287	290	312	296
			90ft	513	523	569	535
			120ft	752	768	845	788
			200ft	1,546	1,577	1,706	1,610
942	Pine Level	US231 Montgomery Co.	30ft	84	83	81	83
			60ft	211	211	205	209
			90ft	400	400	389	396
			120ft	616	615	599	610
			200ft	1,463	1,464	1,423	1,450
960	Whatley	US84 Clark Co.	30ft	106	106	107	106
			60ft	271	269	271	270
			90ft	511	511	514	512
			120ft	767	767	772	769
			200ft	1,761	1,774	1,782	1,772
961	Mobile	I65 Mobile Co.	30ft	94	97	91	94
			60ft	238	246	231	238
			90ft	454	468	438	454
			120ft	699	719	674	697
			200ft	1,657	1,701	1,599	1,652
964	Ozark	US231 Dothan Co.	30ft	93	93	93	93
			60ft	234	233	234	234
			90ft	445	443	445	444
			120ft	684	682	684	683
			200ft	1,605	1,610	1,610	1,609

Table C-32. Number of cycles at cover plate end for Lane 3 & 4 (Class 4-13)

Station code	**Name**	**Location**	**Span, ft**	**Number of cycles (N), cycles**			**Average**
				2014	**2015**	**2016**	
911	Alex City	US280 Cosa Co.	30ft	475,502	491,423	416,320	461,082
			60ft	362,417	370,784	313,151	348,784
			90ft	328,737	337,241	284,593	316,857
			120ft	315,385	324,780	274,478	304,881
			200ft	177,859	181,330	154,180	171,123
931	Athens	I65 Limestone Co.	30ft	2,120,833	2,195,102	2,053,937	2,123,291
			60ft	1,578,492	1,628,885	1,529,719	1,579,032
			90ft	1,419,448	1,466,632	1,371,008	1,419,029
			120ft	1,380,386	1,427,005	1,334,993	1,380,795
			200ft	742,536	768,605	727,468	746,203
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	175,891	113,593	45,968	111,817
			60ft	136,410	86,070	34,047	85,509
			90ft	125,473	79,303	31,717	78,831
			120ft	121,807	77,479	31,103	76,796
			200ft	73,734	44,448	16,981	45,054
934	Sumiton	US78 Walker Co.	30ft	208,900	186,877	199,321	198,366
			60ft	155,413	141,682	152,417	149,837
			90ft	131,345	116,339	125,097	124,260
			120ft	122,338	107,427	111,354	113,706
			200ft	85,352	77,524	83,668	82,181
942	Pine Level	US231 Montgomery Co.	30ft	1,159,041	1,199,338	1,244,432	1,200,937
			60ft	857,947	887,947	922,009	889,301
			90ft	769,238	801,368	828,734	799,780
			120ft	748,587	778,795	806,824	778,069
			200ft	412,444	426,548	442,531	427,174
960	Whatley	US84 Clark Co.	30ft	-	-	-	-
			60ft	-	-	-	-
			90ft	-	-	-	-
			120ft	-	-	-	-
			200ft	-	-	-	-
961	Mobile	I65 Mobile Co.	30ft	488,498	133,363	1,393,196	671,686
			60ft	374,624	102,622	1,073,332	516,859
			90ft	325,088	86,969	906,791	439,616
			120ft	309,691	84,199	879,641	424,510
			200ft	205,930	45,475	473,800	241,735
964	Ozark	US231 Dothan Co.	30ft	950,825	212,832	819,369	661,009
			60ft	723,292	161,682	622,154	502,376
			90ft	626,397	139,869	536,634	434,300
			120ft	604,542	135,367	519,768	419,892
			200ft	336,662	74,940	289,566	233,723

Table C-33. Effective moment at cover plate end for Lane 3 & 4 (Class 4-13)

Station code	Name	Location	Span, ft	Effective moment (M_{eff}), kip-ft			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	88	87	88	88
			60ft	226	221	226	224
			90ft	418	414	423	418
			120ft	634	632	645	637
			200ft	1,466	1,474	1,501	1,480
931	Athens	I65 Limestone Co.	30ft	114	116	119	116
			60ft	288	291	300	293
			90ft	549	555	569	558
			120ft	847	857	875	860
			200ft	2,018	2,042	2,072	2,044
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	127	114	100	114
			60ft	326	292	252	290
			90ft	580	524	471	525
			120ft	858	779	717	785
			200ft	1,908	1,766	1,680	1,785
934	Sumiton	US78 Walker Co.	30ft	91	89	100	93
			60ft	251	246	282	260
			90ft	465	457	529	484
			120ft	696	682	799	726
			200ft	1,459	1,405	1,625	1,497
942	Pine Level	US231 Montgomery Co.	30ft	104	102	102	103
			60ft	268	262	264	265
			90ft	504	492	496	498
			120ft	761	745	751	752
			200ft	1,763	1,733	1,745	1,747
960	Whatley	US84 Clark Co.	30ft	-	-	-	-
			60ft	-	-	-	-
			90ft	-	-	-	-
			120ft	-	-	-	-
			200ft	-	-	-	-
961	Mobile	I65 Mobile Co.	30ft	133	70	69	91
			60ft	348	177	174	233
			90ft	651	340	337	443
			120ft	988	523	518	676
			200ft	2,156	1,242	1,232	1,543
964	Ozark	US231 Dothan Co.	30ft	101	99	101	100
			60ft	253	249	253	252
			90ft	481	473	481	479
			120ft	738	729	739	735
			200ft	1,731	1,718	1,736	1,728

Table C-34. Number of cycles at cover plate end for Class 0

Station code	Name	Location	Span, ft	Number of cycles (N), cycles			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	497	207	172	121
			60ft	392	169	153	281
			90ft	309	117	89	510
			120ft	252	99	67	770
			200ft	213	67	56	1,480
931	Athens	I65 Limestone Co.	30ft	2,133	3,920	7,323	169
			60ft	1,744	3,175	5,926	392
			90ft	1,336	2,736	5,099	716
			120ft	1,226	2,558	4,794	1,090
			200ft	925	2,213	3,681	2,104
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	1,671	711	128	138
			60ft	1,295	563	101	320
			90ft	1,019	457	68	580
			120ft	906	400	56	872
			200ft	701	322	34	1,665
934	Sumiton	US78 Walker Co.	30ft	214	191	333	127
			60ft	195	177	280	321
			90ft	131	119	225	563
			120ft	95	81	190	820
			200ft	75	63	163	1,521
942	Pine Level	US231 Montgomery Co.	30ft	321	266	217	146
			60ft	278	237	177	340
			90ft	166	148	111	616
			120ft	141	115	93	924
			200ft	101	83	68	1,757
960	Whatley	US84 Clark Co.	30ft	308	180	183	224
			60ft	269	155	148	191
			90ft	178	100	89	122
			120ft	163	92	81	112
			200ft	89	63	56	69
961	Mobile	I65 Mobile Co.	30ft	815	52	283	127
			60ft	701	47	245	298
			90ft	507	37	162	536
			120ft	434	31	137	809
			200ft	304	24	107	1,557
964	Ozark	US231 Dothan Co.	30ft	236	46	77,246	144
			60ft	203	41	58,567	328
			90ft	123	24	50,529	595
			120ft	112	22	48,850	905
			200ft	83	16	27,153	1,750

Table C-35. Effective moment at cover plate end for Class 0

Station code	Name	Location	Span, ft	Effective moment (M_{eff}), kip-ft			Average
				2014	2015	2016	
911	Alex City	US280 Cosa Co.	30ft	317	131	95	137
911	Alex City	US280 Cosa Co.	60ft	954	372	287	315
911	Alex City	US280 Cosa Co.	90ft	1,838	708	603	580
911	Alex City	US280 Cosa Co.	120ft	2,886	1,125	999	872
911	Alex City	US280 Cosa Co.	200ft	5,734	2,787	2,468	1,666
931	Athens	I65 Limestone Co.	30ft	370	455	426	156
931	Athens	I65 Limestone Co.	60ft	1,013	1,395	1,268	370
931	Athens	I65 Limestone Co.	90ft	1,873	2,563	2,337	653
931	Athens	I65 Limestone Co.	120ft	2,784	3,777	3,467	989
931	Athens	I65 Limestone Co.	200ft	5,721	7,252	7,007	1,908
933	Muscle Shoals	AL157 US72 Colbert Co.	30ft	387	357	124	129
933	Muscle Shoals	AL157 US72 Colbert Co.	60ft	1,189	1,095	367	301
933	Muscle Shoals	AL157 US72 Colbert Co.	90ft	2,280	2,067	712	554
933	Muscle Shoals	AL157 US72 Colbert Co.	120ft	3,468	3,144	1,214	827
933	Muscle Shoals	AL157 US72 Colbert Co.	200ft	7,090	6,285	3,313	1,568
934	Sumiton	US78 Walker Co.	30ft	84	106	215	145
934	Sumiton	US78 Walker Co.	60ft	246	296	628	360
934	Sumiton	US78 Walker Co.	90ft	503	589	1,212	615
934	Sumiton	US78 Walker Co.	120ft	841	1,006	1,899	886
934	Sumiton	US78 Walker Co.	200ft	1,920	2,635	3,858	1,621
942	Pine Level	US231 Montgomery Co.	30ft	133	113	133	118
942	Pine Level	US231 Montgomery Co.	60ft	372	317	384	270
942	Pine Level	US231 Montgomery Co.	90ft	761	636	756	493
942	Pine Level	US231 Montgomery Co.	120ft	1,285	1,089	1,246	751
942	Pine Level	US231 Montgomery Co.	200ft	3,301	2,835	3,214	1,456
960	Whatley	US84 Clark Co.	30ft	162	149	157	153
960	Whatley	US84 Clark Co.	60ft	406	411	443	349
960	Whatley	US84 Clark Co.	90ft	839	832	917	644
960	Whatley	US84 Clark Co.	120ft	1,378	1,333	1,493	961
960	Whatley	US84 Clark Co.	200ft	3,557	3,346	3,772	1,815
961	Mobile	I65 Mobile Co.	30ft	142	69	109	134
961	Mobile	I65 Mobile Co.	60ft	377	169	300	304
961	Mobile	I65 Mobile Co.	90ft	776	351	588	561
961	Mobile	I65 Mobile Co.	120ft	1,260	571	986	855
961	Mobile	I65 Mobile Co.	200ft	2,849	1,279	2,444	1,650
964	Ozark	US231 Dothan Co.	30ft	187	102	97	132
964	Ozark	US231 Dothan Co.	60ft	497	276	244	302
964	Ozark	US231 Dothan Co.	90ft	996	588	464	550
964	Ozark	US231 Dothan Co.	120ft	1,570	955	714	836
964	Ozark	US231 Dothan Co.	200ft	3,791	2,490	1,683	1,618

APPENDIX D : EFFECTIVE MOMENT AND NUMBER OF CYCLES OF A RATING TRUCK FOR DIFFERENT SPAN LENGTHS

The effective moment (M_{eff}), kip-ft and number of cycles (N) at mid-span (0.5 L), upstream cover plate end (0.2 L) and downstream cover plate end (0.8 L) created by the AASHTO fatigue design truck are listed in this appendix. Span lengths from 20 to 300 ft with varying increments are considered.

Span length, L [ft]	Location along girder								
	x/L = 0.5			x/L = 0.2			x/L = 0.8		
	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]
20	3	145.14	9.17E+06	3	90.35	2.21E+06	2	103.19	2.20E+06
22	2	177.40	1.12E+07	3	104.86	3.46E+06	2	103.19	2.20E+06
24	2	177.40	1.12E+07	3	119.47	5.12E+06	2	103.19	2.20E+06
26	2	179.44	1.16E+07	3	134.04	7.23E+06	2	129.02	4.29E+06
28	2	185.81	1.28E+07	3	143.10	8.79E+06	2	132.31	4.63E+06
30	2	218.01	2.07E+07	2	152.87	7.15E+06	2	132.31	4.63E+06
32	2	247.58	3.04E+07	2	152.70	7.12E+06	2	140.57	5.55E+06
34	2	240.60	2.79E+07	2	151.13	6.90E+06	2	150.84	6.86E+06
36	2	237.15	2.67E+07	2	151.80	7.00E+06	2	150.84	6.86E+06
38	2	239.63	2.75E+07	2	162.18	8.53E+06	2	157.88	7.87E+06
40	2	266.57	3.79E+07	2	173.97	1.05E+07	2	176.18	1.09E+07
42	2	297.09	5.24E+07	2	187.00	1.31E+07	2	170.36	9.89E+06
44	2	300.28	5.42E+07	2	201.19	1.63E+07	2	199.32	1.58E+07
46	2	304.94	5.67E+07	2	215.10	1.99E+07	2	222.48	2.20E+07
48	2	310.86	6.01E+07	2	233.18	2.54E+07	2	218.22	2.08E+07
50	2	339.59	7.83E+07	2	252.47	3.22E+07	2	243.18	2.88E+07
52	2	371.52	1.03E+08	2	271.92	4.02E+07	2	268.76	3.88E+07
54	2	377.64	1.08E+08	2	291.65	4.96E+07	2	268.31	3.86E+07
56	1	384.00	5.66E+07	2	307.24	5.80E+07	2	288.53	4.80E+07
58	1	400.00	6.40E+07	2	318.78	6.48E+07	2	318.89	6.49E+07
60	1	432.00	8.06E+07	2	330.68	7.23E+07	2	318.89	6.49E+07
62	1	464.00	9.99E+07	2	343.02	8.07E+07	2	333.34	7.41E+07
64	1	480.00	1.11E+08	2	355.74	9.00E+07	2	369.71	1.01E+08
66	1	512.00	1.34E+08	2	368.46	1.00E+08	2	374.88	1.05E+08
68	1	544.00	1.61E+08	2	390.05	1.19E+08	2	384.30	1.14E+08
70	1	576.00	1.91E+08	2	413.04	1.41E+08	2	420.66	1.49E+08
75	1	640.00	2.62E+08	2	470.45	2.08E+08	2	445.63	1.77E+08
80	1	720.00	3.73E+08	2	527.92	2.94E+08	2	496.78	2.45E+08
85	1	784.00	4.82E+08	2	559.53	3.50E+08	2	547.95	3.29E+08
90	1	864.00	6.45E+08	2	591.48	4.14E+08	2	599.12	4.30E+08
95	1	928.00	7.99E+08	2	642.67	5.31E+08	2	650.31	5.50E+08
100	1	1008.00	1.02E+09	2	700.26	6.87E+08	2	675.81	6.17E+08

Span length, L [ft]	Location along girder								
	x/L = 0.5			x/L = 0.2			x/L = 0.8		
	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]	N	M_{eff} [kip-ft]	$D=NM_{eff}^3$ [N(kip-ft)^3]
110	1	1152.00	1.53E+09	2	789.80	9.85E+08	2	778.21	9.43E+08
120	1	1296.00	2.18E+09	2	873.00	1.33E+09	2	880.61	1.37E+09
130	1	1440.00	2.99E+09	2	988.20	1.93E+09	1	957.40	8.78E+08
140	1	1584.00	3.97E+09	1	1052.20	1.16E+09	1	1059.80	1.19E+09
150	1	1728.00	5.16E+09	1	1161.00	1.56E+09	1	1136.60	1.47E+09
160	1	1872.00	6.56E+09	1	1250.60	1.96E+09	1	1239.00	1.90E+09
170	1	2016.00	8.19E+09	1	1333.80	2.37E+09	1	1341.40	2.41E+09
180	1	2160.00	1.01E+10	1	1449.00	3.04E+09	1	1418.20	2.85E+09
190	1	2304.00	1.22E+10	1	1513.00	3.46E+09	1	1520.60	3.52E+09
200	1	2448.00	1.47E+10	1	1621.80	4.27E+09	1	1597.40	4.08E+09
210	1	2592.00	1.74E+10	1	1711.40	5.01E+09	1	1699.80	4.91E+09
220	1	2736.00	2.05E+10	1	1794.60	5.78E+09	1	1802.20	5.85E+09
230	1	2880.00	2.39E+10	1	1909.80	6.97E+09	1	1879.00	6.63E+09
240	1	3024.00	2.77E+10	1	1973.80	7.69E+09	1	1981.40	7.78E+09
250	1	3168.00	3.18E+10	1	2082.60	9.03E+09	1	2058.20	8.72E+09
260	1	3312.00	3.63E+10	1	2172.20	1.02E+10	1	2160.60	1.01E+10
270	1	3456.00	4.13E+10	1	2255.40	1.15E+10	1	2263.00	1.16E+10
280	1	3600.00	4.67E+10	1	2370.60	1.33E+10	1	2339.80	1.28E+10
290	1	3744.00	5.25E+10	1	2434.60	1.44E+10	1	2442.20	1.46E+10
300	1	3888.00	5.88E+10	1	2543.40	1.65E+10	1	2519.00	1.60E+10

APPENDIX E : ALDOT_WIM_QC V1.0 USER MANUAL

Contents

Introduction

Long-term WIM recording is often associated with errors that may occur due to WIM system malfunction, out-of-calibration or irregular vehicle position on the sensor. If an error in recorded WIM data is not recognized and eliminated at the earlier stage, the quality of entire accumulated data is questionable. Therefore, it is essential to use a Quality Control (QC) procedure. The procedure is developed by AU to check the quality of the traffic data and detect the root cause of questionable records. Inconsistency in recording due to communication failure, operational problems with the sensor and drift in calibration can be interpreted from this proposed procedure. The developed algorithm consists of three sets of QC checks: Completeness check, Logical checks and Statistical checks (Figure E-48).

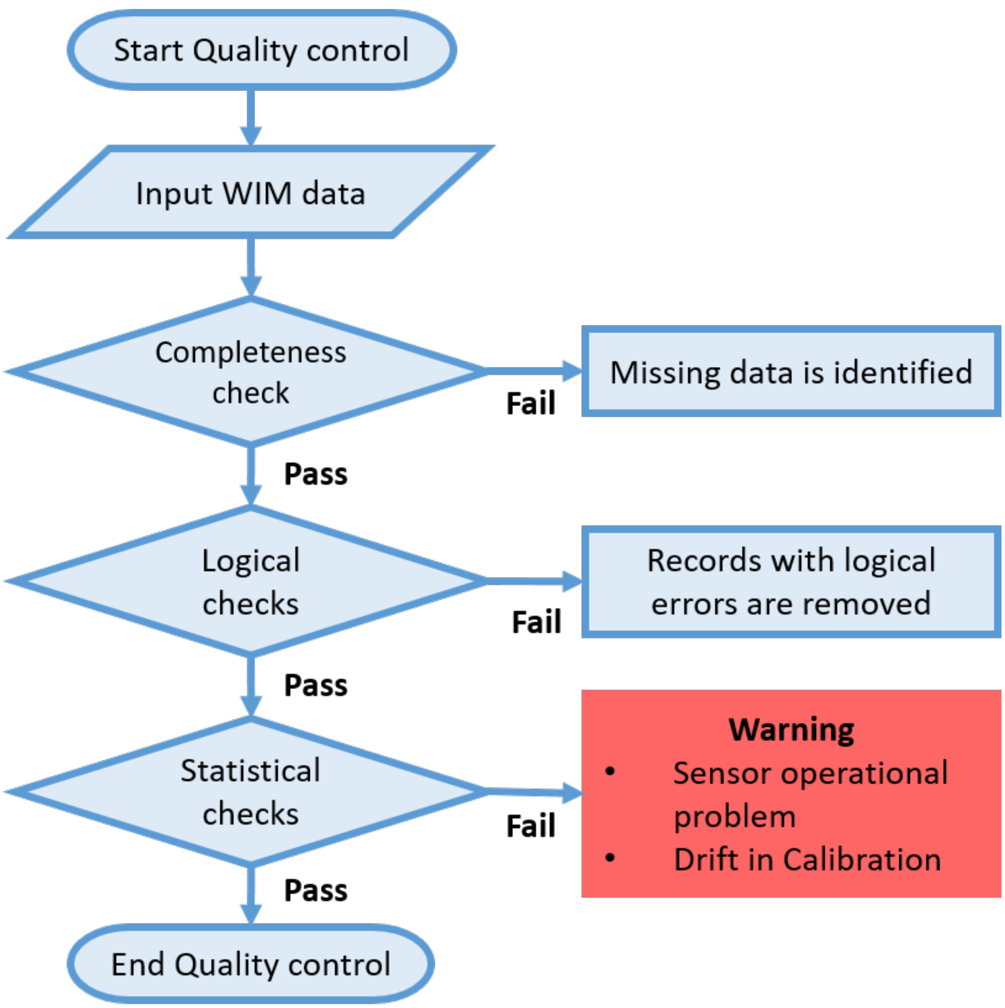


Figure E-48. Quality Control Procedure Flowchart

Completeness check: This missing data is identified and possible cause for missing data can be investigated.

Logical check: This set of filtering criteria, so-called "logical," was developed based on the common practice reported in the literature and modified according to the database of permits issued by ALDOT. In some cases, the current research has identified combinations of QC criteria that can detect certain vehicle configurations that are always recorded incorrectly.

Logical check requirements can be applied instantly once the single-vehicle record is delivered to the database or after a number of vehicle records are accumulated over a period of time. Random and systematic errors are distinguished based on the frequency of violation of a single criterion or a combination of criteria. The systematic errors are usually associated with the malfunctioning of the WIM system, misrecording, non-typical vehicle configuration, or vehicle position with regard to the sensor, and other causes.

Statistical checks: As stated in Traffic Monitoring Guide (2001) the best way to have a reliable record from the WIM sensors is to calibrate the sensors and then compare the output from the sensors and expected weight and volume statistics of the recorded traffic data.

Statistical analysis helps to investigate the possible changes in the traffic mix, GVW and vehicle configurations, and helps to find a possible reason causing an error. Most of the checks are on vehicle class 9 as it is the dominating vehicle class for most of the WIM sites. Until today the statistics developed on vehicle class 9 are being used by many National and State agencies as a way to maintain "health" of the WIM systems.

Statistical checks include a vehicle class distribution check and checks on vehicle class 9 such as GVW check, front axle weight check, axle spacing check and tandem axle load spectra checks.

Chapter 1. Preparing Input Data

The data recorded by WIM sensors are stored in the data storage medium maintained by ALDOT in an encrypted format. The iAnalyze software provided by WIM system vendor International Road Dynamics Inc. (IRD) is used to decrypt WIM data to the desired format. For using it in this application, the Class 0 data is required to be decrypted in IRD ASCII Raw data format (as referred in section D.13.1 of iAnalyze Software operator’s manual) and Class 4-13 in TMG 2001 Truck Weight format (as referred in section D.9.5 of iAnalyze Software operator’s manual). For every WIM site for the selected month and year, there is always two input files, one containing Class 0 data and another containing Class 4-13.

Once the data is decrypted, it has to be renamed in the following format to use in the application and can be stored in the user desired folder.

Class 0 data:

Syntax: **<Year>_<Month>_<WIMID>.csv**

Where,

<Year> is the year of the data

<Month> is the month of the data in number

<WIMID> is WIM station ID used by ALDOT

.csv is an extension of the file type which is saved by default

For example, the WIM data for WIM location 911 for the Year 2018 and Month of January the filename will be **2018_1_911.csv**

Class 4-13 data:

Syntax: **<Year>_<Month>_<WIMID>.WGT**

Where,

<Year> is the year of the data.

<Month> is the month of the data in number.

<WIMID> is WIM station ID used by ALDOT.

.WGT is the extension of the file type which is saved by default

For example, the WIM data for WIM location 911 for the Year 2018 and Month of January the filename will be **2018_1_911.WGT**

Note: It is important that filename of Class 0 data is in .csv and Class 4-13 is in .WGT

Chapter 2. Installing the application

The users are provided with the installation file named "MyApplnstaller_web" as shown in Figure E-49. Once the user double-clicks the installation file, the installation processes start as shown in Figure E-50. The installer will request the path to the installation folder where the application package is stored as shown in Figure E-51. A desktop shortcut can also be created for easier assess. After that *Next* button is clicked.

A Matlab compiler is required to run the application so the dialog box as shown in Figure E-52 is requested and the user is required to click *Install*. After the installation is complete the dialog box as shown in Figure E-53 is seen indicating the successful completion of installation. Click *Finish* to complete the setup.

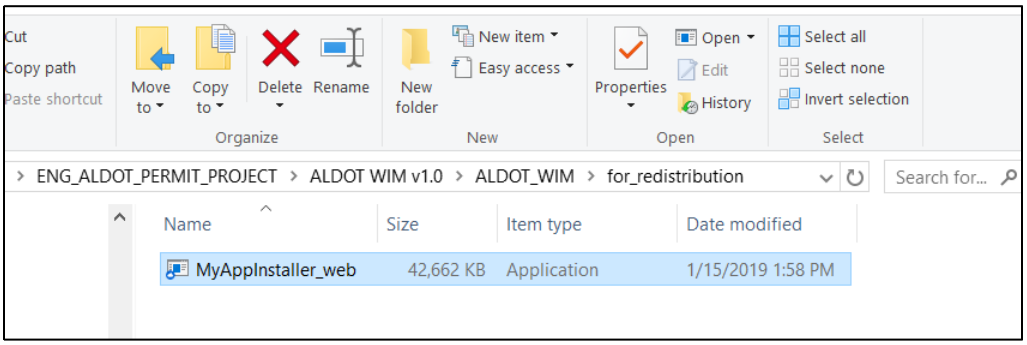


Figure E-49. Redistribution file provided to the user

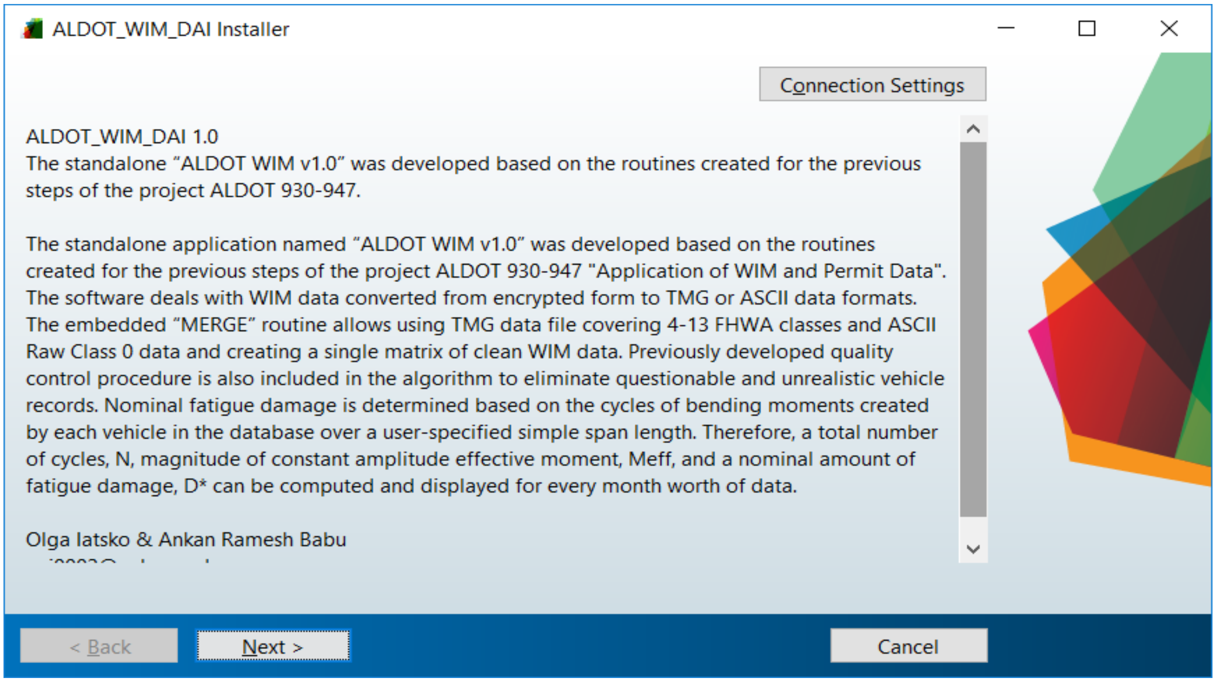


Figure E-50. Application installation startup screen

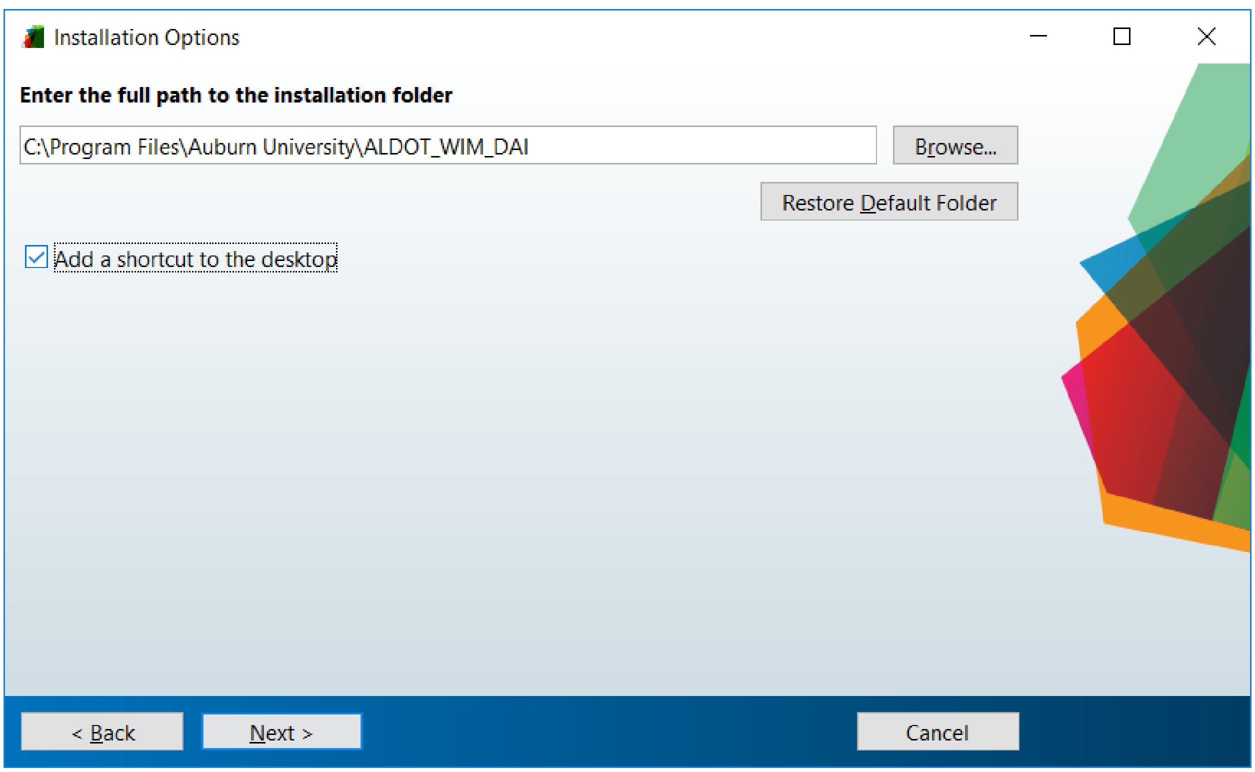


Figure E-51. Installation folder selection

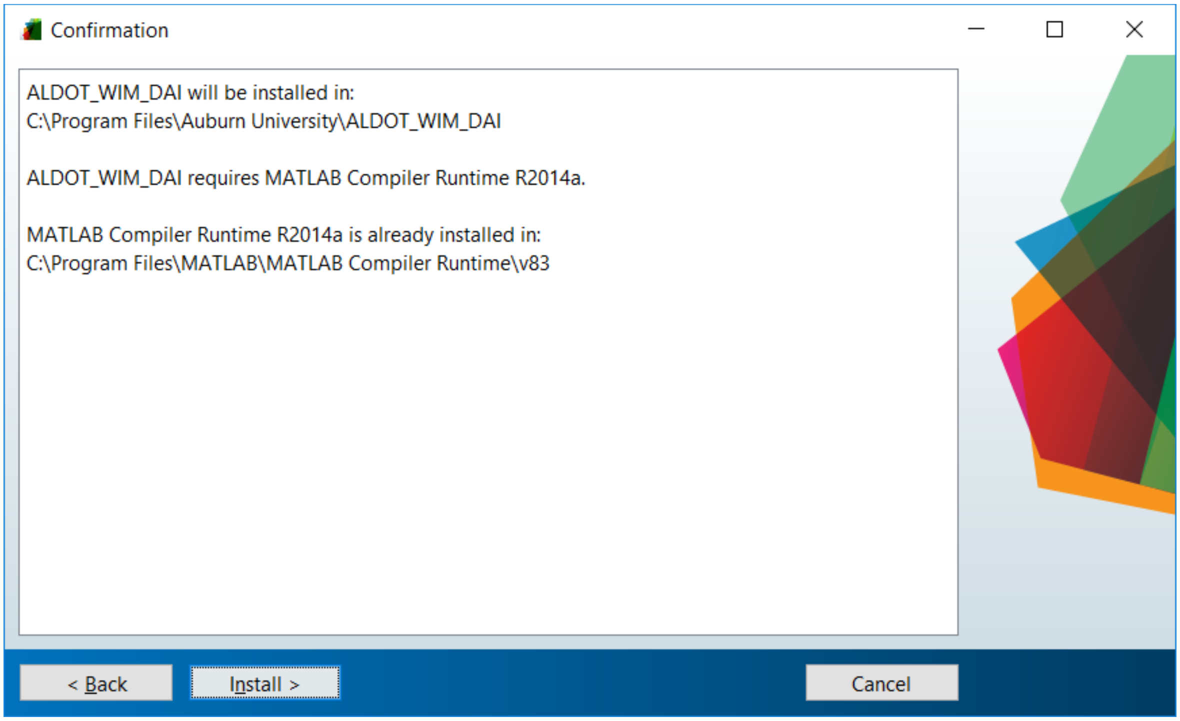


Figure E-52. Installation of MATLAB Compiler Runtime

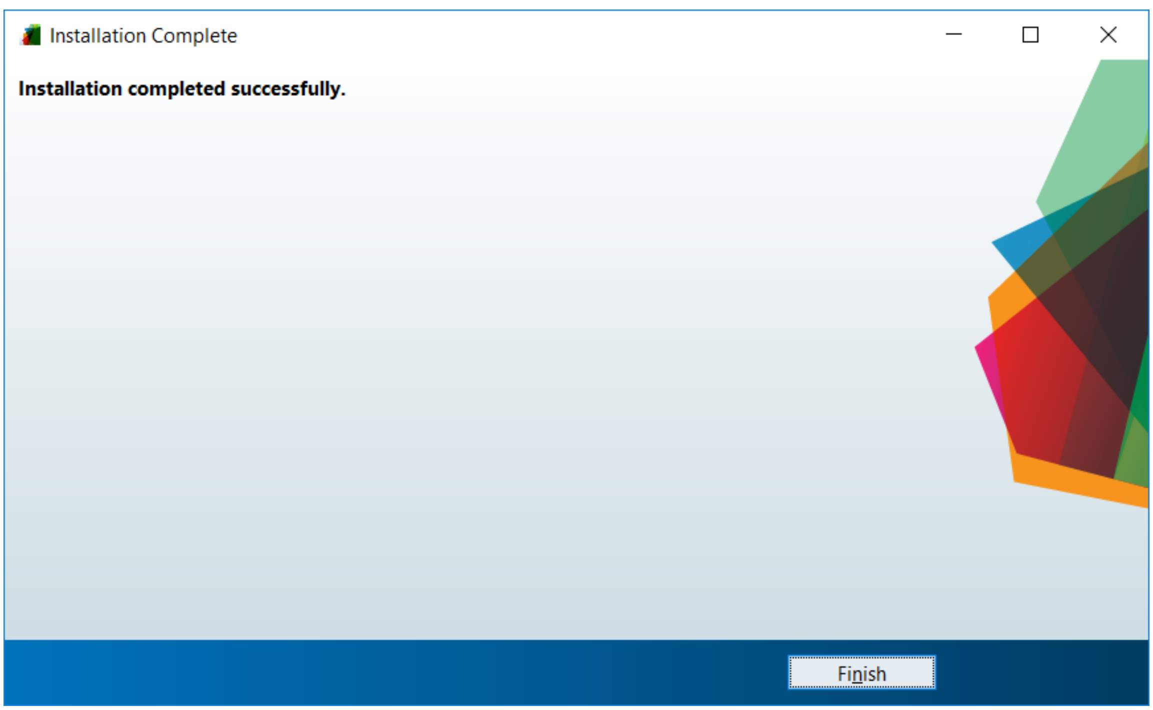


Figure E-53. Installation completed dialog box

Chapter 3. Step-by-step instructions to use application

After installing the application, double-clicking on the desktop shortcut icon opens the application. Alternatively, the application can also be opened by searching in the start menu. The startup screen of the application looks like it is shown in Figure E-54.

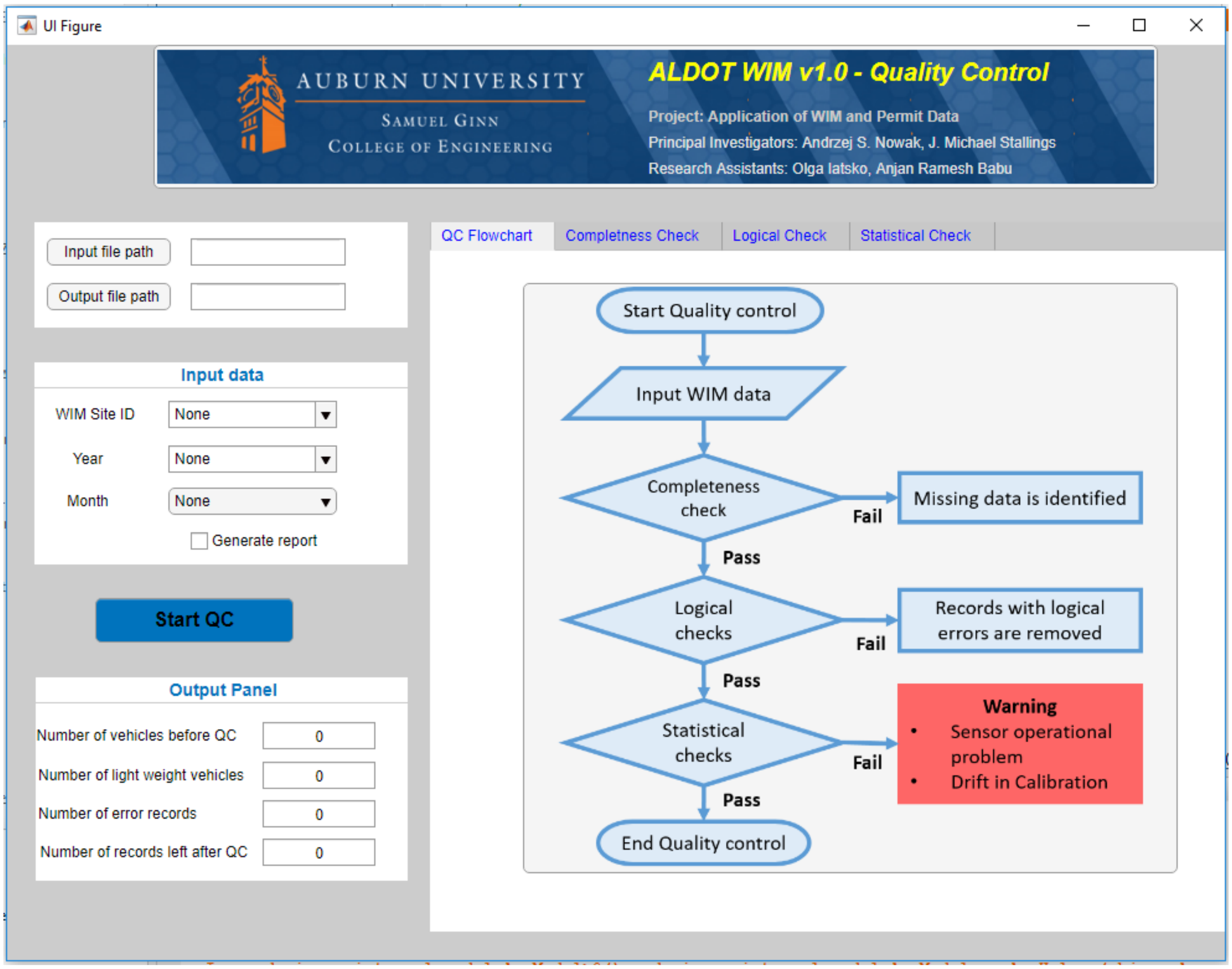


Figure E-54. ALDOT_WIM_QC application startup screen

<u>Step 1:</u> Selecting the input and output file path.

The input and out file path has to be selected by clicking on the button as it is shown in Figure E-55. The *input file path* is the folder where the *renamed Class 0 data in a .csv* format *and Class 4-13 data in .WGT format* is stored. The output folder can be created by clicking on the "output file path" button and once the window pop-ups a new folder can be created by right-clicking the mouse and clicking on *New>>Folder* option. It is recommended to create output folder name in:

<Year>_<Month>_<WIMID> format as shown earlier. The results of the QC of each WIM Site are stored in the form of images in the output folder. Also, the input data compiled of Class 0 and 4-13 are stored.

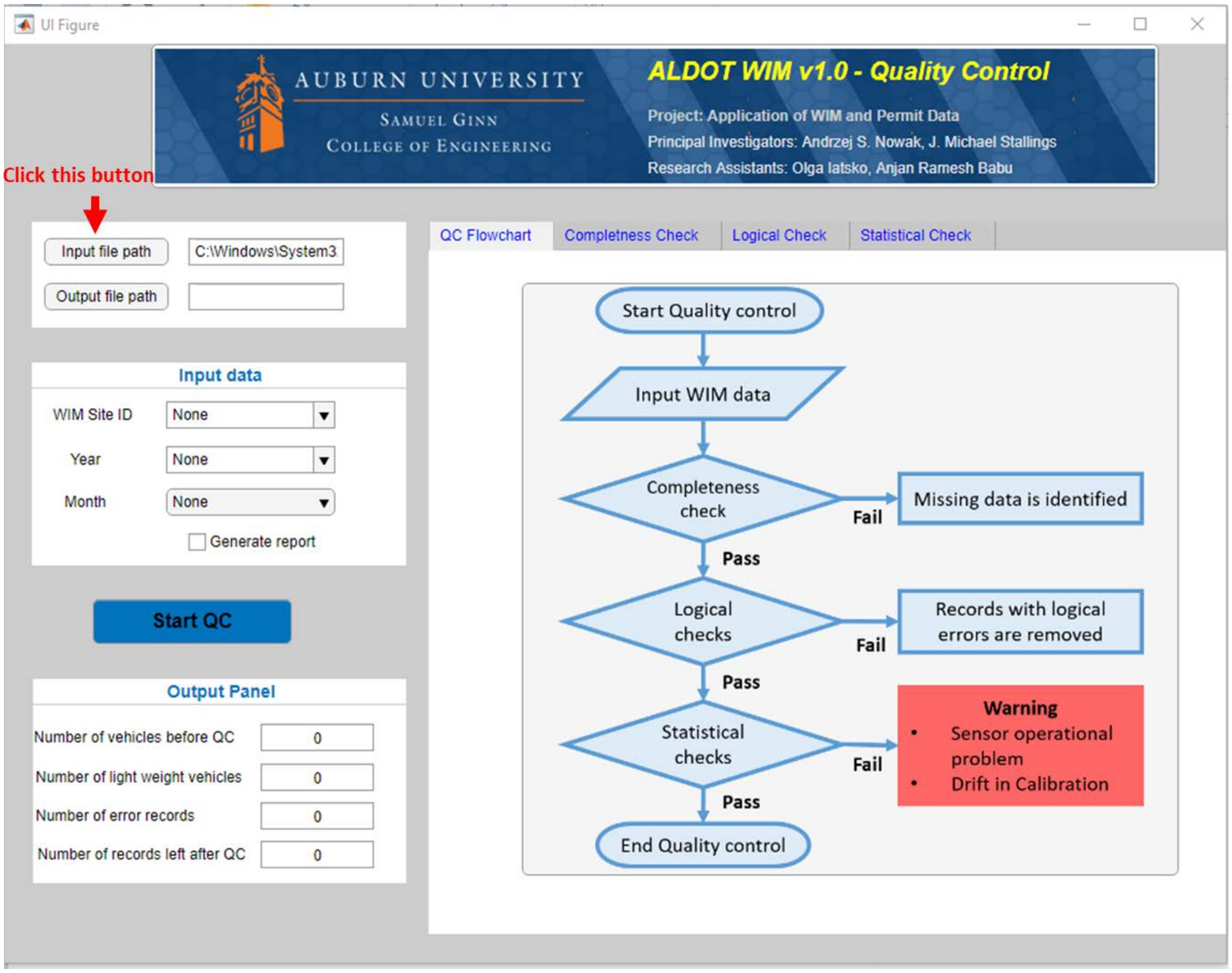


Figure E-55. Selecting input and output file path

Step 2: Inputting the data in *Input Data* panel

The Input Data panel is self-explanatory, the preferred *WIM Site ID* is selected from drop-down menu or by inputting the WIM Station ID. Also, preferred *Year* and *Month* is selected. *Generate report* is selected if needed. An example of a screen after inputting the data is shown in Figure E-56.

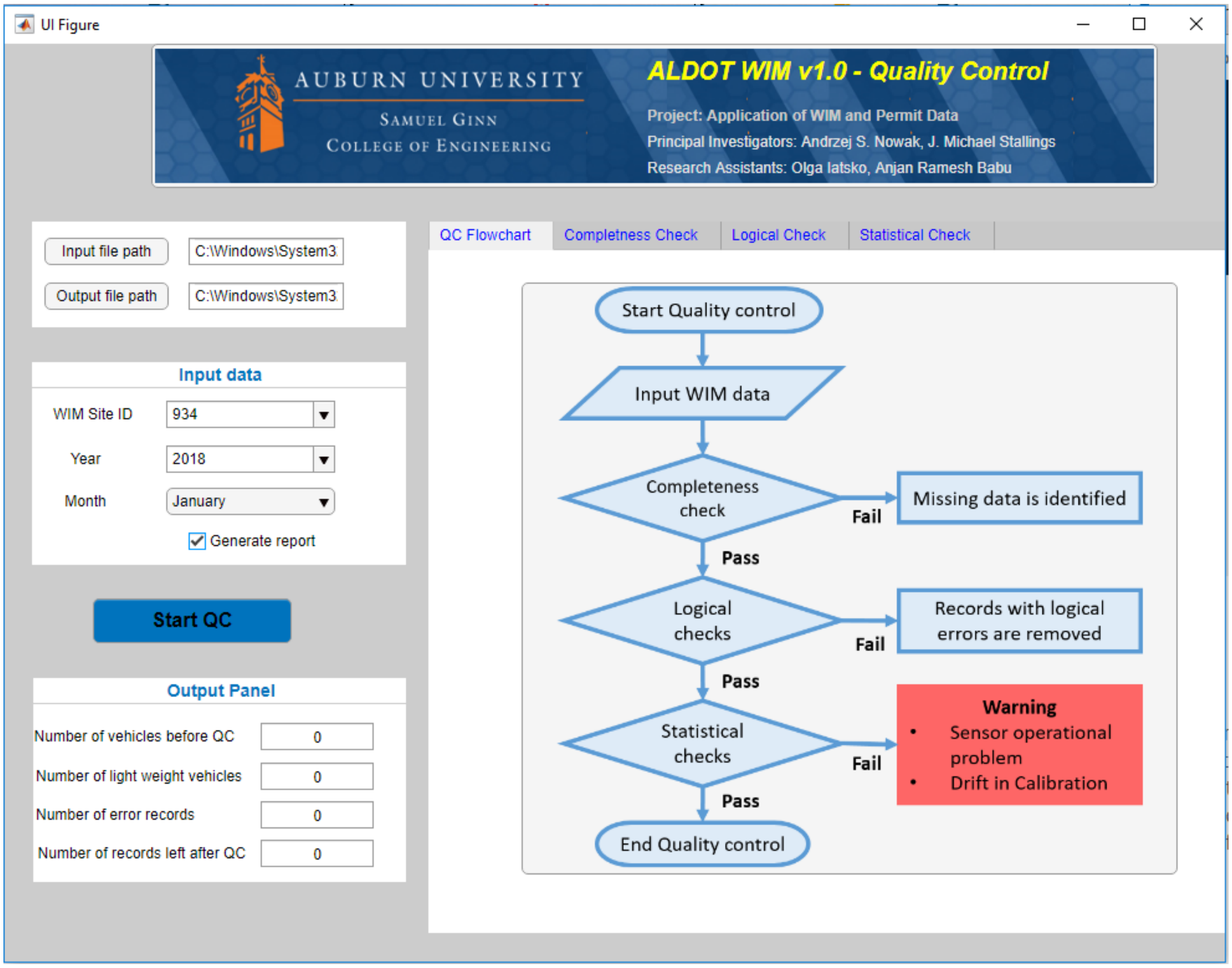


Figure E-56. Inputting the data in *Input Data* panel

<u>Step 3:</u> Starting the Quality Control (QC)

The QC is started once the *Start QC* button is pushed. The wait bar dialog box as shown in Figure E-57 is pop-upped once the *Start QC* button is pushed indicating the progress of the QC. Once the process is complete, the wait bar closed automatically indicating the QC is finished. The interpretation of results is shown in the next chapter.

In case the input data filename is in the wrong format or input data is not in the input file path for the selected WIM Site ID, Year or Month then the error window pop-ups as shown in Figure E-58. For every WIM site for the selected month and year, there is always two input files, one containing Class 0 data and another containing Class 4-13. In case there is no data in Class 0, the iAnalyze creates an empty file.

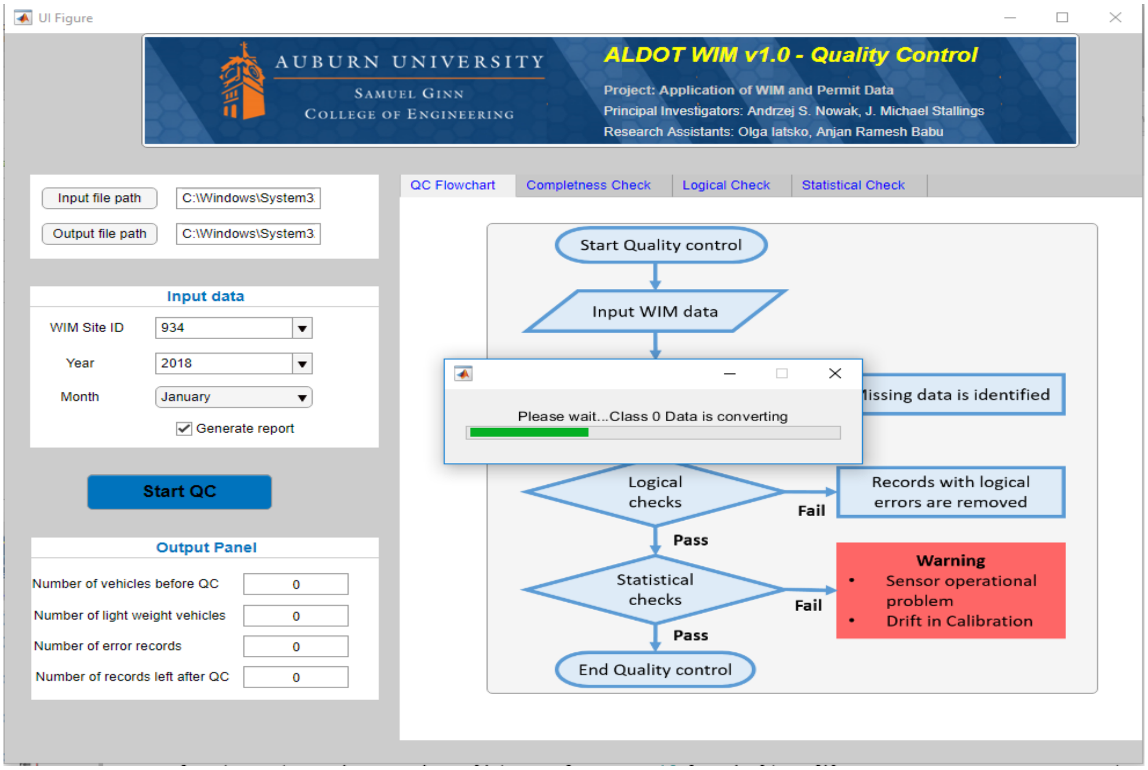


Figure E-57. Wait bar dialog box indicating the progress of QC

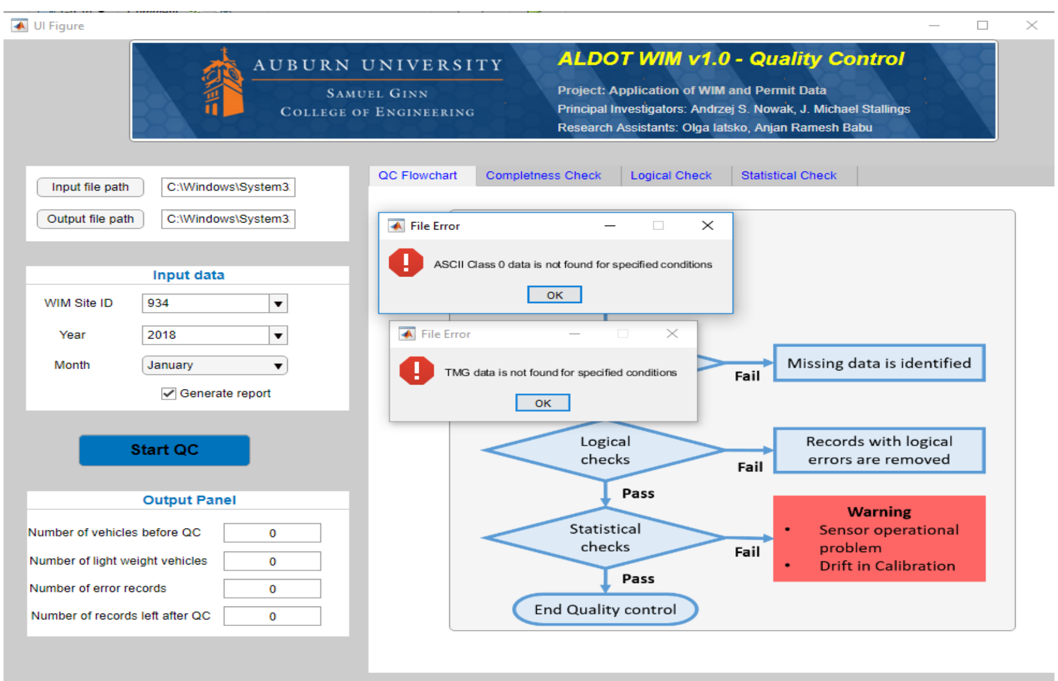


Figure E-58. An error dialog box indicating the problem with input data

Chapter 4. Interpretation of the results

After the QC is finished, the wait bar dialog box closes and the results are displayed in the *output panel* as shown in Figure E-59. The completeness, logical and statistical checks are discussed in the following sections.

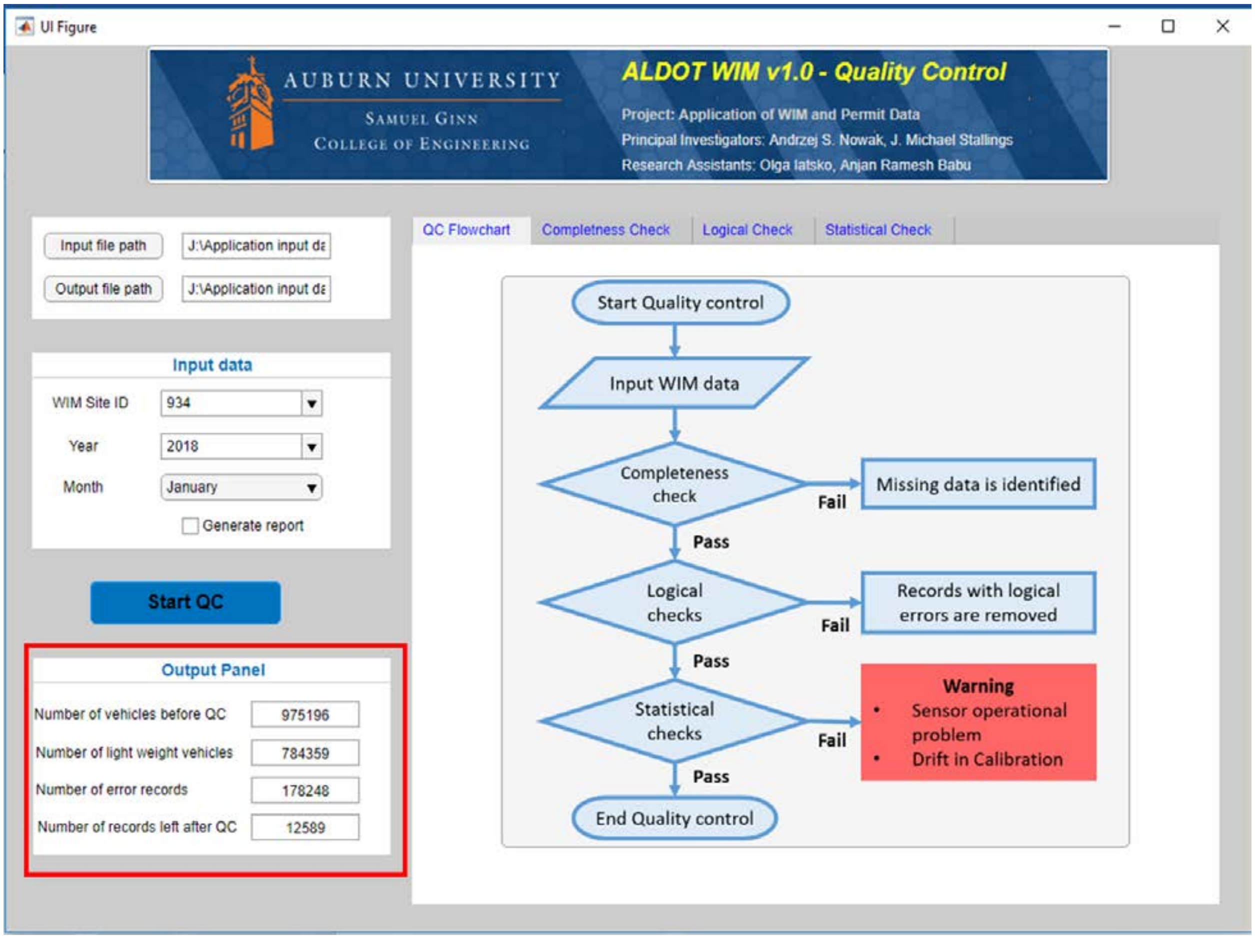


Figure E-59. QC results shown in output panel after completion of the QC procedure

1. Completeness Check

<u>Objective:</u> To check whether the data is present for each hour every day of the month. The inconsistency can be caused by a system malfunction or lack of maintenance.

When the data is present, the respective hour value is listed below. If no data is present in that particular hour then '999' is listed. Day 1 is the first day of the month, and hour zero is from midnight until 1 a.m. An example for WIM site 934 for the year 2018 and the month of January is shown in Figure E-60, where for Day 17 from Hour 3-4 the '999' indicates that no data was present.

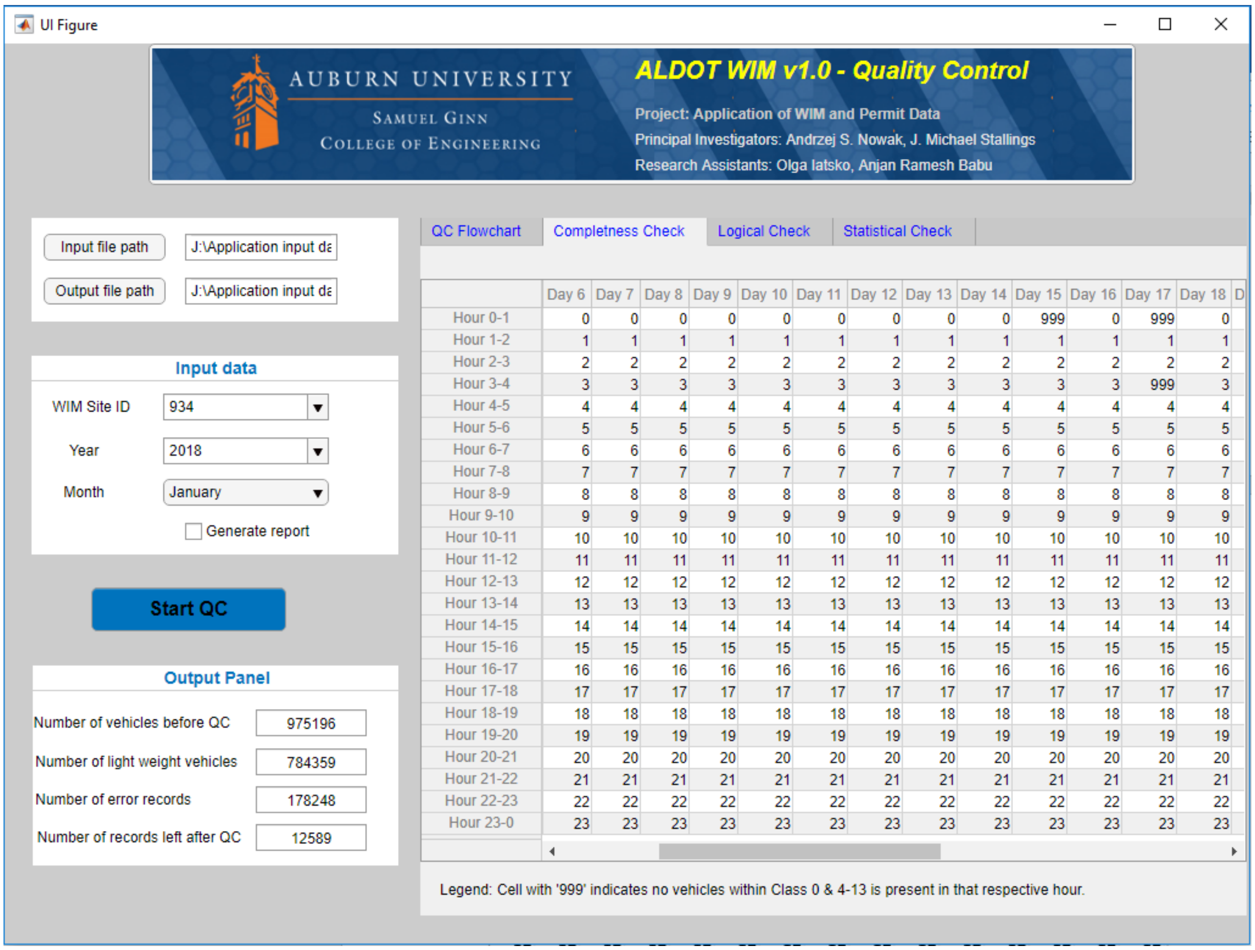


Figure E-60. Completeness check result

2. Logical Check

Objective: To identify and eliminate random and systematic errors.

After the lightweight vehicles (Gross vehicle weight < 20 kips) are eliminated, the remaining data is used for the logical check. Some quality control criteria have an acceptance range defined based on the physical limits and site-specific vehicle configurations. The *Filtering criteria* and *Threshold limits* for one of the location is shown in Figure E-61. Total error records detected is shown in the last row.

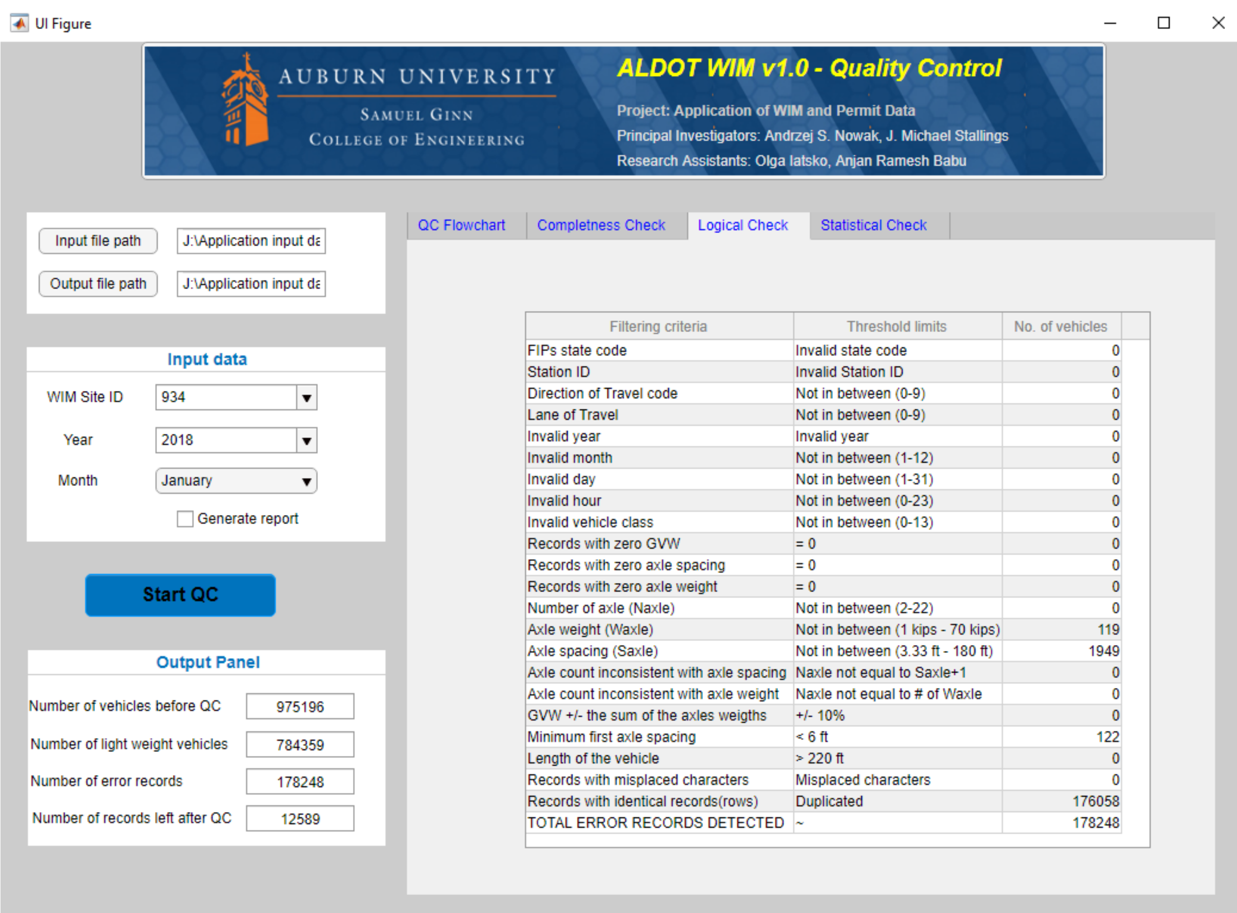


Figure E-61. Logical check results

3. Statistical Check

Objective: To check the errors in the recorded data that are usually caused due to communication failures, operational problems with sensor and drift in calibration of the systems. Most of the checks are on Vehicle class 9 as it is the dominating vehicle class.

The statistical check flowchart is shown in Figure E-62 . Step by step interpretation of the results are shown in the following section.

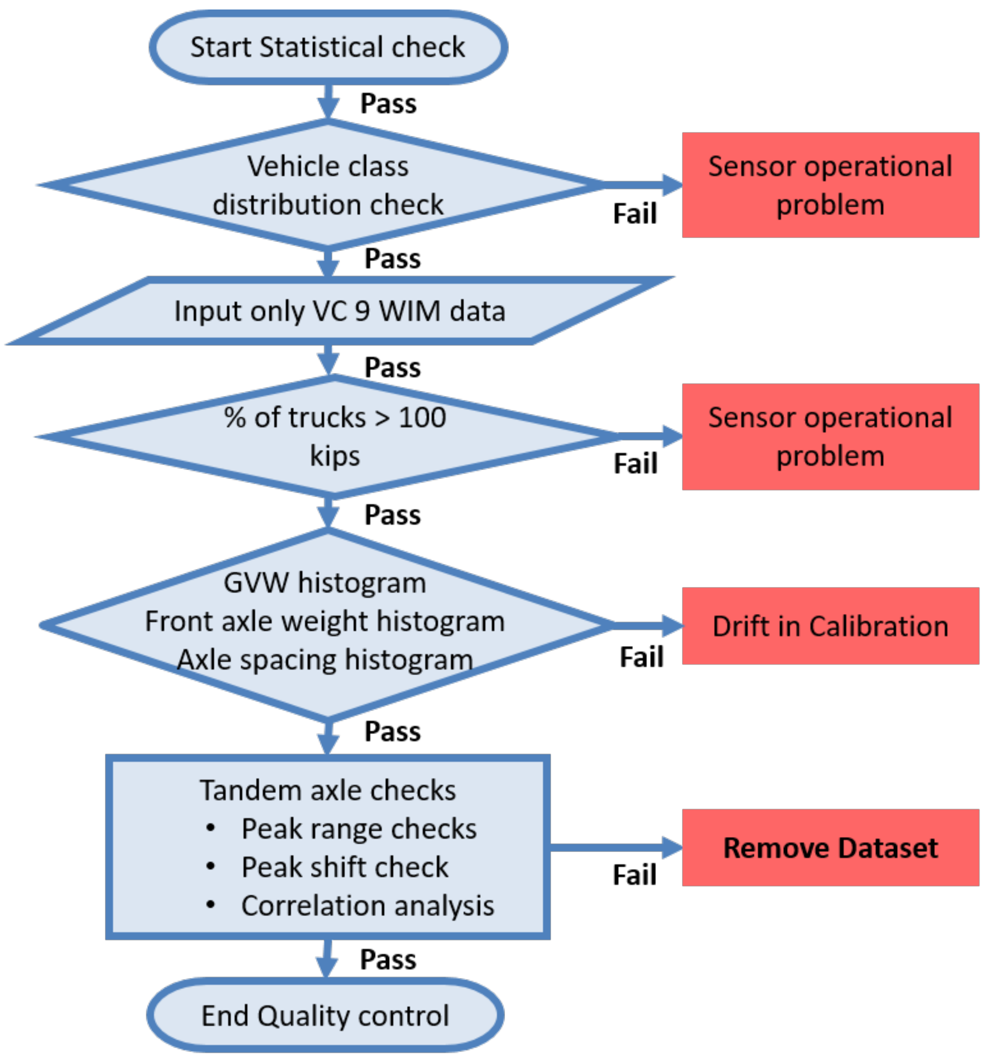


Figure E-62. Statistical check flowchart

3.1. Vehicle class distribution check

Objective: The percentage of vehicles in each class is calculated to check the health of the WIM sensors. Data can be compared for different years and months in each location. If an abrupt change is noticed when compared to historical data or consecutive months, it might indicate a problem with the sensor or vehicle classification algorithm.

An example of one of the WIM site is shown in Figure E-63. The results are in percentage (%).

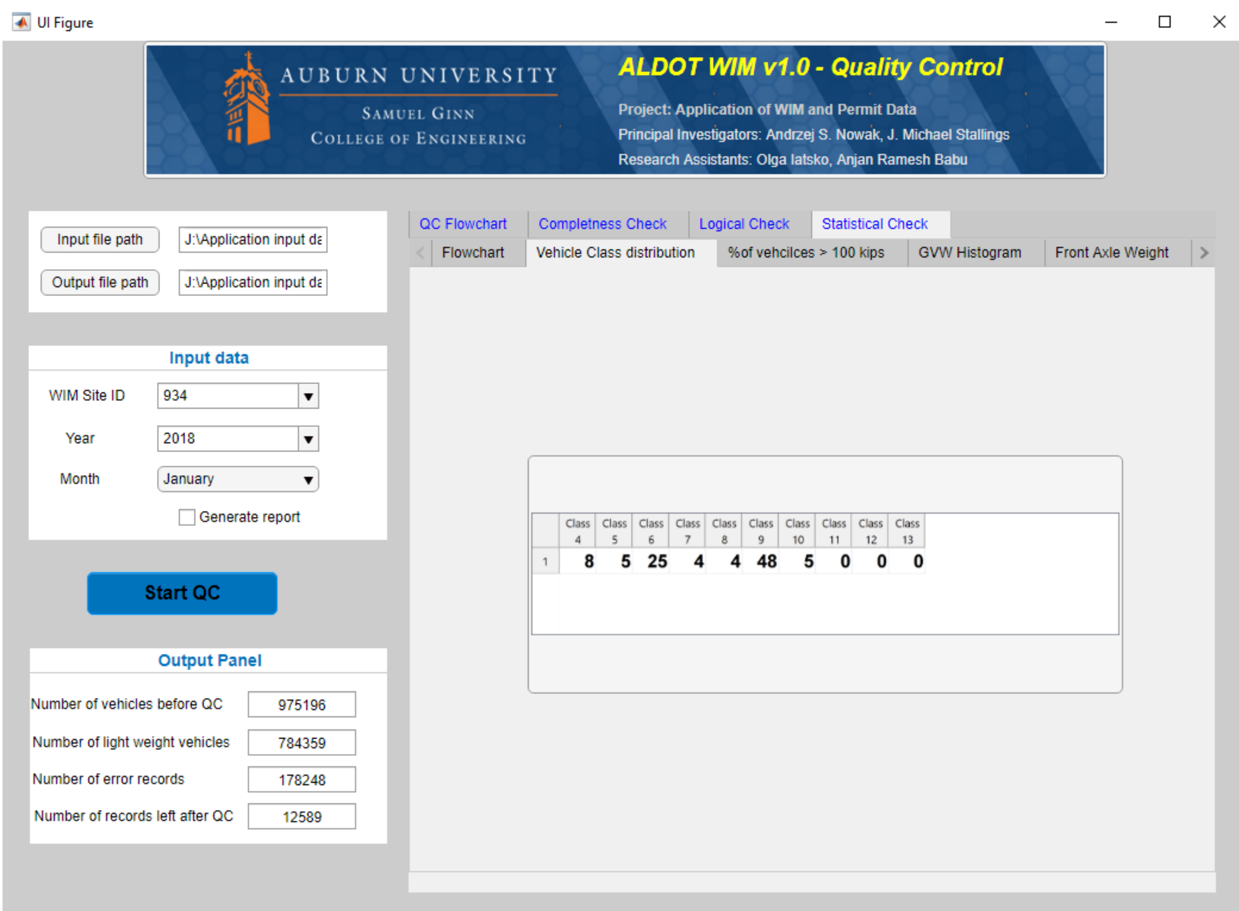


Figure E-63. Vehicle class distribution check result

3.2. Class 9 Check - Gross Vehicle Weight (GVW) > 100 kips

Objective: If there are a sensor operational problems, a large percentage of the GVW data of Class 9 vehicles are above 100 kips.

An example of one of the WIM Site is shown in Figure E-64. One way to interpret is to compare the results with other location. Usually, most of the locations have the same percentage Class 9 vehicles above 100 kips.

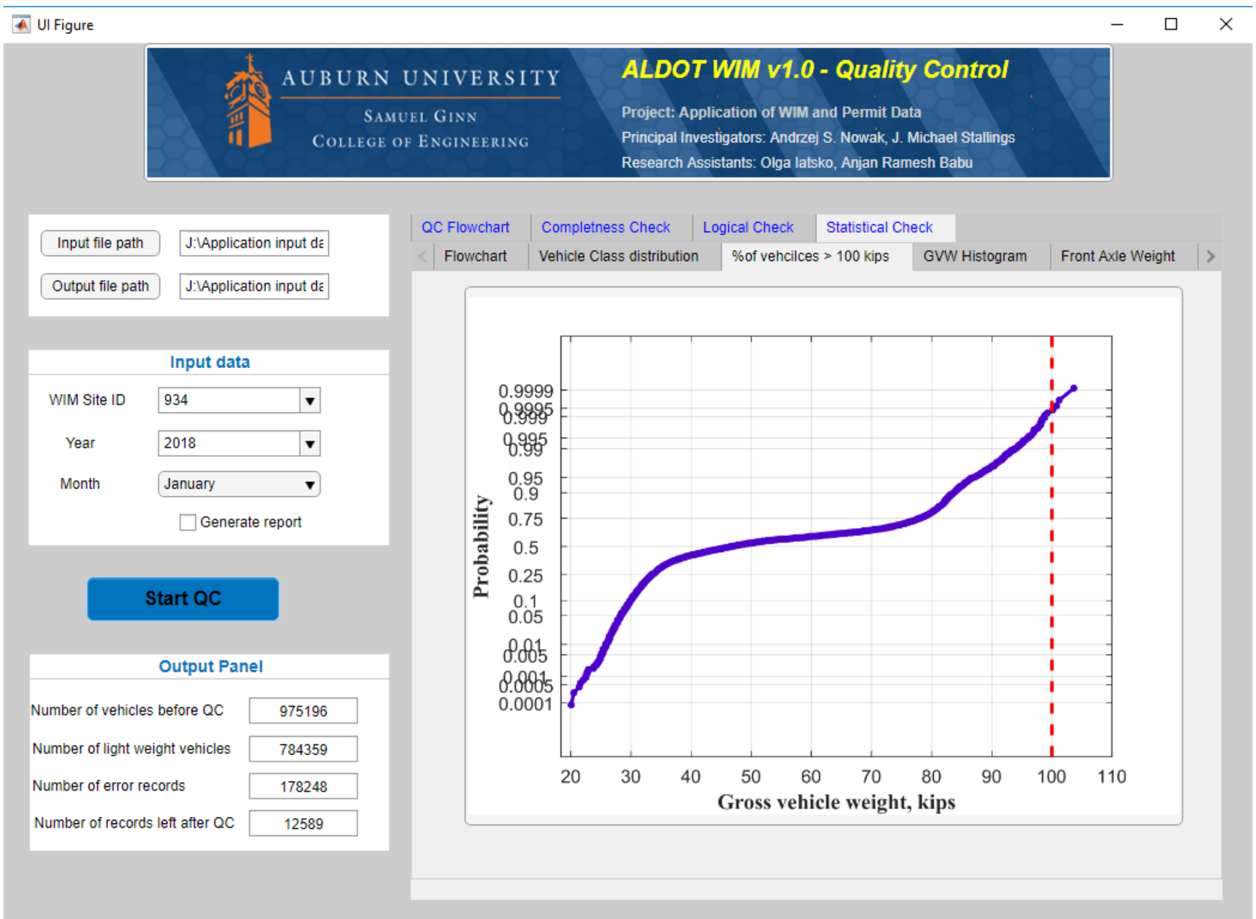


Figure E-64. Probability plot of GVW of Class 9 vehicles

3.3. Class 9 Check - GVW histogram check

Objective: A 4-kip bin width histogram is plotted and two peaks - unloaded peak between 28 and 36 kips range and a loaded peak between 72 and 80 kips range should be seen. A shift in the peak is of importance. Both peaks shifted in the same direction indicates most probably scale out of calibration. Single peak shift indicates an error, or it might be because of a change in traffic characteristics. If a valid reason can not explain a peak shift, then it is most probable that the sensor is out of calibration.
An example of one of the WIM Site is shown in Figure E-65.

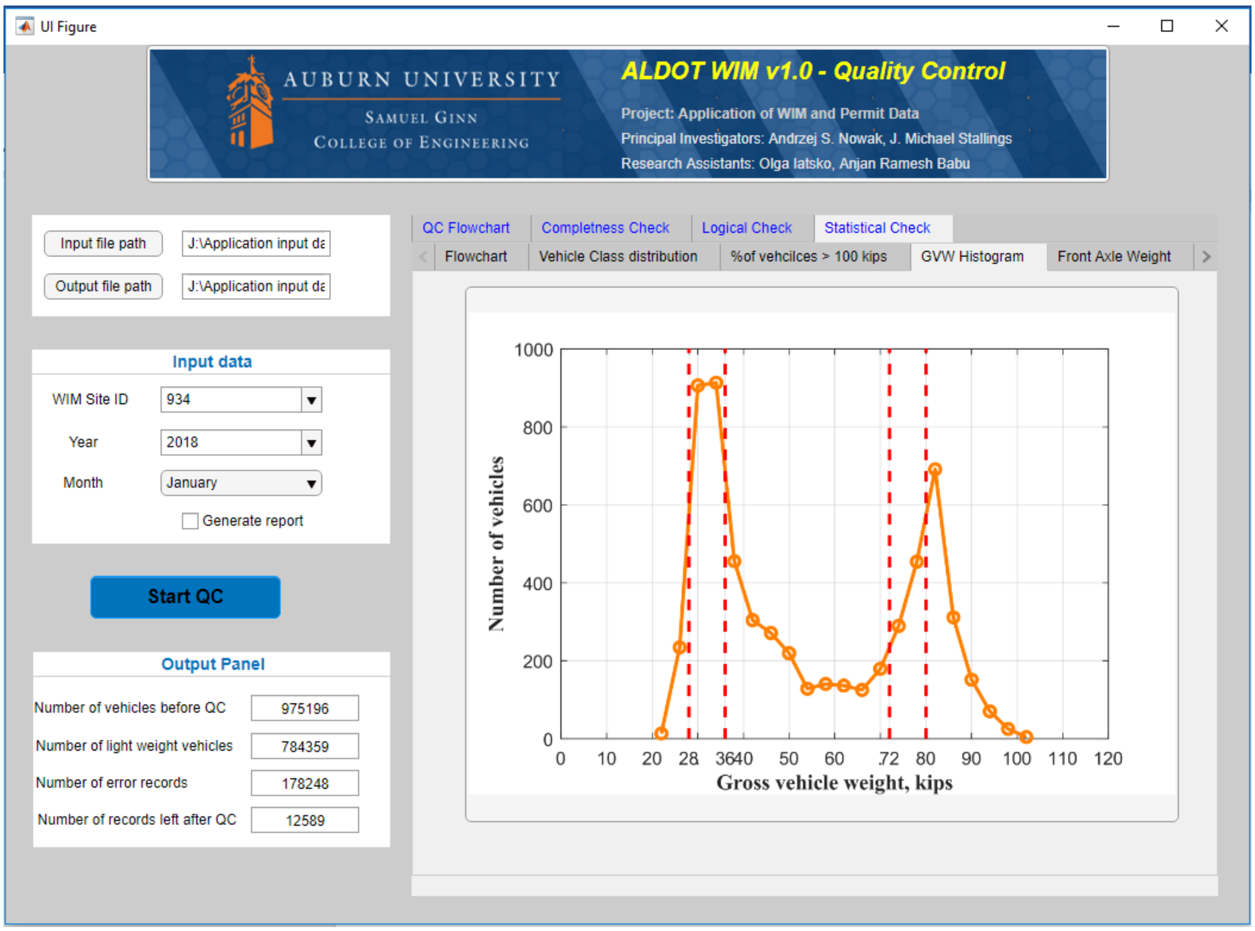


Figure E-65. Histogram of GVW of Class 9 vehicles

3.4. Class 9 Check - Front axle weight histogram check

Objective: A 1-kip bin width histogram is plotted and one peak between 8 and 12 kips range is seen. Front axle weight in most Class 9 vehicles are constant as its cabin part of a truck, and there cannot be much of weight difference irrespective of a truck loaded or unloaded. Alabama has front axle weight limit of 12 kips + 10% change on State highways. If a peak is not seen, the most probable cause is a problem with the sensor.

An example of one of the WIM Site is shown in Figure E-66.

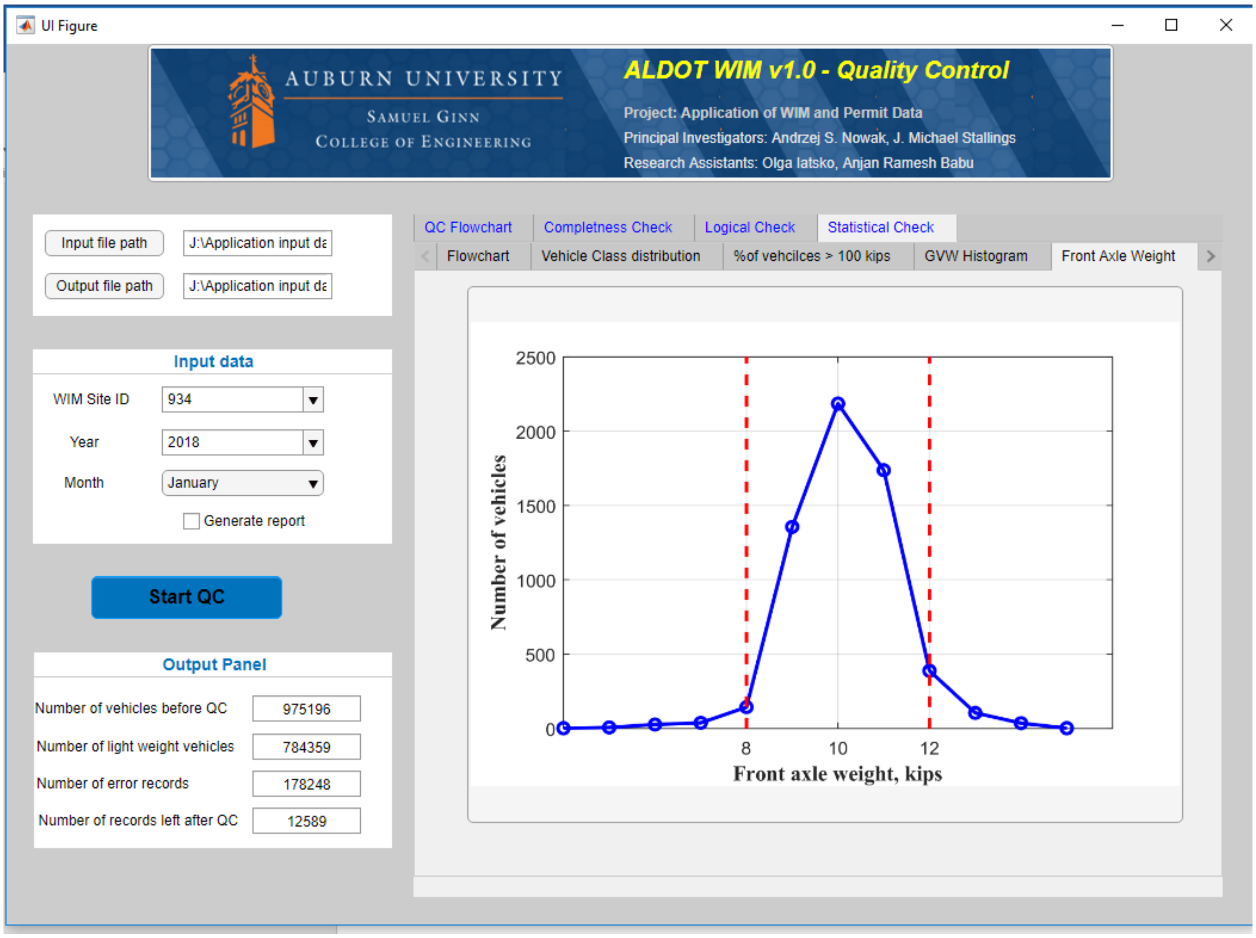


Figure E-66. Histogram of front axle weight of Class 9 vehicles

3.5. Class 9 Check – Tandem axle spacing histogram check

Objective: Probability plot of tandem axle spacing is plotted to check the condition of sensors. Class 9 trucks on the drive and rear tandem axle have almost constant spacing. Measurement of speed is an important factor to find the axle spacing in a WIM record. Also, inaccuracy in axle weight measurements is correlated to speed measurements. The results are not shown in the application but saved in the output folder.

3.6. Class 9 Check - Tandem Axle load spectra histogram

Objective: A 2-kip bin width histogram is plotted and one peak between 14 and 16 kips range and another peak between 32 and 38 kips range should be seen. Data are compared within each location for different years and months. If an abrupt change is noticed when compared to historical data it indicates a problem with the sensor.

An example of one of the WIM Site is shown in Figure E-67.

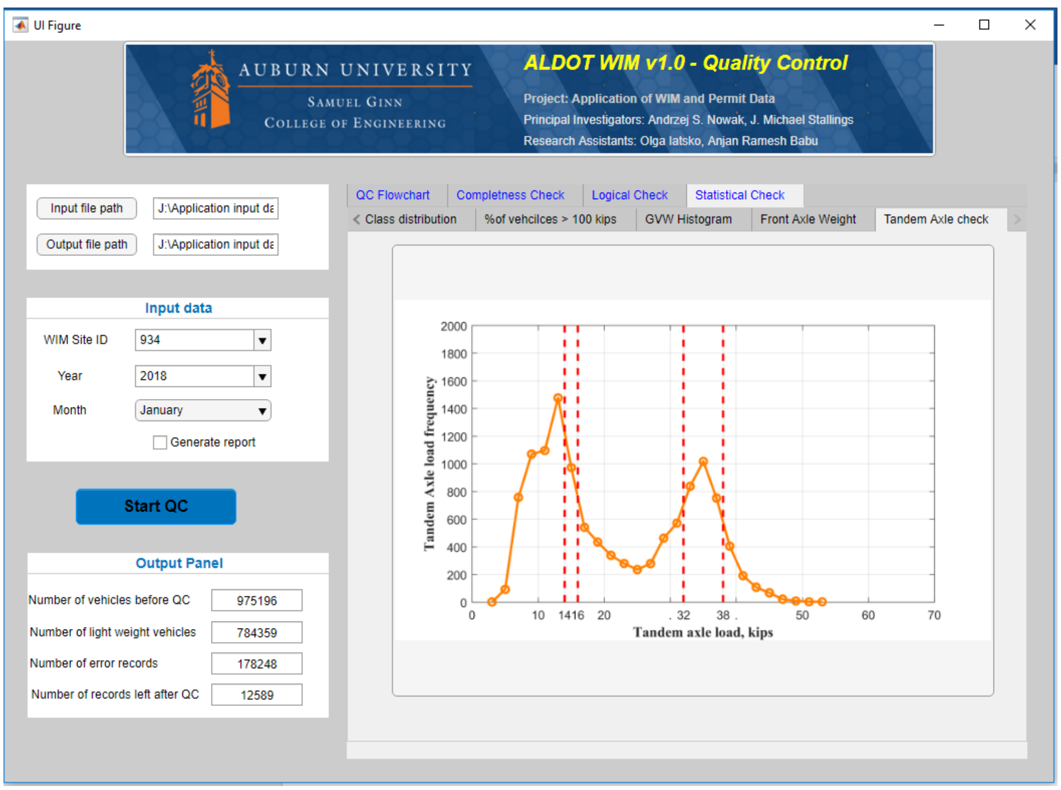


Figure E-67. Histogram of tandem axle loads of Class 9 vehicles

APPENDIX F : ALDOT_WIM_DAI V1.0 USER MANUAL

Contents

Introduction

The service life of the bridge is affected by many factors such as traffic loads, natural hazards, defects in material production, etc. Traffic-induced loads by vehicular traffic cause damage to the bridge by fatigue and overload. Steel bridges are more prone to fatigue failure compared to other types of bridges. Every passage of a truck creates multiple stress cycles on a bridge and accumulates damage on a bridge. The entire fatigue process in a member includes the formation of a fatigue crack, crack growth, and final failure (Fisher et al. 1998). If the fatigue crack is not detected and properly maintained it might lead to the failure of the member. AASHTO LRFD Bridge design specifications (AASHTO 2017) has a design approach to design for fatigue. A code-specified fatigue design truck is used to restrict the stress range to address the fatigue. The AASHTO fatigue design truck used in the design is intended to control crack growth under repetitive loads and prevent fracture. However, in the service life of the bridge, there is an uncertainty of traffic loads the bridge experiences and damage accumulated on the bridge has to be accessed periodically for proper maintenance and evaluation.

Long-term WIM recording provides an excellent tool to estimate the accumulated fatigue damage. ALDOT_WIM_DAI v1.0 application provides a user-friendly interface to estimate the damage accumulated by the most fatigue prone details.

Firstly this application checks the quality of WIM data and eliminates the questionable records, and a Quality Control (QC) procedure is shown in Figure E-48. Then the effective moment, M_{eff} and number of constant-amplitude cycles with the magnitude M_{eff}, N, is calculated to determine the nominal damage. The outputs from this application can be used to find site-specific and bridge-specific fatigue damage using the bridge-specific parameters, as demonstrated in the Final report of the project mentioned above.

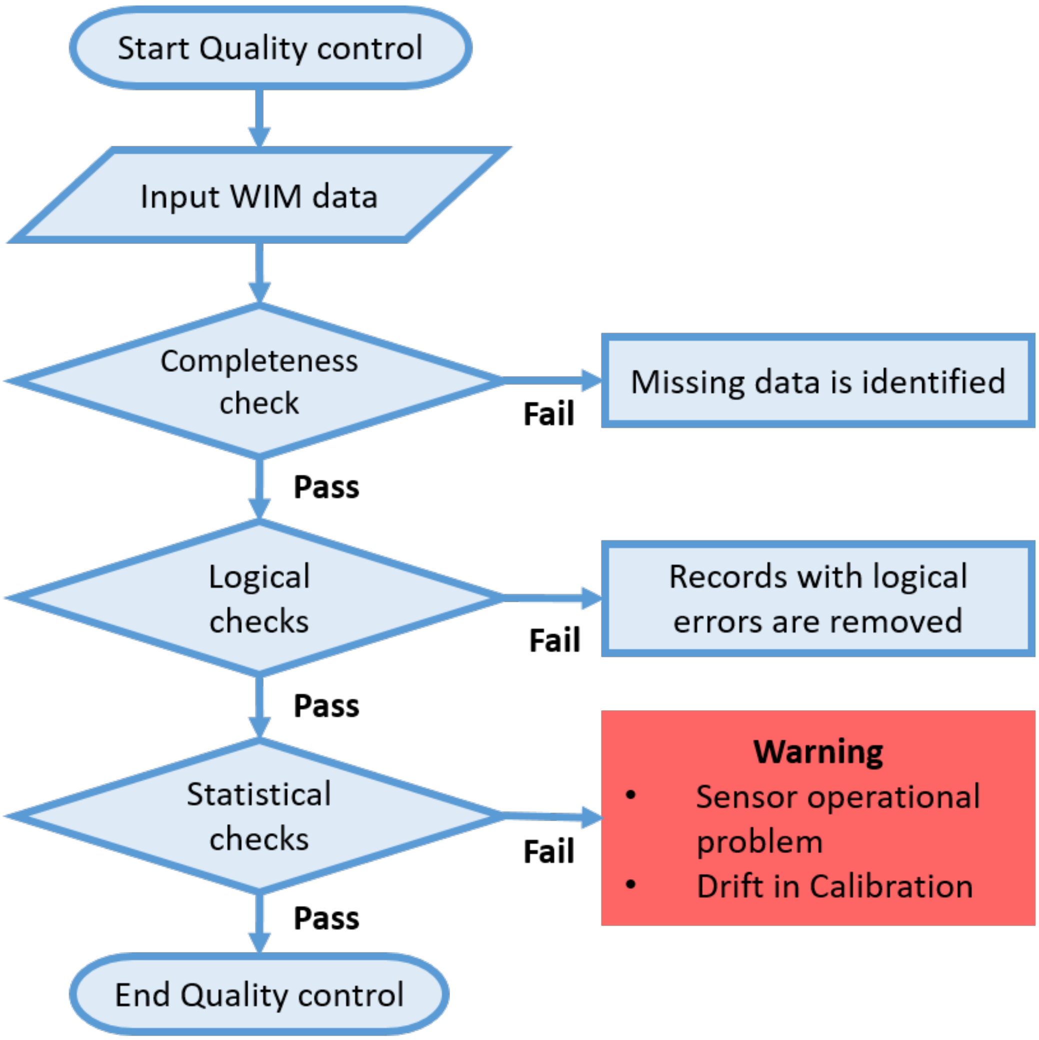


Figure F-68. Quality Control Procedure Flowchart

Chapter 1. Preparing Input Data

The data recorded by WIM sensors are stored in the data storage medium maintained by ALDOT in an encrypted format. The iAnalyze software provided by WIM system vendor International Road Dynamics Inc. (IRD) is used to decrypt WIM data to the desired format. For using it in this application, the Class 0 data is required to be decrypted in IRD ASCII

Raw data format (as referred in section D.13.1 of iAnalyze Software operator's manual) and Class 4-13 in TMG 2001 Truck Weight format (as referred in section D.9.5 of iAnalyze Software operator's manual). For every WIM site for the selected month and year, there is always two input files, one containing Class 0 data and another containing Class 4-13.

Once the data is decrypted, it has to be renamed in the following format to use in the application and can be stored in the user desired folder.

Class 0 data:
Syntax: **<Year>_<Month>_<WIMID>.csv**

Where,

<Year> is the year of the data
<Month> is the month of the data in number
<WIMID> is WIM station ID used by ALDOT
.csv is an extension of the file type which is saved by default

For example, the WIM data for WIM location 911 for the Year 2018 and Month of January the filename will be **2018_1_911.csv**

Class 4-13 data:
Syntax: **<Year>_<Month>_<WIMID>.WGT**

Where,

<Year> is the year of the data.
<Month> is the month of the data in number.
<WIMID> is WIM station ID used by ALDOT.
.WGT is the extension of the file type which is saved by default

For example, the WIM data for WIM location 911 for the Year 2018 and Month of January the filename will be **2018_1_911.WGT**

Note: It is important that filename of Class 0 data is in ".csv" and Class 4-13 is in ".WGT"

Chapter 2. Installing the application

The users are provided with the installation file named "MyApplnstaller_web" as shown in Figure E-49. Once the user double-clicks the installation file, the installation processes start as shown in Figure E-50. The installer will request the path to the installation folder where the application package is stored as shown in Figure E-51. A desktop shortcut can also be created for easier assess. After that ***Next*** button is clicked.

A Matlab compiler is required to run the application so the dialog box as shown in Figure E-52 is requested, and the user is required to click ***Install***. After the installation is complete, the dialog box as shown in Figure E-53 is seen indicating the successful completion of installation. Click *Finish* to complete the setup.

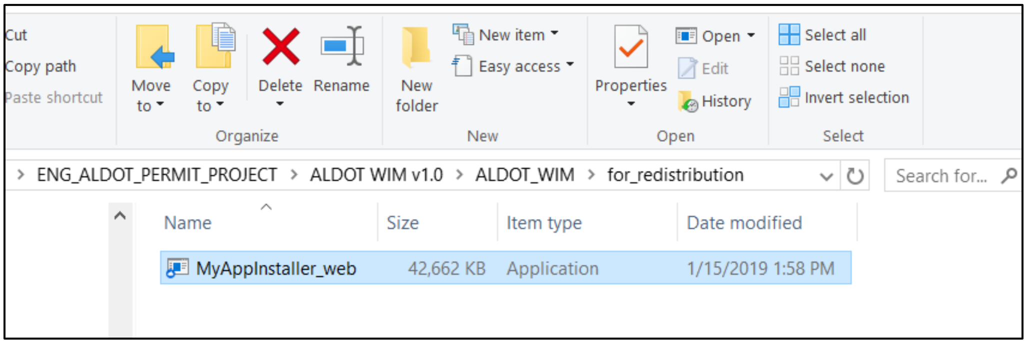


Figure F-69. Redistribution file provided to the user

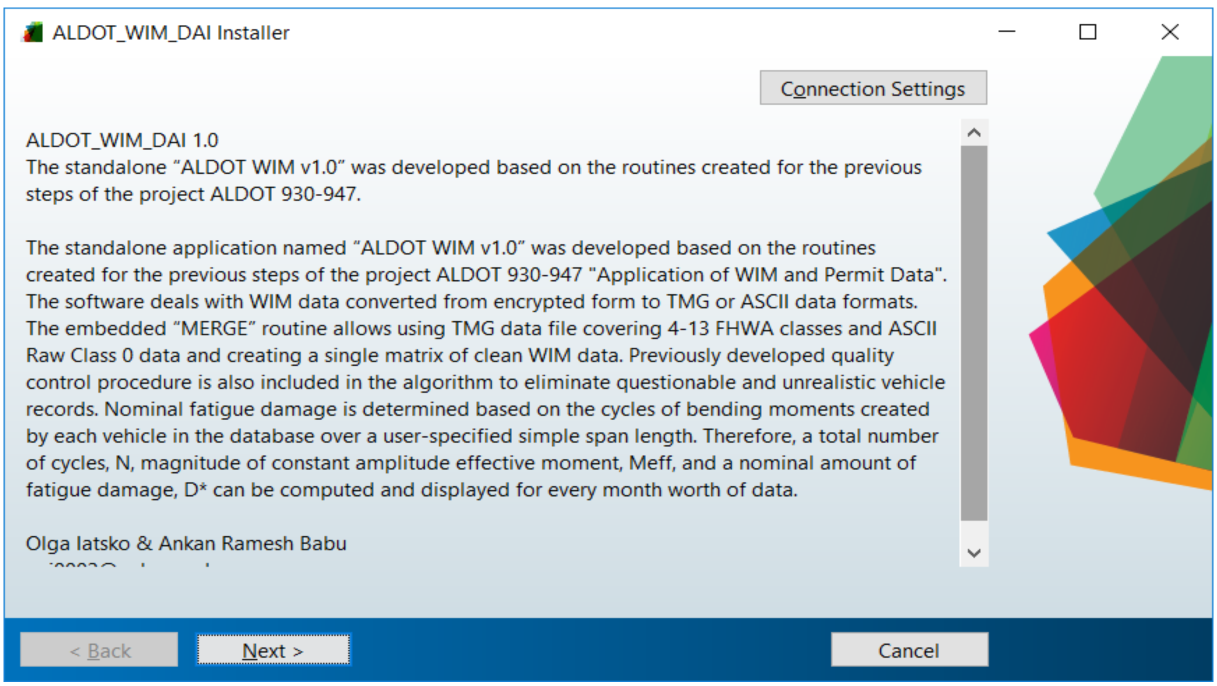


Figure F-70. Application installation startup screen

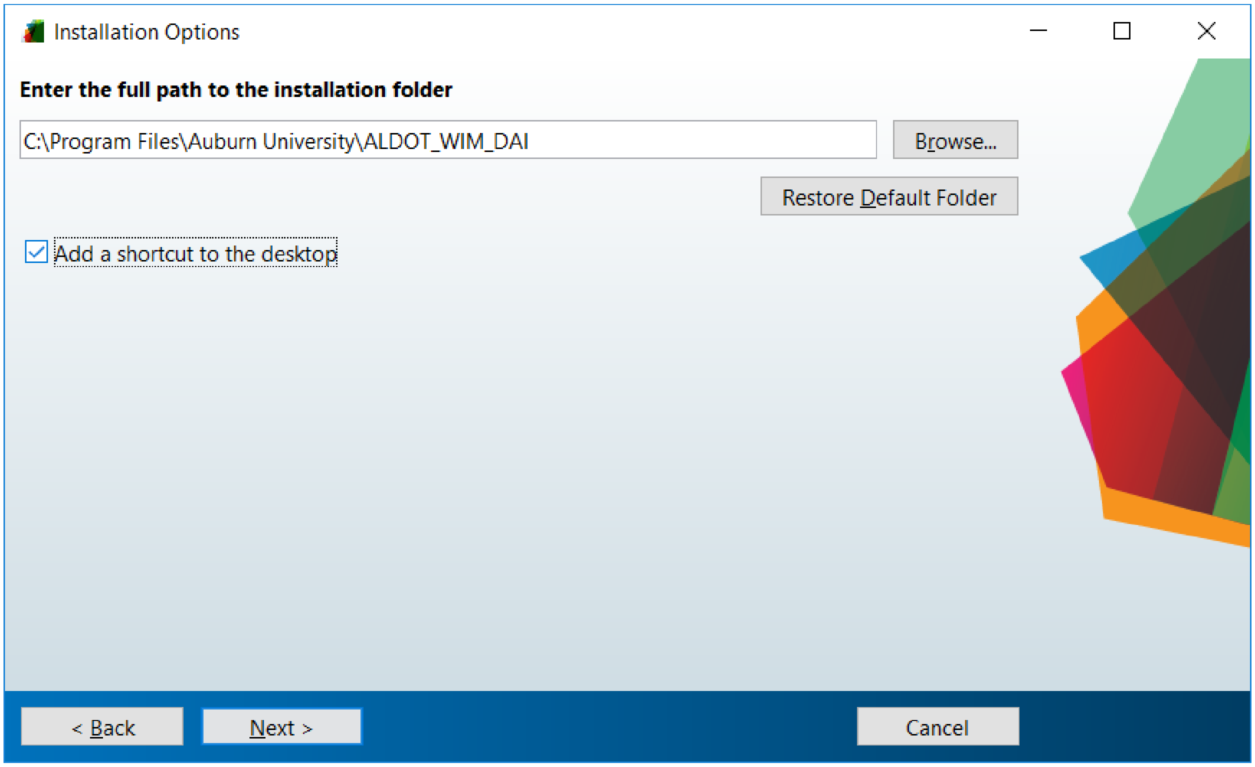


Figure F-71. Installation folder selection

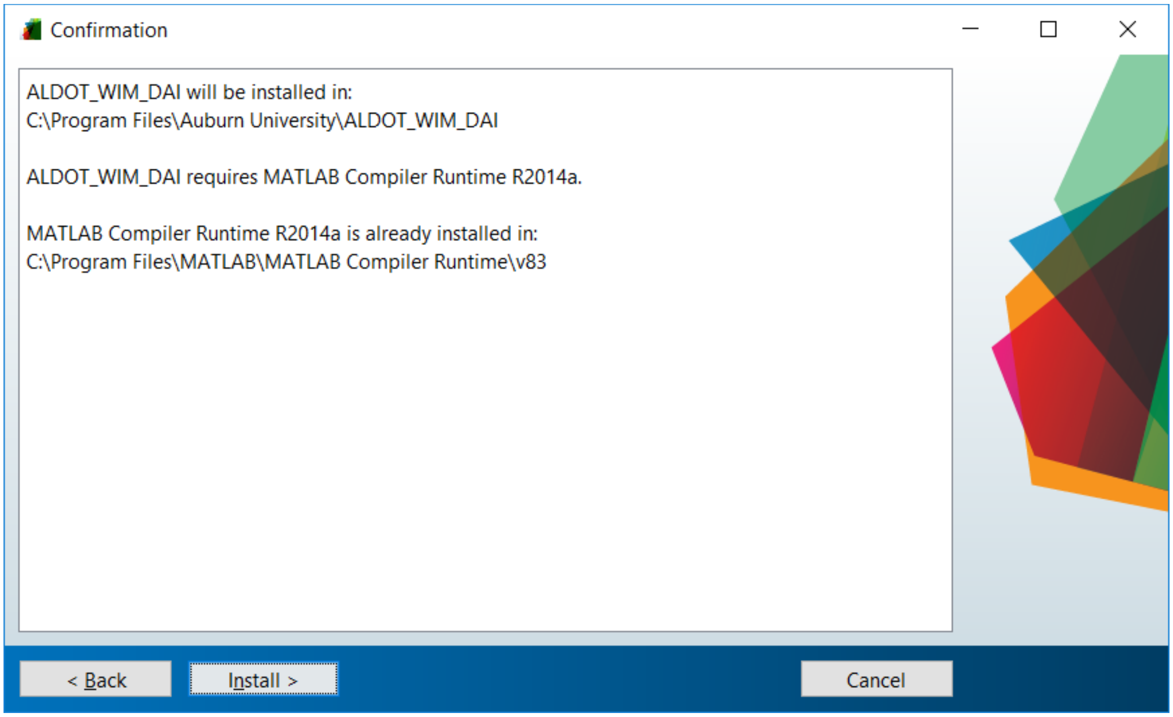


Figure F-72. Installation of MATLAB Compiler Runtime

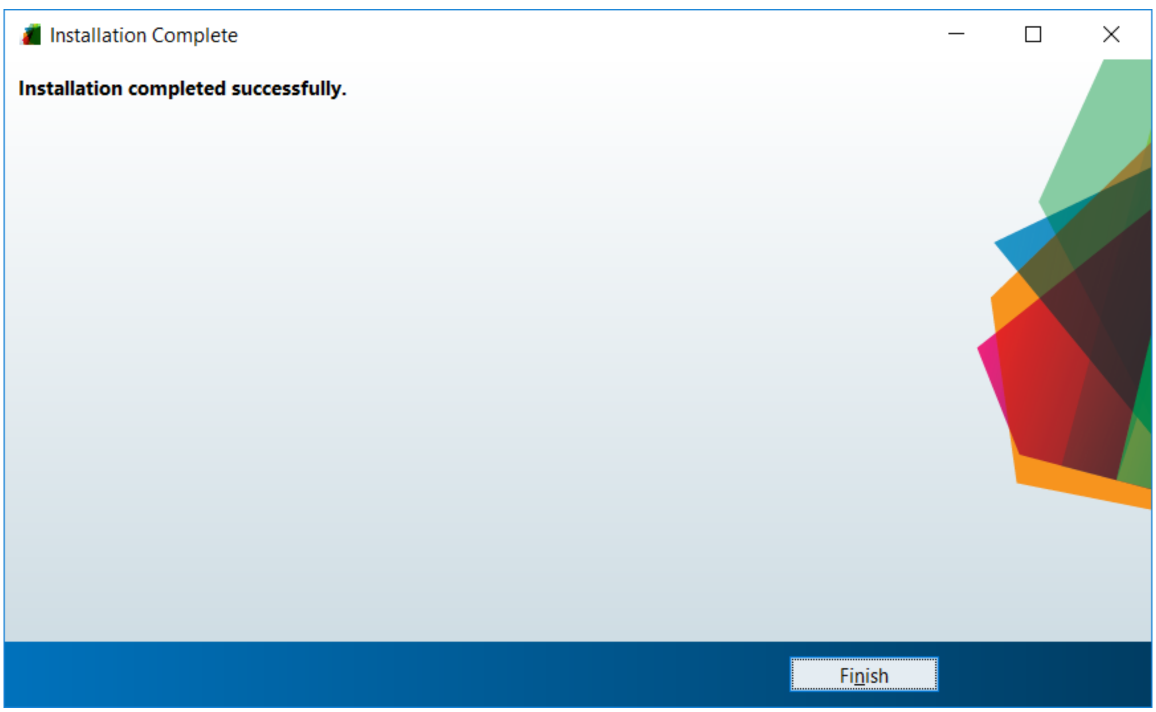


Figure F-73. Installation completed dialog box

Chapter 3. Step-by-step instructions to use application

After installing the application, double-clicking on the desktop shortcut icon opens the application. Alternatively, the application can also be opened by searching in the start menu. The startup screen of the application looks like it is shown in Figure E-54.

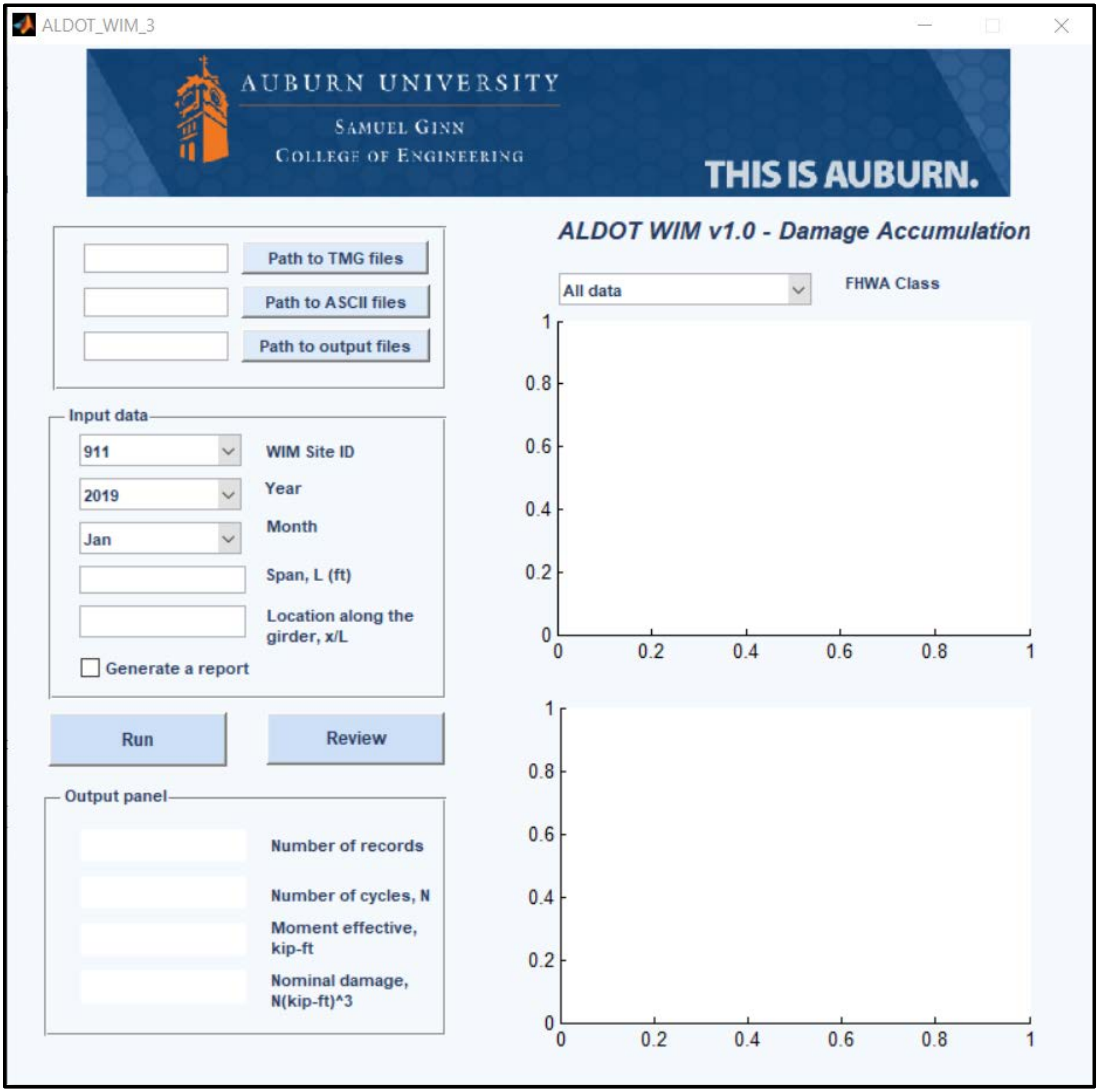


Figure F-74. ALDOT_WIM_DAI application startup screen

Step 1: Selecting the input (TMG and ASCII) and the output file path.

The input (TMG and ASCII) and out file path has to be selected by clicking on the button as it is shown in Figure E-55. The ***Path to TMG files*** is the folder where the ***Class 4-13 data in .WGT format*** *and* ***Path to ASCII files*** where the ***renamed Class 0 data in a .csv*** **format** is stored. The output folder can be created by clicking on the "output file path" button and once the window pop-ups a new folder can be created by right-clicking the mouse and clicking on *New>>Folder* option. It is recommended to create output folder name in: **<Year>_<Month>_<WIMID>** format as shown earlier. The results of the DAI of each WIM Site are stored in the output folder. Also, the input data compiled of Class 0 and 4-13 are stored.

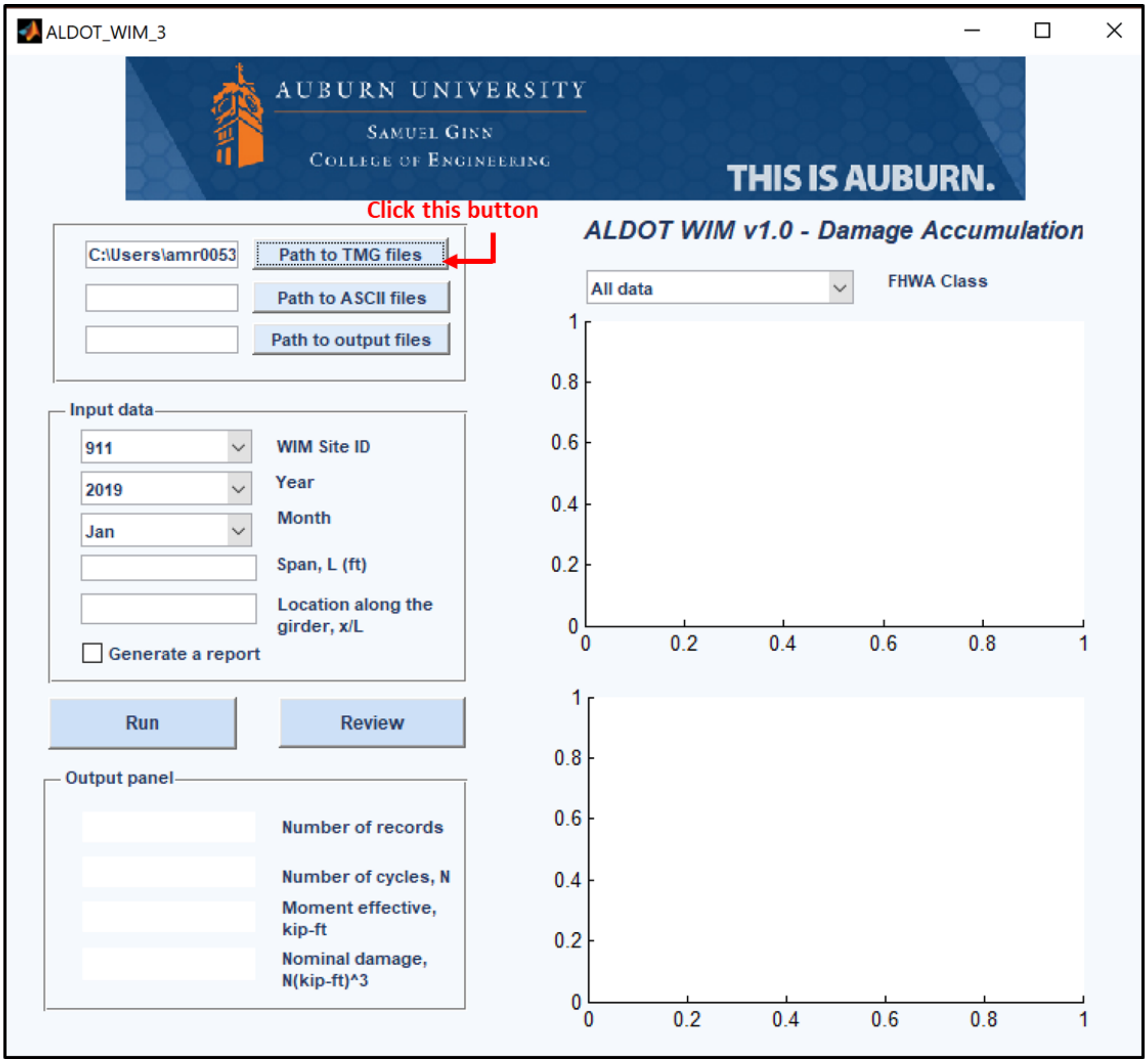


Figure F-75. Selecting input and output file path

Step 2: Inputting the data in *Input Data* panel

The Input Data panel is self-explanatory, the preferred *WIM Site ID* is selected from the drop-down menu or by inputting the WIM Station ID. Also, preferred *Year* and *Month* is selected. The span length and location along the span length can be specified. The effective moment and cycles are calculated for that location of the bridge. *Generate report* is selected if needed. An example of a screen after inputting the data is shown in Figure E-56.

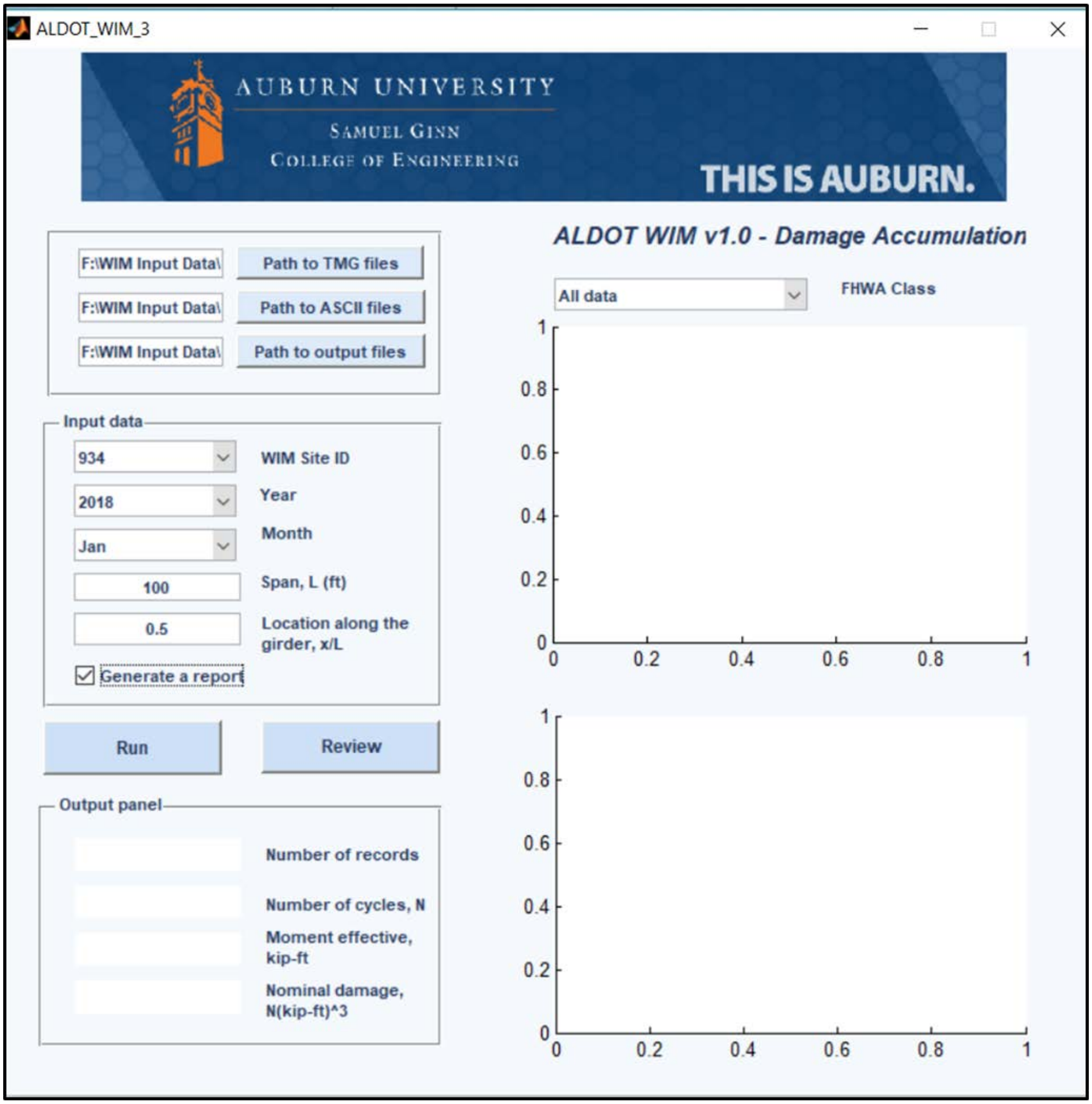


Figure F-76. Inputting the data in *Input Data* panel

<u>Step 3:</u> Starting the DAI

The DAI is started once the ***Run*** button is pushed. The wait bar dialog box as shown in Figure E-57 is pop-upped once the ***Run*** button is pushed indicating the progress. Once the process is complete, the wait bar closes automatically indicating the process is finished. The interpretation of results is shown in the next chapter.

In case the input data filename is in the wrong format or input data is not in the input file path for the selected WIM Site ID, Year or Month then the error window pop-ups as shown in Figure E-58. For every WIM site for the selected month and year, there is always two input files, one containing Class 0 data and another containing Class 4-13. In case there is no data in Class 0, the iAnalyze creates an empty file.

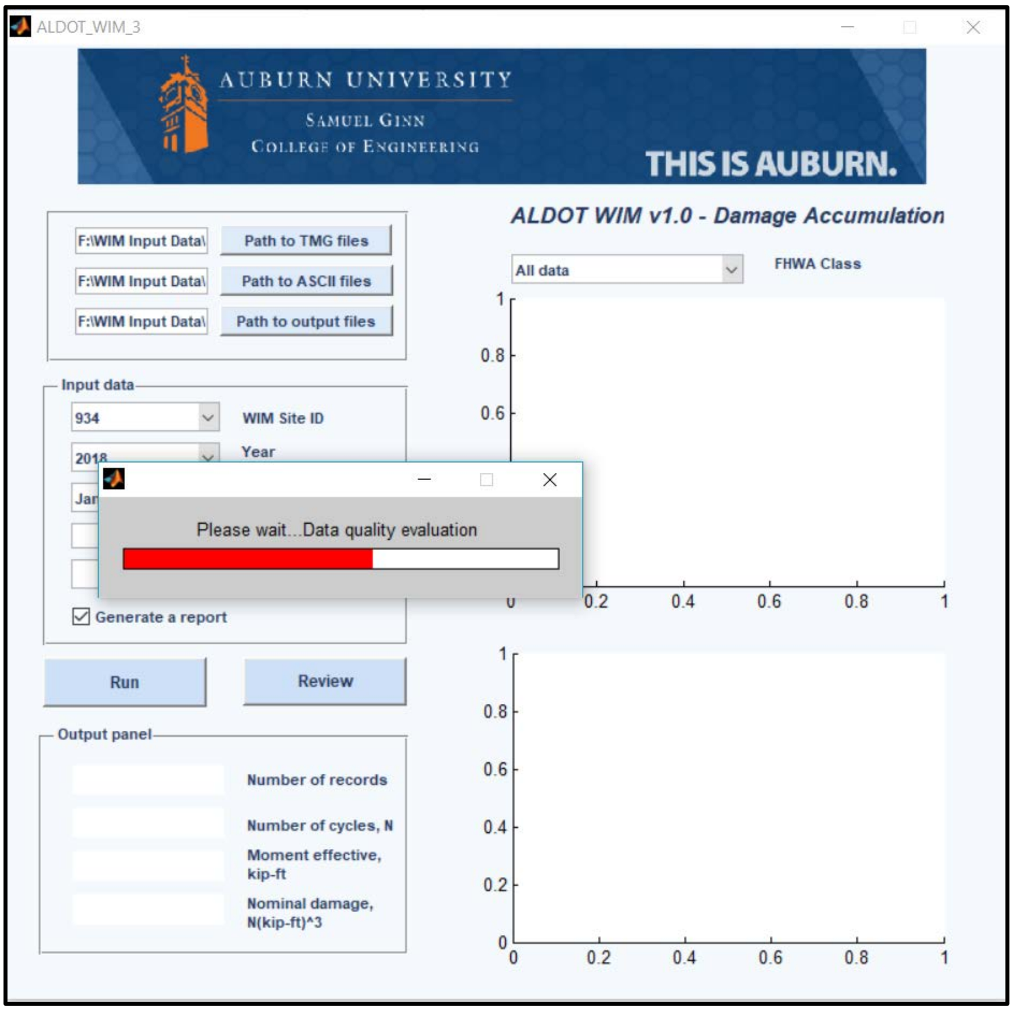


Figure F-77. Wait bar dialog box indicating the progress of DAI

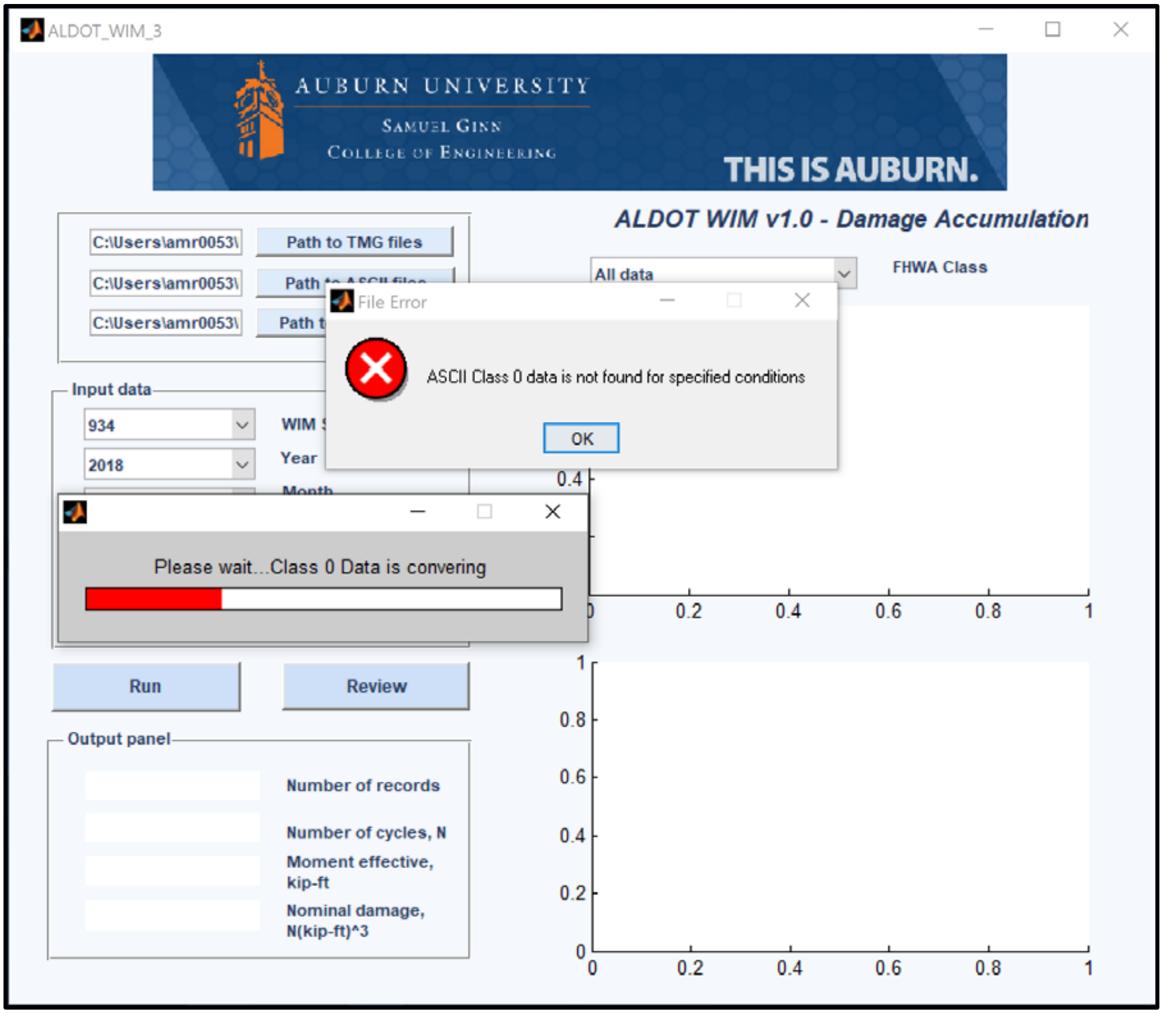


Figure F-78. An error dialog box indicating the problem with input data

Chapter 4. Interpretation of the results

After the DAI calculations are finished, the wait bar dialog box closes, and the results are displayed in the *output panel* as shown in Figure E-59. The number of cycles, N and moment effective, M_{eff} for the selected location along the span length is calculated. Also, an interactive plot on the right side of the screen is generated showing the gross vehicle weight distribution among different FHWA classes and another plot showing the percentage of vehicles distributed among different FHWA classes.

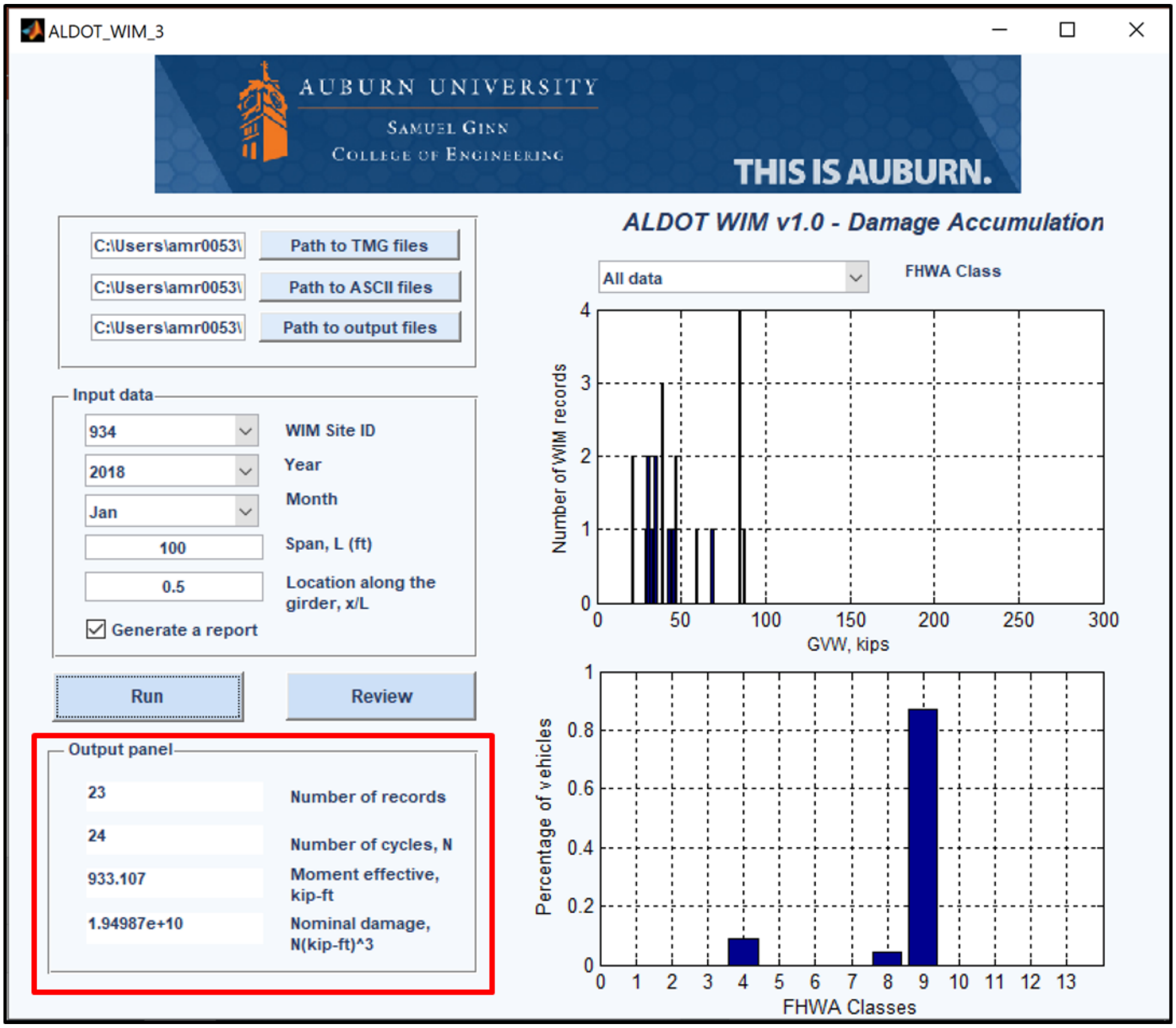


Figure F-79. DAI results shown in output panel after completion of the QC procedure

4. Viewing results for a particular vehicular class.

One the process has completed the results for all the FHWA vehicles together is shown by default. By selecting the drop-down menu as shown in Figure F-80 a particular class of interest can be selected.

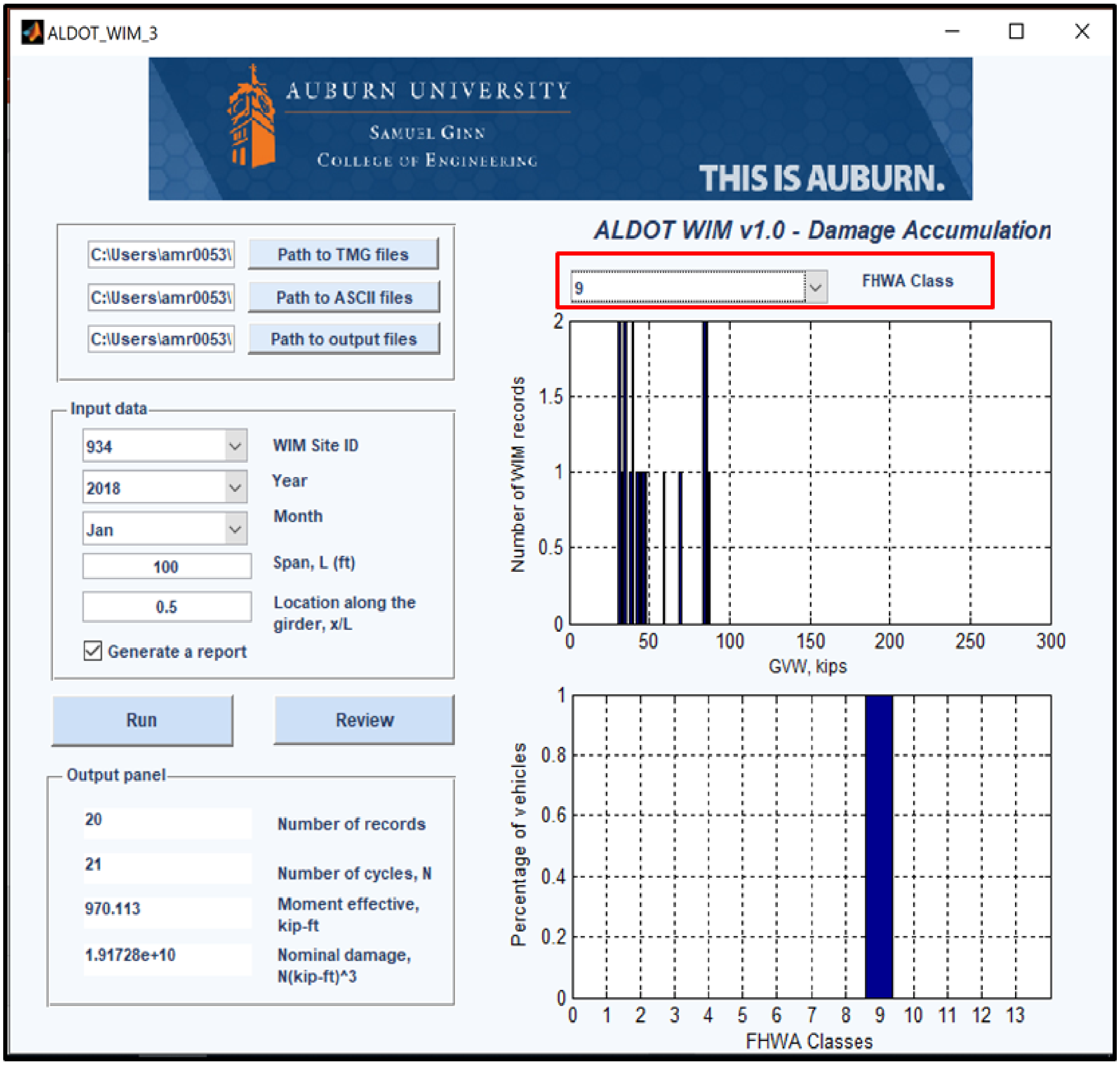


Figure F-80. DAI results selection for the particular Vehicle class

5. Viewing results for a particular direction of travel.

One the process has completed the results for all the directions together is shown by default. By selecting the drop-down menu as shown in Figure F-80 a particular direction of travel of interest can be selected.

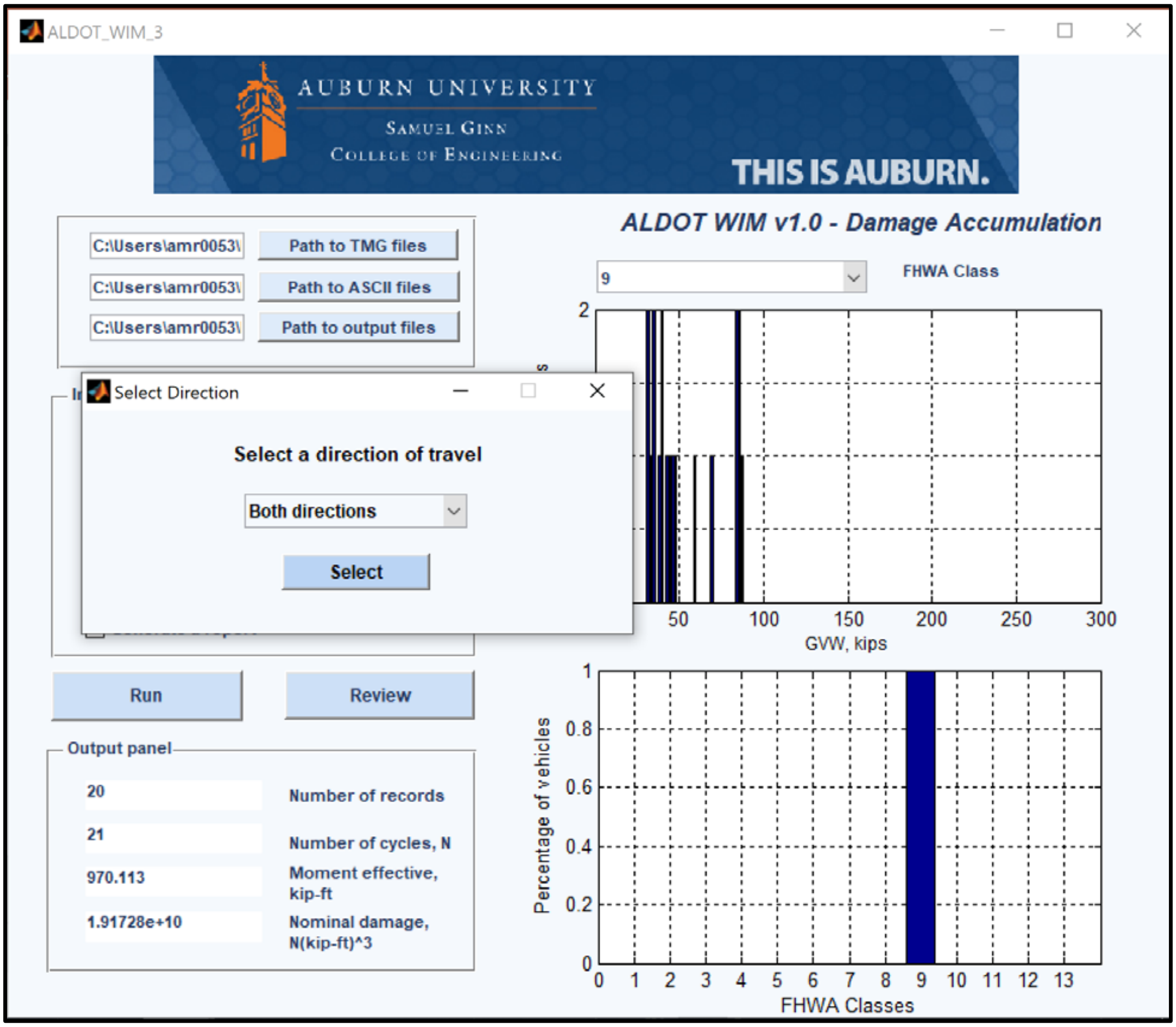


Figure F-81. DAI results selection for particular direction of travel

Chapter 5. Review of previously processed data.

Once the data for a particular WIM location, period, span length and location along span length is run, it is stored in the output folder. The results can be viewed later without running that whole process. Just the output folder location can be selected as shown in Figure F-82, and reminder input data is inputted to see the processed data. Rest of the feature such as the selection of class and direction of travel remains the same as discussed in Chapter 4.

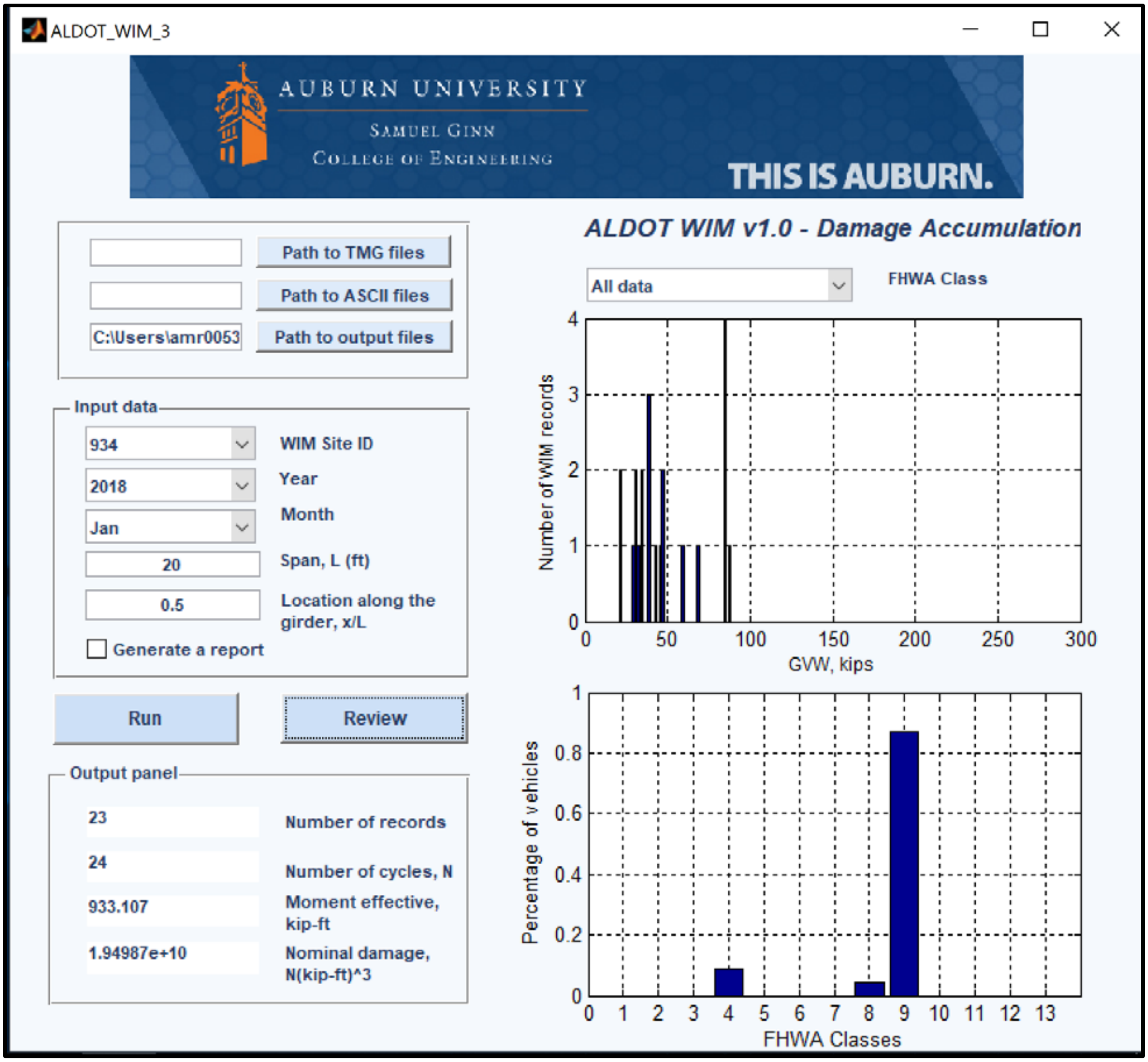
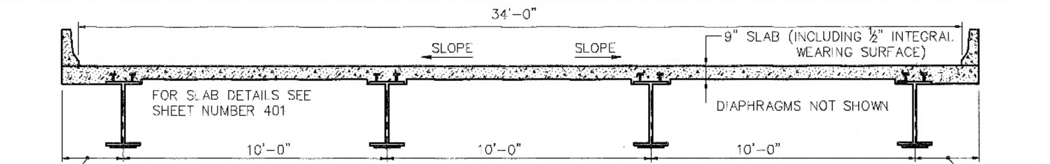
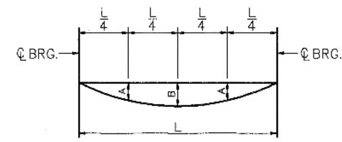


Figure F-82. Review of the processed data

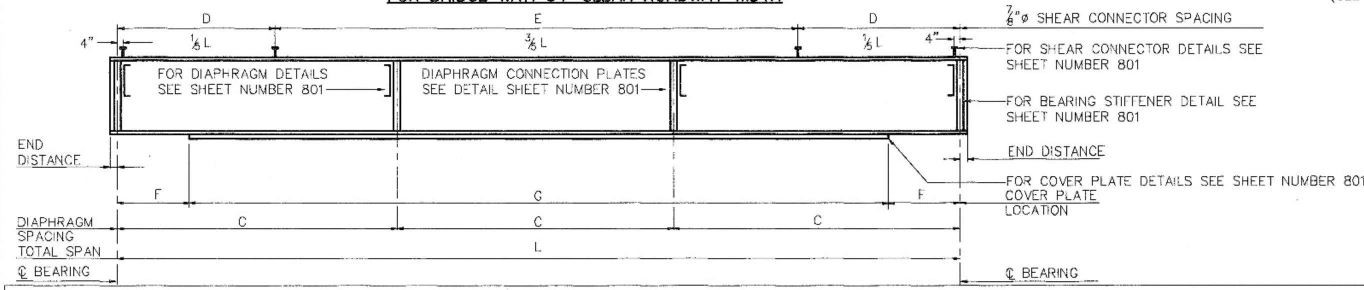
APPENDIX G : AISI SHORT-SPAN STEEL BRIDGE DESIGNS



TYPICAL CROSS SECTION
FOR BRIDGE WITH 34' CLEAR ROADWAY WIDTH



DEAD LOAD
DEFLECTION DIAGRAM
(SEE TABLE BELOW)



COMPOSITE ROLLED BEAMS WITH WELDED COVER PLATE

SPAN (L) – Ft.	REQUIRED BEAM	REQUIRED COVER PLATE: THICKNESS X WIDTH	REQUIRED COVER PLATE: WELD SIZE	REQUIRED COVER PLATE: F	REQUIRED COVER PLATE: G	SIZE OF DIAPHRAGM	DIAPHRAGM SPACING (C) – Ft.	NUMBER OF DIAPHRAGMS	DEAD LOAD DEFLECTION – In.: A	DEAD LOAD DEFLECTION – In.: B	SUPERIMPOSED DEAD LOAD DEFLECTION – In.: A	SUPERIMPOSED DEAD LOAD DEFLECTION – In.: B	SHEAR CONNECTOR MAX. SPACING–In.: D	SHEAR CONNECTOR MAX. SPACING–In.: E	REACTION–Kips. (UNFACTORED): DEAD LOAD	REACTION–Kips. (UNFACTORED): SUPERIMPOSED DEAD LOAD	REACTION–Kips. (UNFACTORED): LIVE LOAD WITH IMPACT	MOMENTS Kips–Ft. (UNFACTORED): DEAD LOAD	MOMENTS Kips–Ft. (UNFACTORED): SUPERIMPOSED DEAD LOAD	MOMENTS Kips–Ft. (UNFACTORED): LIVE LOAD WITH IMPACT
55	W 30x99	15/16 x 8 1/2	5/16	4.5	46	C 15x33.9	18.33	4	1 7/16	1	1/8	3/16	5	7	41.8	11.7	91.5	574.8	160.7	1032.0
60	W 33x118	3/4 x 9 1/2	1/4	5.5	49	C 15x33.9	20.00	4	1 1/2	2 1/8	3/16	1/4	5	7	46.2	12.8	92.4	693.0	191.3	1155.9
65	W 33x130	7/8 x 9 1/2	5/16	6.0	53	C 15x33.9	21.67	4	1 13/16	2 9/16	3/16	5/16	5	7	50.4	13.8	93.1	818.6	224.5	1278.8
70	W 36x135	15/16 x 10	5/16	6.5	57	MC 18x42.7	23.33	4	2	2 7/8	1/4	5/16	6	8	55.0	14.9	93.7	961.6	260.3	1400.6
75	W 40x149	15/16 x 10	5/16	7.5	60	MC 18x42.7	25.00	4	2 5/16	3 3/16	1/4	3/8	6	8	60.0	15.9	94.1	1125.0	298.8	1521.4
80	W 40x167	15/16 x 10	5/16	8.5	63	MC 18x42.7	20.00	5	2 9/16	3 5/8	5/16	7/16	6	8	64.8	17.0	94.5	1296.0	340.0	1641.3
85	W 40x167	1 3/8 x 10	5/16	8.5	68	MC 18x42.7	21.25	5	3	4 1/4	3/8	1/2	6	8	70.6	18.1	94.7	1499.2	383.8	1760.4
90	W 40x183	1 1/2 x 10	5/16	9.5	71	MC 18x42.7	22.50	5	3 1/2	5	3/8	9/16	6	8	79.2	19.1	94.9	1782.0	430.3	1878.7
95	W 40x211	1 1/2 x 10	5/16	10.5	74	MC 18x42.7	23.75	5	4 1/16	5 9/16	1/2	11/16	7	9	83.6	20.2	95.1	1985.5	479.5	1996.3
100	W 40x211	1 7/8 x 10	5/16	10.5	79	MC 18x42.7	25.00	5	4 1/2	6 3/8	9/16	3/4	7	9	88.0	21.3	95.2	2200.0	531.3	2113.2
105	W 36x230	1 5/8 x 14	5/16	11.0	83	MC 18x42.7	21.00	6	5 5/8	7 15/16	11/16	1	6	8	92.4	22.3	95.2	2425.5	585.7	2229.5
110	W 36x245	1 7/8 x 14	5/16	11.5	87	MC 18x42.7	22.00	6	6 9/16	9 1/4	13/16	1 1/8	6	8	102.3	23.4	95.3	2813.3	642.8	2345.2
115	W 36x280	1 7/8 x 14	5/16	13.5	88	MC 18x42.7	23.00	6	6 13/16	9 11/16	7/8	1 1/4	7	8	107.0	24.4	95.3	3074.8	702.6	2460.3
120	W 36x300	2 x 14	5/16	14.5	91	MC 18x42.7	24.00	6	7 1/2	10 5/8	1	1 3/8	7	9	111.6	25.5	95.3	3348.0	765.0	2574.9

NOTES:
1. FOR BEARINGS AND END DISTANCES SEE SHEET NUMBER 807.
2. THE DEAD LOAD IS THE ADDITION OF THE LOADS IMPOSED BY THE BEAM/GIRDER, THE CONCRETE DECK SLAB, THE STAY-IN-PLACE DECK FORM AND THE CONCRETE HAUNCH. THE SUPERIMPOSED DEAD LOAD IS THE ADDITION OF THE LOADS IMPOSED BY THE CONCRETE PARAPETS AND THE FUTURE WEARING SURFACE.

STATE OF MARYLAND · CHARLES ROBERT KENNEDY · REGISTERED PROFESSIONAL ENGINEER

AISI SHORT SPAN STEEL BRIDGES

COMPOSITE ROLLED BEAMS WITH WELDED COVER PLATE NORMAL WEIGHT CONCRETE

DATE: SEPTEMBER, 1994 — DO NOT SCALE — HS 25-44 LOADING

DRAFTED BY:	DESIGNED BY:	CHECKED BY:	34'-0" ROADWAY
S.L.P.	S.T.	C.R.K.	406

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