AUBURN UNIVERSITY
Samuel Ginn College of Engineering

**Research Report**

# IMPACT OF PERMIT VEHICLES ON BRIDGES AND PAVEMENTS IN ALABAMA

*Submitted to*

The Alabama Department of Transportation

*Prepared by*

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**16. Abstract**
Permit regulations and heavy traffic monitoring procedures are developed to provide safety and protect the infrastructure from accelerated wear and tear. The number of issued permits is growing, but the impact of the overloaded vehicles has not been quantified. Alabama permit fee schedule has not been changed for decades; therefore, there is a need to evaluate the permit traffic-induced load effects. Thus, the objectives of this project are to assess the damage to bridges and pavements caused by permitted overweight vehicles in Alabama, calculate the damage for various types of vehicles and permits, and provide a background for the selection of a rational and equitable permit fee schedule. This project used ALDOT permit data for the years 2013-2021 to assess the damage. The study developed Alabama Transport Demand Model to identify heavy permit corridors and determine the types of bridges and roads utilized by the overloaded permit traffic. Over 160,000 permit trucks were considered. These permit trucks were run over 750,000 road links, and 195,000 bridges to determine the bridge and pavement damage. The damage analysis served as a basis for the development of new permit fee schedule scenarios. Four permit scenarios are presented for consideration. The permit fee is based on the calculated damage and depends on: (1) Gross Vehicle Weight (GVW) and number of trips, (2) GVW, number of trips, and number of axles, (3) GVW, number of trips and trip distance, and (4) GVW, number of trips, number of axles and trip distance. For the number of trips, the considered options include a single trip or multiple trip permits for 1, 3, 6, and 12 months. The permit fees were developed for GVW from 80,000 lbs to 200,000 lbs and vehicles with less than 6, 6, 7, and more than 7 axles. To calculate the actual permit fee, a Permit Fee Calculator was developed, and it is available in the form of an interactive spreadsheet attached to this report.

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# ABSTRACT

Permit regulations and heavy traffic monitoring procedures are developed to provide safety and protect the infrastructure from accelerated wear and tear. The number of issued permits is growing, but the impact of the overloaded vehicles has not been quantified. Alabama permit fee schedule has not been changed for decades; therefore, there is a need to evaluate the permit traffic-induced load effects. Thus, the objectives of this project are to assess the damage to bridges and pavements caused by permitted overweight vehicles in Alabama, calculate the damage for various types of vehicles and permits, and provide a background for the selection of a rational and equitable permit fee schedule. This project used ALDOT permit data for the years 2013-2021 to assess the damage. The study developed Alabama Transport Demand Model to identify heavy permit corridors and determine the types of bridges and roads utilized by the overloaded permit traffic. Over 160,000 permit trucks were considered. These permit trucks were run over 750,000 road links, and 195,000 bridges to determine the bridge and pavement damage. The damage analysis served as a basis for the development of new permit fee schedule scenarios. Four permit scenarios are presented for consideration. The permit fee is based on the calculated damage and depends on: (1) Gross Vehicle Weight (GVW) and number of trips, (2) GVW, number of trips, and number of axles, (3) GVW, number of trips and trip distance, and (4) GVW, number of trips, number of axles and trip distance. For the number of trips, the considered options include a single trip or multiple trips permits for 1, 3, 6, and 12 months. The permit fees were developed for GVW from 80,000 lbs. to 200,000 lbs. and vehicles with less than 6, 6, 7, and more than 7 axles. To calculate the actual permit fee, a Permit Fee Calculator was developed, and it is available in the form of an interactive spreadsheet attached to this report.

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# Chapter 1

# INTRODUCTION

In most U.S. states, the oversize and overweight permit regulations are outdated, and they have not been changed for decades. State agencies seek to establish a rational and fair permit fee structure based on damage assessment analysis. The permit fee schedule is to help control the operation of heavy vehicles and maintain the good condition of bridges and roads. Therefore, it is necessary to provide a method to adequately assess the monetary damage to bridges and pavements by overloaded vehicles.

The Weigh-in-Motion (WIM) data shows a growing number of overloaded vehicles operating on roads and bridges. These vehicles can cause overstress, fatigue cracking, etc., and therefore, can significantly reduce the service life of transportation infrastructure (bridges and pavements). Moreover, according to Alabama Oversize and Overweight Permits System database records, a growth in the number of issued permits is observed. Therefore, there is a need to determine the damage caused by overloaded permit vehicles and revise the permit fee schedule accordingly.

The objectives of this study are as follows:

- Assess the damage to bridges and pavements caused by permitted overweight vehicles in Alabama.
- Calculate the dollar damage for various types of permit vehicles.
- Provide a basis for a rational permit fee schedule.

This study developed an approach to calculate the damage to bridges and pavements in Alabama caused by permitted vehicles. The analysis is based on issued permit records provided by databases from 2013-2021. The results of the damage analysis serve as a basis for new permit fee schedule scenarios to be selected by the Alabama Department of Transportation. The proposed permit fee scenarios are presented for ALDOT consideration.

# Chapter 2

# LITERATURE REVIEW

## 2.1 FEDERAL TRUCK WEIGHT AND SIZE LAW

Traffic flow consists of vehicles with various types and configurations, number of axles, spacings, axle weights, and consequently different impacts on the bridges and pavements. Vehicles can be grouped as:

1) legal vehicles that do not exceed general regulations (federal truck weight and size law and state laws) for axle spacings and weights and do not require a permit;
2) special vehicles have exemptions under grandfather provisions; grandfather vehicles are legally overloaded vehicles under grandfather provisions, which are old rules that remain unchanged after new rules were introduced. Based on that, some vehicles can operate above the federal truck weight and size law;
3) permit vehicles, which can legally exceed the legal limits after purchasing a permit;
4) illegal vehicles, which do not meet the regulations exceeding gross vehicle weight, size, or weight and size limits, and operate without a valid permit.

Truck weight and size limits are legislated to ensure the safety of roads and bridges. The impact of heavy traffic needs to be monitored to control wear and tear caused by heavy traffic. Federal truck weight and size laws prevent states from imposing vehicle weight limits on interstate highways that deviate from established federal weight limits in the U.S. The traffic on an interstate highway is subjected to the standard federal weight limits ("23 U.S. Code § 127 - Vehicle weight limitations—Interstate System," 1974). There are also state-specific exceptions from standard law, called grandfather provisions.

Grandfather provisions allow exceptions to the federal limits on vehicle weight and size. These provisions are exempt from previously existing rules. The first provision, enacted in 1956, deals primarily with gross vehicle weights, axle weights, and permitting practices.

In 1975, federal law employed a Federal Bridge Formula (FBF) that limits the axle configuration and axle load distribution. Many states adopted their interpretations of weight laws under grandfather provisions, depending on local traffic conditions. The most common exemptions include vehicles carrying agricultural and farm products and commodities. The Federal Highway Administration (FHWA) reports that 41 states provide exemptions for "agricultural vehicles" (FHWA, Freight Management, and Operations, 2019).

Permit vehicles are overloaded vehicles that can operate legally after purchasing the permit. Overloaded permit vehicles can be oversized, overweight, or both. Permit vehicles need to follow the limitations specified in their permit, which may restrict the gross weight, single axle, and group axle weights. In the U.S., every state has its own policies on issuing permits but must follow federal rules. Permits allow vehicles of specific configurations and sizes to exceed the standard vehicle size and weight limitations. Permits can be issued for single or multiple trips. The permit may have limitations on designated routes, the number of trips, times of operation, and the necessity, or not, for escort vehicles. The movement of permitted oversized or overweight vehicles must also comply with the requirements and safety considerations specified by state law.

Illegally overloaded vehicles, with or without permits, belong to an unanalyzed portion of bridge traffic load more likely to create an extreme loading case. The traffic composition, with the presented types of vehicles, is shown in **Figure 2-1**.

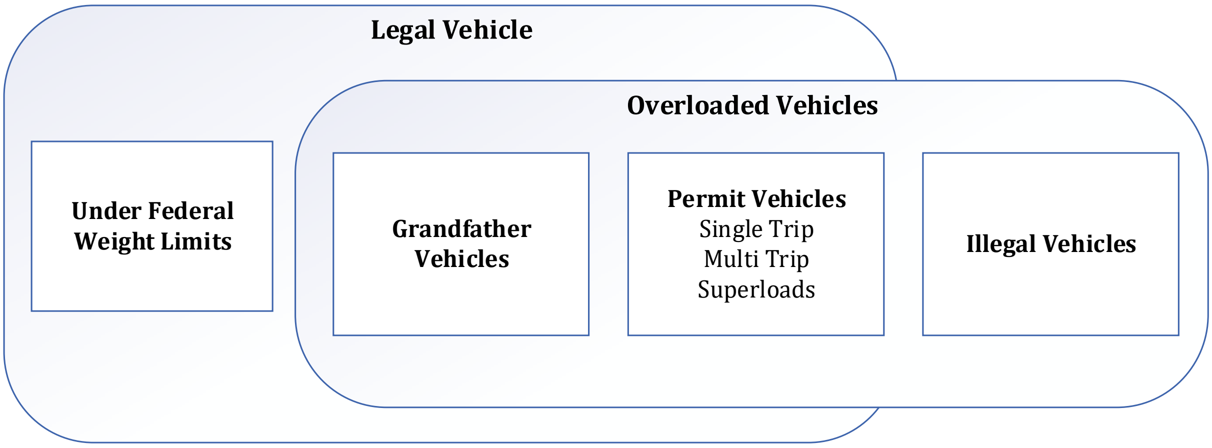



**Figure 2-1: Traffic flow – types of vehicles.**

Federal truck weight and size law consist of four conditions, which state that the vehicle is legal if its maximum Gross Vehicle Weight does not exceed 80 kips; the maximum single axle weight is no more than 20 kips, and the maximum tandem axle weight is 34 kips. The vehicle does not exceed Federal Bridge Formula (FBF), shown in Equation (2-1).

The U.S. Federal Bridge Formula is used to check the axle configuration and the axle load distribution. The formula limits the weight of any set of consecutive axles, and it is expressed as:

$$W = 500\left[\frac{(L \cdot N)}{N-1} + 12N + 36\right] \quad \textbf{(2-1)}$$

where:

$W$ – the overall gross weight on any group of two or more consecutive axles to the nearest 500 pounds [lbs.],

$L$ – the distance in feet between the outer axles of any group of two or more consecutive axles [ft],

$N -$ the number of axles in the group under consideration.

In general, bridge and pavement design codes specify a notional load model to represent the maximum expected legal vehicle loading. Vehicles seeking permits are compared to abnormal vehicles that the bridge has been found to have the capacity to carry. Overloaded vehicles are considered in the permit live load model and aim to represent heavy truck traffic. Illegally overloaded vehicles without permits belong to an unanalyzed portion of the bridge live load that is more likely to create an extreme lifetime stress condition.

## 2.2 PERMIT REGULATIONS

Permit regulations and heavy truck traffic monitoring procedures are developed to provide safety to the road and bridge infrastructure. Nevertheless, the issue of controlling the drivers violating the law remains unresolved, as well as the question of to what extent the vehicles can be overloaded. The law intends to protect motorists from traffic hazards caused by overweight and oversized vehicles or loads on state highways to minimize damage to infrastructure, thus protecting the investment in the highway system.

It is required by the federal truck weight and size law for every state jurisdiction that vehicles exceeding the legal limits on size and/or weight must purchase permits to legally operate within that jurisdiction. State DOTs issue permits daily to oversize, overweight, or oversize and overweight vehicles. The permit fee structure varies significantly by state. There are typically single and annual multi-trip permits. The annual multi-trip permits are valid for 12 months and an unlimited number of trips. Single trip permits are valid for one trip from one point of origin to one destination. In the U.S., there are five basic permit fee structures, including flat fees, distance-based fees, weight-based fees, weight-distance-based fees, and axle-based fees. **Figure 2-2** shows the permit fee structure adopted by different states (Chowdhury et al., 2013).

Permit regulations vary from state to state, but also the permit fees are very different. The comparison of permit fees for selected states was presented by (Ali et al. 2020). **Figure 2-3** presents single trip permit fees in the selected states for the vehicles with a total gross weight of 95 kips in terms of miles traveled. It can be noticed that fees are very different, which indicated the discrepancies in the approach. **Figure 2-4** presents the multi-trip permit fees comparison in terms of a fixed price, where in Alabama it is $100, but in Tennessee, the same permit fee is $750, and in Mississippi $4500. The permit fee schedule may be distinctive because some of the permit fee schedules are outdated and have not been changed for many decades. A growing number of permit vehicles raises concerns, and there is an evident need to develop a method to assess the state-specific impact of permit vehicles.

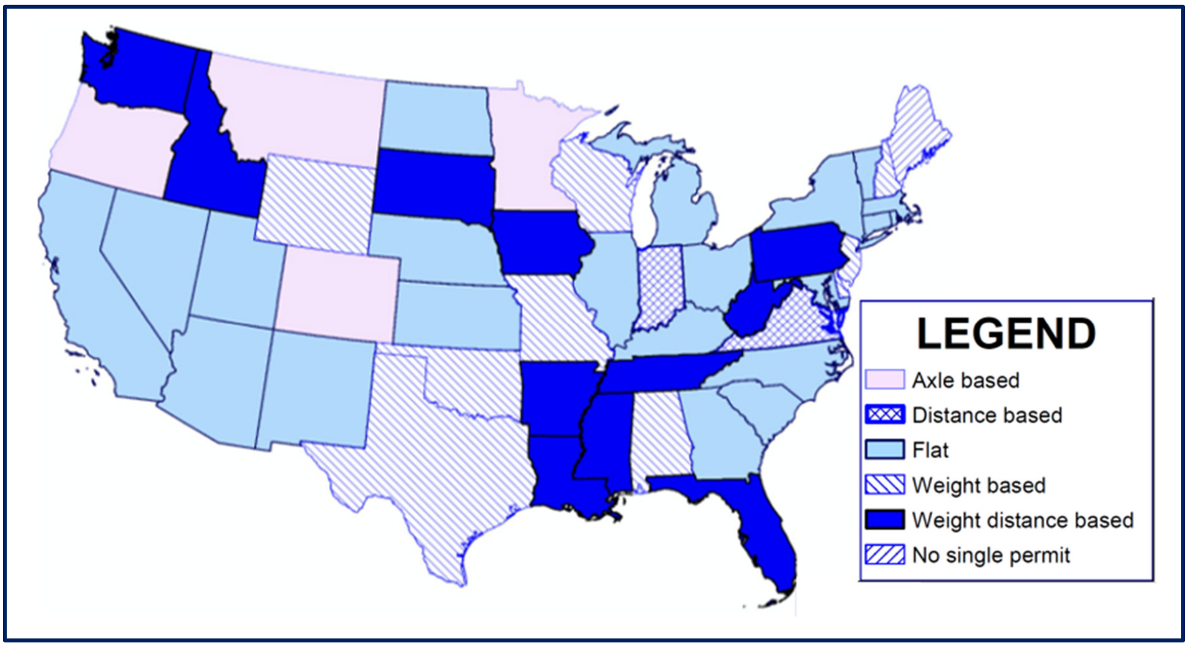



**Figure 2-2: Permit fee schedule types in the U.S.**

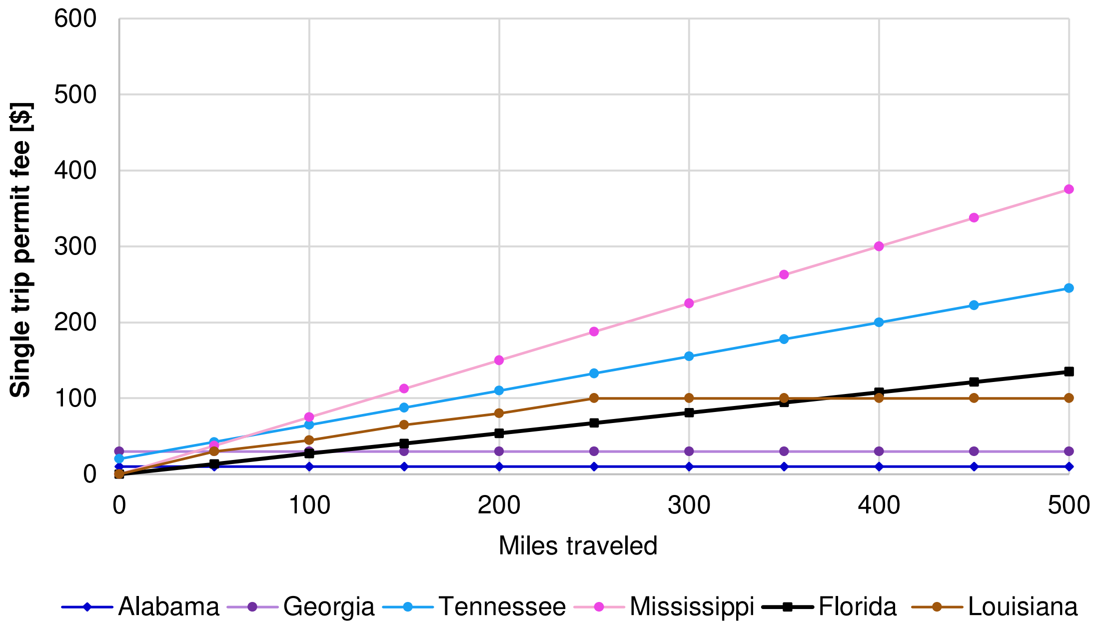



**Figure 2-3: Single trip permit fees vs. miles traveled for a single vehicle.**

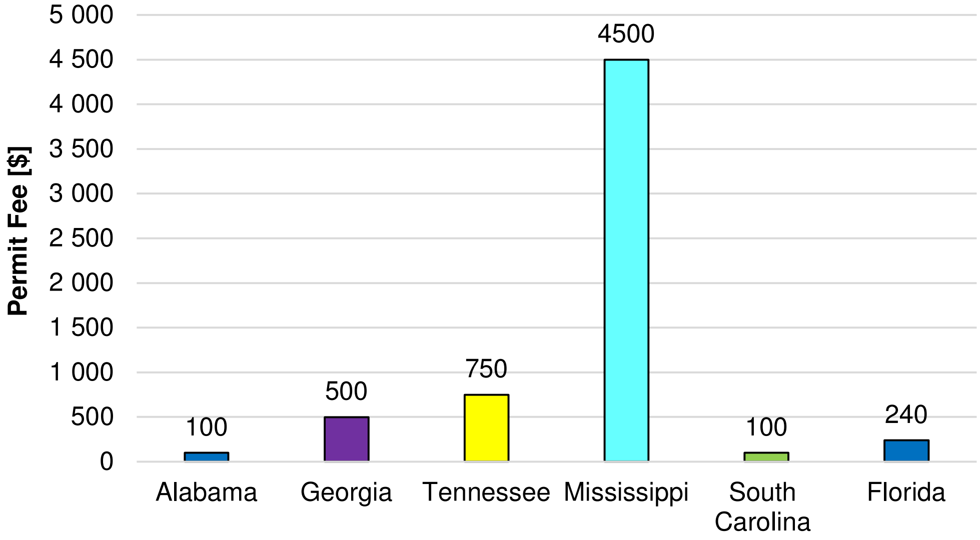



**Figure 2-4: Permit fees for an annual multi-trip for the selected states.**

### 2.3 TRAFFIC MONITORING DATA

The monitoring of traffic is an essential role of all road administrators, like DOTs and the Federal Highway Administration. It allows traffic management to make traffic operations at the required and sufficient level of service and safety. Moreover, traffic monitoring enables observation of the induced load effects, which is essential to maintain the safety of the road infrastructure. It uses static methods, which are local, selective, and measure only a small fraction of the highway network truck traffic. Static measurements can be performed by portable scales and weigh stations. Weigh stations are located off-road and typically have static scales built into the pavement. In these systems, an operator checks if the legal weight limits have been violated. It should be emphasized that the weigh station locations are known by truck drivers, and illegally overloaded vehicles may avoid them, resulting in biased truck weight data.

Weight-in-Motion (WIM) systems provide in-motion measurements. WIM enables continuous recording of vehicles passing a given cross-section at full speed. It is a powerful tool to collect a big traffic database. They can operate for a long time when only periodical maintenance and calibration activities are required. In most cases, WIMs are installed like weigh stations at known locations, and they can be avoided by illegally overloaded vehicles either. WIM systems collect traffic data, which are recorded automatically without any operator. Detailed attributes including a vehicle configuration, vehicle class, measurement date and time, occupied lane, trip direction, moving speed, and truck axle weights and spacings are stored in the WIM data.

## 2.4 DATA QUALITY CONTROL

Assessment of the live load effect is critical in designing and evaluating roads and bridges as well as maintaining the infrastructures' safety. Hence, it is vital to assess the load effects adequately. Underestimating the live load effect can cause premature damage to road infrastructure, and overestimation can cause a significant increase in road infrastructure construction cost and maintenance.

It is required to verify the data quality to accurately assess traffic-induced load effects and to eliminate any data inconsistency and sensor failures. There are uncertainties involved in the measurement process that has to be considered while dealing with large traffic data sets. Several factors can affect the accuracy of the weigh-in-motion measurements, such as pavement roughness (causing bouncing axle movement or dynamic impact), temperature effects, multiple vehicle presences, incorrect vehicle position, etc.

There are many studies considering quality control checks of traffic data (Anitori et al. 2017; Elkins and Higgins 2008; Fiorillo and Ghosn 2014; Kulicki et al. 2015; Liao et al. 2015; Nichols and Bullock 2004; Quinley 2010b; Ramachandran et al. 2011; Ramesh Babu et al. 2019; Sivakumar et al. 2008; Stawska et al. 2021a). However, there is still no uniform Quality Control procedure. All states collect traffic data as part of FHWA's Highway Policy Management System, and the data quality must meet the minimum requirements prescribed in the guides (Quinley 2010). The quality and quantity of traffic data for bridge design and evaluation purposes have been examined extensively by Ghosn et al. (2011) and Sivakumar et al. (2008).

The Auburn Team developed a Quality Control (QC) procedure with various data checks, such as WIM site description, timestamps, duplicated or null records, and vehicle configurations. The QC procedure begins with the basic checks concerning WIM station ID, traffic lane, and trip direction. If the data does not pass the data description check, it is flagged as invalid and, in most cases, discarded from further analyses. WIM data is validated for the correct year, month, day, and time. It is also checked for duplicated records with identical vehicle weights and configurations. Duplicated and null records are flagged and discarded. Based on previous experience with WIM data analysis, it is observed that data duplication or null records are common errors.

After WIM data are checked for description, time, nulls, and duplicates, the major step to identify errors in the vehicle configuration includes analyzing Gross Vehicle Weight (GVW) and axle weights and spacings. All data records with zero weight are flagged and eliminated. The number of axles and axle spacings is checked to determine if the vehicle was recorded correctly by the system sensors. The sum of axle weight is also compared with the GVW, with ±a 10% tolerance. Left and right wheel weights are compared for every axle, with ± 40% tolerance.

The WIM records are checked for the minimum first axle spacing and minimum axle spacing based on the literature review and traffic analysis to verify tandem and tridem axles. Also, the threshold limit is verified for steering axle weight and for a single, tandem, and tridem axle weight. **Table 2-1** presents the developed filtering criteria for the QC procedure to check the truck traffic data quality.

**Table 2-1: Filtering criteria for WIM Quality Control procedure.**

| Type | Filtering criteria | Threshold limits |
|---|---|---|
| **WIM description** | Station ID | Null or invalid state I.D. |
| | Lane of travel | ≠ (0-9) |
| | Direction of travel | ≠ (0-9) |
| **Timestamp** | Invalid year | Null or irrespective year |
| | Invalid month | ≠ (1-12) |
| | Invalid day | ≠ (1-31) |
| | Invalid time | ≠ (0-86399) sec. |
| **Duplicates** | Identical records | Exact copy |
| | Same axle weight for consecutive axles | Axle weight = Axle weight n+1 |
| **Vehicle configuration** | Invalid vehicle class | ≠ (1-13) |
| | Zero GVW | = 0 |
| | Zero axle spacings | = 0 |
| | Number of axles is an equal number of recorded axles weights | Number of axles = Number of axle weights |
| | Number of axles spacings | ≠ (1-21) |
| | The number of axles is equal to the number of axles spacings + 1 | Number of axles ≠number of axles spacing +1 |
| | Sum of axle weights is equal to GVW ± 10% | ± 10% of GVW |
| | Minimum first axle spacing | < 6 ft |
| | Minimum axle spacing | < 3.3 ft |
| | Steering axle weight | > 18 kips |
| | Single axle weight | ≠ 1.2-60 kips |
| | Tandem axle weight | > 60 kips |
| | Tridem axle weight | > 80 kips |
| | Left and right wheel weight difference | ± 40% |
| **Speed limits** | Vehicle speed | ≠ 10-90 mph |

WIM data records were used in many research studies to account for the site-specific nature of traffic and to develop more efficient traffic design provisions (Ali et al. 2020; Anitori et al. 2017; Leahy et al., 2015).The changes in truck traffic volume, axle load, and configuration in recent decades are reviewed by (Ali et al. 2020; Anitori et al. 2017; Ghosn et al. 2011; Liao et al. 2015; Stawska et al. 2021b, 2022).

Protocols for collecting and using traffic data in infrastructure design provide a methodology to calculate site-specific traffic load effects using the Weigh-in-Motion database. The traffic volume, gross vehicle weight, and configuration had changed. The available truck traffic data collected from different WIM sites around the U.S. can be utilized, as it includes detailed information about vehicle weight and configuration. Sivakumar provides a step-by-step procedure that can be followed to obtain site live load models for design. The methodology includes requirements for WIM data collection, quality, and quantity control. The traffic data needs to be verified to eliminate questionable records. Quality Control procedures are introduced to eliminate biased records. WIM data validation and system calibration must be checked to recognize eventual issues. The multiple presence of vehicles is presented, and the actual percentage of side-by-side multiple truck events needs to be verified. The protocols provide a recommendation on live load model updates. It is a complex procedure that can be utilized to update the live load factors for AASHTO provisions (Sivakumar et al. 2008)

### 2.5 IMPACT OF PERMIT VEHICLES ON BRIDGES

The impact of overloaded vehicles on bridges is essential to assess the damage and behavior of bridges under excessive traffic loading. To protect the public's safety and maintain the bridge condition, regular bridge inspections and traffic enforcement are required. This section presents significant studies on the impact of overloaded traffic on bridges.

The behavior of steel bridges under superload permit vehicles was investigated for different types of vehicles to develop a simplified analysis method (Culmo et al. 2004). The longitudinal and lateral load distributions over different bridge spans for various truck trailers were examined. The study was based on the passage of a large permit vehicle used to transport power plant equipment across a specific bridge in Connecticut. Strain gauges were used to check the strains and dynamic impact on the bridge girders. The measured strains from superload vehicles were significantly lower than those calculated by the AASSHTO Guide Specification for Distribution of Loads for Highway Bridges. The conservative damages in the AASHTO guide are appropriate for the superloads. This is a very important and practical conclusion that there is no need to change the method for superload analysis.

Fatigue of older bridges in northern Indiana due to overweight and oversize loads was conducted to evaluate the fatigue behavior of steel bridges on the heavy-duty corridor between Indiana and Michigan. This research was presented in two volumes. The first one was to determine heavy load spectra in the considered corridor and check the bridge response on that traffic. The second volume aimed to estimate the remaining fatigue life of steel bridges along the heavy-weight corridor. The major contributions for both volumes are presented.

In the first volume, Reisert and Bowman (2005) assessed the magnitude of the traffic-induced load on the heavy-duty corridor to determine the effects on the fatigue strength of the steel bridge structures. The representative bridge structures were selected within the extra heavy-duty highway. The WIM system situated in proximity to bridges was used to evaluate the truck loads. Also, strain gauges were installed to assess the response of the bridge under the traffic loading. The structural analysis models (2D and 3D) of the bridge were presented. The predictive analysis was conducted, and structural models' behavior on known truck loading was compared to the strain measurements. It was found that a 3-D finite element model was accurately predicting the bridge response. In the analysis, class 9 and class 13 vehicles were chosen as representative heavy trucks. The legal limit for class 9 trucks is 90,000 lbs. and 134,000 for class 13. The results indicated that 15% of the Class 9 trucks and 26% of the Class 13 trucks traveled heavier than their respective legal limits. Extreme weights of more than 200,000 lbs. were observed. The analytical model on the heavy-weight corridor did not appear to be a fatigue issue. However, the second stage of the study was to develop a more thorough analytical model (Reisert and Bowman 2005).

In the second volume, Chotickai and Bowman (2005) analyzed the fatigue strength of steel bridges on extra-heavy corridors. The fatigue truck model was developed for the 3-axle and 4-axle vehicles that accurately represent the existing traffic for 2-5 axle trucks and 8-11 axle vehicles. The study introduced a fatigue reliability model. The developed procedure allows for determining the remaining fatigue life of in-service steel bridge structures. The reliability model may provide a more accurate estimate of fatigue life evaluating uncertainties involved in the fatigue damage assessment method. The reliability model was evaluated through field measurements of two bridges using the strain gauge measurements and the development of 2D and 3D analytical models. The fatigue evaluation of the remaining fatigue life for selected bridges was obtained on the heavy-weight corridor. The remaining fatigue life for critical details was estimated as 25 years (Chotickai and Bowman 2005).

Bridge analysis and evaluation under overload vehicles were studied by Han-Ug Bae and Michael Oliva (2009). They developed a user guide to calculating the impact of overloaded vehicles for single and dual-trailer configurations. A procedure was introduced to assess the impact of vehicles on the multi-girder bridges. The number of possible special vehicle configurations of vehicles is significant, and it is problematic for state DOTs to assess the damage for every individual vehicle. The overloaded vehicles need to be adequately evaluated to keep bridge structures safe. Special vehicle permits are evaluated individually for the vehicles and the route. It is very time-consuming and vulnerable to errors. Therefore, a simplified multi-girder bridge analysis was introduced. Girder distribution factor for a moment and shear for a single and dual trailer is provided. A minimum number of girders, bridge span, girder spacing, and deck thickness ranges are given. This method does not include multi-presence and dynamic allowance. The deck investigation is also included and considered punching and flexural failure. Punching shear is determined by the correlation between the single wheel and two-wheel set space 6 ft apart, with interpolated factors for minimum longitudinal and transverse wheel spacing for overloaded vehicles. The example calculations for simplified methods are presented in that study (Bae and Oliva 2009).

In the second phase of the project, Ug-Bae and Oliva (2012) analyzed the effect of overload vehicles on bridges, specifically on concrete decks and steel girders. This study examined long-term effects on bridge behavior. Bridge life cycle cost was checked along with the development of mean costs assign per overload of vehicle. The analysis considered the effect of design truck HL-93 and overloaded vehicles per single and dual lanes for the most severe permit case noticed for ten years of permit data in the Wisconsin Department of Transportation (WisDOT). The effects of selected trucks were checked for two types of decks and steel girders. Then the bridge life cycle was considered in the design and construction cost of a bridge and maintenance and rehabilitation costs. The Net Present Value calculation was introduced, accounting for the discount rate, cash flow period, and present value. A procedure to calculate the cost assigned to overloaded vehicles to the deck and steel girders was presented for long-term fatigue damage. The approach included moment calculations for overloaded vehicles, a number of cycles to failure at the considered stress level, and the cost of deck and steel girders. For future recommendations, the simplified approach for common bridges was to be developed to assess the cost associated with permit vehicles to bridges (Ug-Bae and Oliva 2012).

Evaluation of a permit vehicle model using weigh-in-motion truck records used 5% of the heaviest WIM vehicles for each vehicle class to verify the adequacy of the notional permit vehicles in Wisconsin. The live load analysis for simple span and 2-3 continuous span bridges was used. It was concluded that 5-axle, short trucks might cause greater load effects in bridge girders than standard permit vehicles. Therefore, a new 5-axle truck model was proposed to supplement the standard permit vehicle for Wisconsin's bridge design and rating procedures. The state-specific traffic model was used to adjust the code provisions (Zhao and Tabatabai 2012).

Another study checked the bridge rating under superloads. The study rated over 50 bridges for a trip from California to Utah for the superload vehicle with a GVW of 1,500 kips. The analysis contained AASHTO rating procedures, with adjustments in analyzing old bridges and their material deficiencies. Concrete and steel strength was adjusted for bridges built before 1980. Also, additional bridge restrictions and specialized inspections were considered, including bridge closing, speed limits temporary shoring. The movement of superload over the bridges was changing and required special analysis that was time-consuming, costly, and damaging to infrastructure. The suggested approach included the use of screening vehicles, which guide permitting procedures. A permitted truck can safely operate for a single trip if its axle weights and spacings fall within any of the proposed screening vehicles (without considering types, capacities, or span configurations of the bridges that a permit truck will pass on its route). Otherwise, a vehicle needs to be further evaluated by other methods. This method offers sets of screening trucks, which then can be checked against rating trucks. The goal is to make the permitting process easier and propose as many as possible screening vehicles that reflect the state-specific permit vehicles (Lawson et al. 2013).

The truck permitting policy on the U.S. bridge loading was analyzed using WIM data from Arizona, Illinois, and Indiana. The accurate effects of traffic loading are essential for bridge management and safety. The selected three configurations of heavy vehicles were analyzed. It was established that the live load model provides a good agreement when compared to the load effects calculated directly from the WIM data. WIM data may be an excellent source of data to evaluate the load effects caused by overloaded vehicles and provide a basis to improve the permit fee structures (OBrien et al., 2013).

The traffic is constantly changing, and the number of issued permitted and overloaded vehicles increase. Overloaded vehicles contribute significantly to bridge life damage. The cost attributed to the repair and maintenance of the highway infrastructure system due to the overloaded vehicles can be appalling. The WIM data may be used to verify the number and load effects of overloaded vehicles operating on bridges. Detailed information provided by the WIM system allows evaluation of the effects caused by existing traffic.

Another study presents the data mining procedure to identify overloaded vehicles, categorized as permits and illegal vehicles. The algorithm was developed to distinguish the heavy vehicles in upstate New York. The algorithm validation was compared with the results of a truck survey performed by the New York State Department of Transportation (NYSDOT). A parametric analysis was executed to assess the sensitivity of the results and the level of accuracy of the WIM system. It was concluded that the algorithm produced statistically robust overweight truck and permit categorizations, which could eventually help highway agencies establish rational permit issuance policies, weight enforcement strategies, and cost allocation studies. Assessment of load effects caused by overloaded vehicles is essential in bridge posting decisions. The maximum expected load effects from permit and illegal vehicles could be distinguished from the WIM database and analyzed separately to update bridge evaluation policies (Fiorillo and Ghosn 2014).

Wyoming DOT conducted a study to assess the safety of the bridges on the I-80 corridor. Wyoming I-80 carries a large volume of heavy trucks compared to many states. Hence, the study verified if the AASHTO provisions provided adequate provisions for heavy traffic. The reliability-based analysis was done to examine if the current provisions provided a minimum safety level at the target reliability index. The WIM data was used to develop a live load model. The traffic-induced loads were computed on a simple span and two equal continuous spans for 30-200 ft. The live load was extrapolated for a 75-years economic bridge lifetime. Reliability analysis was conducted for steel bridges, with varying dead, wearing surface, and live load ratios. It was concluded that the AASHTO LRFD did not provide adequate safety, and it was proposed to increase the live load factor from 1.75 to 2.0 to achieve the minimum required safety set by the target reliability index for design 3.50 (Barker and Puckett 2016).

The second phase of the Wyoming DOT study on assessment and evaluations of I-80 truck loads was conducted to assess the serviceability of existing bridges. Reliability-based analysis was performed for 112 steel bridges and 60 prestressed concrete bridges. The considered limit state functions were Service II and Service III. The aim was to verify the adequacy of safety levels for serviceability limit states. The analysis showed that the AASHTO provisions were deficient for I-80 Wyoming traffic. The live load factor for Service II limit state (yielding) and Service III (prestressed concrete cracking) was increased from 1.30 to 1.45 and 0.80 to 1.00 to provide a minimum acceptable safety level (Barker et al. 2020).

Load-carrying capacity evaluation of the girder bridge using the moving vehicle was checked by displacement analysis of moving vehicles using a radar measurements system. The FEM model verified the method, and it was proven that the presented bridge evaluation was effective and could be used instead of the conventional bridge testing method (Sun et al., 2021).

The presented literature review emphasizes the importance of bridge damage assessment under heavy traffic. There is a need to quantify the effect of a growing number of permit vehicles. This is an important issue, which has been sponsored by federal and state agencies. Damage assessment under overloaded permit vehicles may provide a rational basis to update a permit fee schedule.

### 2.6 Impact of Permit Vehicles on Pavements

The impact of heavy traffic on roads is crucial to assess the damage and behavior of pavements. This section presents significant studies on the impact of overloaded vehicles on pavements.

Sadeghi et al. (2007) conducted research to evaluate the deterioration pattern of flexible pavement under heavy traffic. A theoretical method was used to assess the impact of overloaded vehicles on pavements. The sensitivity analysis allowed a selection of the most critical pavement damage parameters such as thickness, pavement temperature, subgrade conditions, and the impact of a vehicle's speed on pavement. These parameters were considered for different loading conditions. Rutting and fatigue damage were two main distresses that were considered in the model (Sadeghi and Fathali 2007). The procedure included modeling the pavement, geometry, mechanical features, loading pattern, failure criteria, and analysis method. It recognized the effective parameters of pavement damage and used them for mathematical modeling of the load-operational life. The pavement deterioration was checked for two, three, and five-axle trucks. The permit fees were determined based on the life reduction factors and the total cost of pavement. The developed method used the following parameters: heavy truck traffic volume, length of the permit vehicle trip, average pavement unit cost, thickness, and temperature of pavement, bearing ratio of subgrade, and vehicle speed and type. An algorithm to calculate individual fees per overload was developed.

The fatigue cracking performance of asphalt concrete was studied by simulating various truck axle configurations and using the indirect tensile cyclic load test. The analysis was based on dissipated energy to determine the number of load cycles to failure. The fatigue curve was fitted for each axle configuration. Based on the results, multiple-axle groups cause less fatigue damage per tonnage compared to single axles. The damage decreased at a significant rate between single, tandem, and tridem axles (Chatti and El Mohtar 2004).

A similar laboratory test was conducted to evaluate the rutting of the asphalt mix and to check if rutting damage was proportional to axle configuration and vehicle weight. It was found that multiple axles produce more rutting damage than those with only single and tandem axles, but single and tandem axles tended to cause more cracking. Pavement roughness results did not show enough evidence to draw a solid conclusion (Salama et al. 2006).

In the Ohio study, the effect of various axle and truck configurations on pavements was studied. This study used the distress index to measure cracking and the ride quality index to measure rutting and roughness. The results showed that trucks with single and tandem axles appeared to affect pavement cracking more than those with multiple axles. On the other hand, trucks with multiple axles cause more rutting damage compared to tandem axles. Thus, the roughness of the pavement did not show a strong correlation with the type of axle configuration (Ohio Department of Transportation 2009). The impact of overloaded vehicles on road pavements was checked using the truck factors for different vehicle cases applied to a set of pavements composed of five different asphalt layer thicknesses and five different subgrade stiffness moduli. For various trucks, the sum of the ESAL for all axles was calculated. Truck factors were taken as the average of a truck factor for each type of truck considered in the traffic spectrum.

Pais et al. (2013) analyzed the impact of overloaded vehicles on pavement performance using the average axle load for each vehicle type, the percentage of overloaded and legal vehicles in each class, and the frequency of passage. The analysis utilized the truck factor of overloaded and legal vehicles, along with pavement thickness and subgrade stiffness moduli on the truck factor. The results showed that the truck factor decreased as the asphalt layer thickness increased, and there was a minor increase in the truck factor when the subgrade stiffness increased. It was confirmed that overloaded vehicles did not cause more damage to the pavement than vehicles with the maximum legal load in all axles. Also, it was concluded that the effect of vehicle loads was diminished by increasing the asphalt layer thickness. The influence of the subgrade on the vehicle load effect was very low when the primary pavement distress was fatigue cracking. The study revealed that if vehicles were considered to be at their maximum legal weights for consideration in pavement design, the effect of overloaded vehicles on pavement performance was reduced. This means that the effect of overloaded vehicles was almost the same as the effect of the maximum legal weights on pavement performance. However, the presence of overloaded vehicles could increase costs by more than 100% compared to the cost of the same vehicles with legal loads. The results showed that pavement thickness required 10 cm for some vehicles, and the proportional cost could be as much as 30% (Pais J. C. et al. 2013).

WIM data was used to find a correlation between the fatigue damage of pavement and the number of overloaded trucks. The analysis showed that an increase in the percentage of overloaded vehicles from 0% to 20% could reduce the fatigue life of asphalt pavement by about 50%. Additionally, the research indicated that a 10% decrease in overloaded trucks could increase the pavement's service life from 4 to 6 years (Rys et al., 2016). The effects of vehicle axle configuration on the pavement were measured based on WIM data in three months to quantify axle loads (Raheel et al. 2018).

In a study on Washington's fine system, the overload truck traffic model was developed to find the relationship between the economic impact and the current system's effectiveness. The investigation was conducted by interviewing weight enforcement officials and court personnel in addition to an examination of over 8,000 overweight citations from nine counties between September 1991 and August 1992. The results showed that increasing the fines for overloaded vehicles would decrease the incentive to overload while also increasing the net revenue per permit and citation. Also, the enforcement effort to capture the overload violation reduced the impact of overload (Jessup 1996).

The costs and benefits of increasing the GVW of the truck's weight legal limits were studied. The GVW was increased by 125%, 135%, and 145% of the legal limit. The fourth-power rule was used to estimate the ESALs for each load level and was assigned to the cost rates of the interstate, state, and local highways (Meyburg et al., 1996). The potential benefit was calculated by assuming that freight traffic made fewer but heavier trips to deliver goods. The analysis showed that by decreasing the number of trucks (heavier loads), trucking companies benefit more from lower labor costs and fewer trips.

The Transportation Association of Canada examined the effects of reducing the number of overweight trucks on the highways. The study used a mechanistic-based pavement analysis method to quantify the incremental damage resulting from commercial vehicle overloading. The distresses were quantified using the structural asset management data and heavyweight deflect meter data. Assuming 30,000 trucks per day, 15% of them being overloaded trucks, it resulted in an overall road damage cost of $621 per kilometer per day and an overall cost of $226,677 per km per year (Podborochynski et al. 2011).

Life-Cycle Cost Analysis (LCCA) estimates the cost over the life of the project segment, which is mainly initial construction and maintenance costs. The two most important factors in the LCCA assessment were an analysis period and discount rate. The analysis period would be long enough to include pavement rehabilitation treatments. The analysis period of 40 years for new construction and 30 years for pavement rehabilitation was suggested by the NCHRP Guide for Pavement-Type Selection. The discount rate was usually from 3% to 5%. The long-term discount rate values can be found in the updated edition of the Office of Management and Budget Circular A-94. Maintenance costs were calculated using the cost formula proposed by the New Jersey DOT (NJDOT) (Nassif et al. 2015).

The state-of-the-art review shows the importance of pavement damage assessment under heavy traffic-induced loading. Two common ways to assess pavement damage are axle equivalency factors and the Mechanistic-Empirical method using fatigue and rutting life. These methods can provide a basis to determine pavement monetary damage under overloaded permit vehicles.

## 2.7 PERMIT FEE SCHEDULE

The permit fee schedule in the U.S. varies significantly from state to state. The permit fees and permit criteria are very different and can be based on axle weight, gross vehicle weight, distance, weight, and distance, or a flat fee.

State agencies seek to establish a rational and fair permit fee structure based on a damage assessment analysis. Therefore, it is necessary to provide a method to assess the monetary damage of overloaded vehicles on bridges and pavements. A growing number of overloaded vehicles needs to be quantified in terms of load effects on bridges and pavements to maintain good conditions and safety. Therefore, the permit fee schedule needs to be checked for adequacy. It raises concerns, and there is an evident need to develop a method to assess the state-specific impact of permit vehicles.

Several states conducted damage assessment analysis on pavements and bridges, and the state of the art is listed below.

***Effects of Hauling Timber, Lignite Coal, and Coke Fuelon Louisiana Highways and Bridges***

(F. L. Roberts et al. 2005)

Roberts et al. (2005) performed a study to assess the economic impact of the overweight permitted vehicle hauling timber, lignite coal, and coke fuel on pavements and bridges. The highway roads and bridges utilized by the hauls were identified. About 2,800 bridges were considered in the study. Three different weight scenarios were selected for the research: 80,000 lbs. (legal limit) 86,600 lbs. or 88,00 lbs. (permit practice), 100,000 lbs. (proposed permit limit). Also, additional analysis for a tandem load of 48,000 lbs. was considered since it was the maximum permissible tandem axle load in Louisiana.

The bridge analysis was considered for simple and two equal span continuous bridges with span lengths varying from 20 ft to 120 ft. Moments, shear load effects, and deflection were computed for H15, HS-2044, and 3S2 loading. The analytical model for the bridge deck was developed, and the stresses caused by the considered truck were checked. The cost to repair fatigue damage for each vehicle passage was calculated.

The study showed that permit fees paid by timber trucks should increase from $10 per year to around $346/year/truck for a GVW of 86,600 lbs. If 48-kip tandem is allowed, the permit price should be increased to $4,377/year/truck. The current permit fee for lignite coal should remain at current levels. The DOT should not raise the GVW level to 100,000 lbs.; such a change from 86,600 lbs., would double the cost of pavement overlays. In many cases, the bridge costs per passage of a loaded truck amount to $8.90, meaning that the cost of bridge damage per truck per year could easily exceed $3,560.

***Estimating the Cost of Overweight Vehicle Travel on Arizona Highways***

(Straus and Semmens, 2006)

Straus and Semmens (2006) assessed the impact of overweight vehicles on Arizona state highways. It was reported that damage caused by overweighed vehicles consumed millions of dollars for maintenance, rehabilitation, and replacements. Overweight vehicles imposed approximately $12-$53 million of damage on Arizona roadways. The Arizona enforcement budget was $5.8 million per year. It was calculated that if doubling the enforcement budget, where 50% of that budget was aimed towards the elimination of illegal vehicles from roadways, the savings would be at the range of $6-$27 million per year.

The enforcement personnel survey was conducted, and the recommendation for the state's enforcement was made. It was concluded that for every dollar invested in motor carrier enforcement efforts, there would be $4.50 in pavement damage avoided.

***Impact of permitted trucking on Ohio's transportation system and economy***

(Ohio Department of Transportation 2009)

Ohio Department of Transportation presented a study on the impact of permitted trucking on Ohio's transportation system and economy. Combined bridge and pavement impact cost was established at $144 million annually, where $122 million resulted in pavement and $22 million in bridges. For bridge structures, the study used the incremental method to quantify the damage directly in terms of dollars. The impact was assessed for various roads, using bridge asset value per square footage, assuming the following bridge maintenance activities $75/sq. ft. for deck replacement, and $20/sq. ft. for steel beam painting. Annual bridge preservation cost assigned to overloaded vehicles was calculated, and total asset damage to find annual bridge costs assigned to overweight vehicles. The multi-trip permit survey was conducted to find the number of trips for annual permits and the average length of the trip. The number of trips was estimated as 24.8 trips per year, and the average length of the trip was 98.8 miles. The permit cost was computed based on permit vehicles' GVW, Equivalent Single Axle Load (ESAL)/mile, and miles traveled.

***Oversize/Overweight Vehicle Permit Fee Study***

(Prozzi et al. 2012)

Prozzi et al. (2012) performed a study to assess the damage caused by oversize and overweight vehicles on bridges and pavements in Texas, along with enforcement and management costs. The methodology was developed to find infrastructure damage in dollars per mile. A new permit fee was proposed for 34 different rate categories. Also, the administrative cost of $10 was added as required for each issued permit and TxDOT Base Fee of $40 to help recover fee revenues. Permit fees from 2011 generated $111.4 million in revenue, the new permit fee structure would generate $521.4 million, and considering permits for exempt vehicles, the revenue was estimated as $671.4 million. The analysis results showed that the current permit fee schedules may be inadequate and disproportional to the damage caused by overloaded vehicles.

***Aligning oversize/overweight fees with agency cost: critical issues***

(Adams et al., 2013)

Adams et al. (2013) reviewed the permit practices and guided the fee structure and permit demand management. It was noticed that some of the freight was favorable by the agencies, but others were the only possible mode of transport. Certain industries were crucial for the state's economic growth, and specific legislative provisions considered it. DOTs had to protect infrastructure first and later promote commerce. The recommendation from the study was to unify the permit fee system, reduce the time required to obtain a permit and simplify the administrative burden.

A new permit system ought to improve the fee structure, recognize, and adapt to traffic and economic trends, and contribute to overall management and uniformity. The study concluded that permit fees did not recover the issuance costs, but for some agencies, the fees were not designed to recover infrastructure damage and accelerated damage on roads and bridges.

***Review and Revision of Overload Permit Classification***

(Barker et al., 2013)

Michigan DOT requested a study to create a more robust system, which ensures the safety and control of the operation of overloaded vehicles. The study aimed to develop a system that assessed the impact of vehicles requesting a permit to more efficiently use the computing capacity and to reduce the number of manual bridge structural analyses. Moreover, it was intended to check the live load capacity of the bridges and flag those that were not able to carry overloaded traffic. The software that enhances the state permitting system was created as the study result. It was developed together with AASHTOWare and Vitris software.

***Rate of Deterioration of Bridges and Pavements as Affected by Trucks***

(Chowdhury et al. 2013)

South Carolina DOT commissioned a study to investigate the impact of heavy vehicles on pavement and bridges to develop policy recommendations. The pavement and bridge deterioration models were introduced, along with the trucking industry response to recommended permit fee schedule changes. The developed permit fee varied between $24 - $175 per trip and the flat fee was charged for all overweight trucks of $65 (including a $10 administrative fee). This research utilized WIM data to assess the live load effect. Finite Element bridge models were created to assess the stress range caused by heavy traffic. The fatigue damage and cost estimation allowed the development of a new permit fee schedule.

***Assessment of Current Design Loads for Permit Vehicles***

(Laman and Shah, 2016)

This study was designed to evaluate the current Pennsylvania DOT (PennDOT) Live Load Design Permit Vehicle, P-82 (8-axle, 204-kip truck configuration) and PHL-93, for adequacy as a model to predict loading effects of current special hauling permit vehicles, specifically from the heaviest Pennsylvania-issued superload permits. The study objective was to develop the analytical tools needed to evaluate the truck data files, both WIM, and superloads. The study proposed a permit vehicle model that enveloped all or most WIM and superload vehicles in the PennDOT-provided databases. The developed permit vehicle model was presented for PennDOT consideration. It could be used in bridge design, evaluation, and simplification of permit issuance.

***Development of a proposed overweight vehicles permit fee structure in Illinois***

(Al-Qadi et al., 2017)

Al-Qadi et al. (2017) performed an analysis to update the current permit system by evaluating the impact of overweight vehicles. The study assessed the damaging impact on pavements, bridges, and traffic safety. The bridge damage assessment was based on bridge load carrying capacity and vehicle weight frequency. National Bridge Inventory (NBI) and Weigh-in-Motion databases were utilized to develop the prediction engine to calculate the bridge fees. Extensive data-cleaning procedures were introduced. It was the first permit study that contained a large bridge data sample.

Previous studies considered only a few bridge structures, providing the FEM model, which involved high computational costs. The limited scope of samples raised the discussion about the bias associated with the research. This study considered the NBI database that included inventory rating for each bridge, which accounts as bridge strength. Also, the vehicle's weight frequency was calculated for available WIM sites and then combined by the location with the bridges.

An expected bridge life calculation considering overweight impact was performed. Bridge life-cycle cost analysis and damage quantification were conducted. It led to calculating the average damage cost per mile for representative bridges and traffic samples for Illinois. Permit fees were calculated as a summation of damage on pavements, bridges, and safety and introduced in a few scenarios compared with neighboring states for DOT consideration.

### *Impact of Heavy Trucks and Permitted Overweight Loads on Highways and Bridges Now and in the Future versus Permit Fees, Truck Registration Fees, and Fuel Taxes*

(Ali et al. 2020)

Ali. et al. (2020) developed a damage assessment approach to calculate the monetary damage caused by overweight permit vehicles on bridges and pavements in Florida. The bridge damage assessment was based on the fatigue damage measured by the equivalent bending moment on a representative bridge. Results of the bridge damage analysis are given in $/miles. For pavement damage, the cost was presented in terms of equivalent single axle loads (ESALs). The pavement and bridge damage costs were combined and presented in the same format as the existing overweight permit fee structure. Proposed fees were higher than the existing ones, and they reflected the actual cost of damage to Florida's roads and bridges. A new permit fee schedule could increase the permit revenue by a factor of 1.6-2.7.

### *Simplified Comparison of Oversize and Overweight Vehicles Permit Fee Structure in the U.S. Western States*

(Dehghan-Niri et al., 2020)

Dehghan-Niri et al. (2020) compared permit fee structures in 14 U.S. western states. The analysis included Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming. It was concluded that single-trip permits were more expensive in Texas, Colorado, Utah, and North Dakota. Also, Texas, Montana, and Arizona charged higher multiple/annual permit flat fees. The minimum and maximum fees for multiple annual permits varied from $88.43 and $981.32 for the considered states.

**Arizona**

The permit fees depend on the actual excess weight over a gross vehicle, axle weight, or both. According to the Arizona Department of Transportation, $4.2 million of revenue was generated in Arizona in the fiscal year 2018 from all oversize and overweight permit vehicles.

**California**

In California, the weight limits depend on the distance between axles, meaning that the legal weight also increases as the distance between axles increases. Also, when the axle separation exceeds a certain distance, they are considered single axles, and the maximum legal weight for the group is calculated by multiplying the legal limit for a single axle by the total number of axles. In 2017, the state of California collected $4.1 million in oversize and overweight permit revenue.

**Colorado**

Colorado issues single and multi-trip permits or special and superloaded vehicles. The single trip permit is $30, and the additional fee is based on the number of axles. Multi-trip permit varies from $250-$800. According to Colorado DOT, approximately $8.3 million was collected in 2018 from oversize and overweight permits.

**Idaho**

Idaho issues single and round-trip permits, along with annual multi-trip permits. The fee depends on the axle weight and distribution of the load. Permit fees start at $0.04 per mile and can go up to $45.54 per mile. The minimum fee for vehicles that exceed weight limits up to 1000 lbs. is $5, and for loads exceeding 20,000 lbs., the fee is $2,500 + $0.30/per lb. In 2018, Idaho DOT collected revenue of $3.1 million from oversize and overweight permit types.

**Montana**

In Montana, the yearly licensing and registration fee can vary from $7/year for vehicles rated by the manufacturer under 0.5 ton to $750/year for vehicles operating at a legal GVW limit of 80,000 lbs. A fee of $100 + $46 per ton is added for a vehicle exceeding the legal GVW. In 2018, the state of Montana collected $4.5 million in all oversize and overweight related fees.

**Nevada**

Nevada uses the same overweight categories as California. In Nevada, the excess weight infractions are assessed incrementally depending on the actual excess weight. Permit fees vary from $10 (up to 1,500 lbs. excess) to $0.08 per excess lb. (over 10,000 lbs.). According to the authors, fines in Nevada can double during Spring restrictions (February through April).

**New Mexico**

New Mexico issues two types of permits, which are single trip permits and multi-trip permits. The overweight criteria are based on the route that each vehicle may take. For this purpose, a bridge map was developed by the New Mexico DOT to determine the maximum allowable weight and axle-load configuration on each route. The fee is dependent on the excess weight, including GVW and axle weights. Idaho, permit revenue in 2017 was estimated at $6.1 million.

**North Dakota**

North Dakota issues three types of permits single trip, multiple trips (seasonal), and annual permits. The annual permit for over-width vehicle and load movements is required in lieu of the single trip permit issued for over-width movements. The seasonal (multiple trip permit) is for hay movers, hay grinders, fertilizers spreaders, grain cleaners, agricultural chemical applicators, and forage harvesters. The permit axle and group weights depend on the spacing between each axle, axle width, number of tires per axle, and tire width. The overweight vehicles permit fees range from $20 to $6,000. For every 1,000 lbs. over 30,000 lbs., a fee of $200 is added to the overall permit fee. North Dakota generated $5.6 million from all oversize and overweight vehicle permits in 2009.

**Oklahoma**

Oklahoma issues single trip, monthly, annual, and special movement vehicle permits. According to the Oklahoma Public Records Department, $42.6 million was generated from oversize and overweight permits during the fiscal year 2017.

**Oregon**

Oregon issues three types of permits: single-trip permits (valid for ten days), continuous-operation variance permits, and continuous-trip permits. Oregon permit fees range from $100 to $600 + $0.03/lb. of excess weight over 10,000 lbs. In 2017, a revenue of $837,000 was generated from all oversize and overweight permits.

**Texas**

Texas uses the most complex permit systems of the western states surveyed. Texas issued 28 different oversize and overweight permit types, in which vehicles are grouped according to the industries they serve, namely, oil and gas, agriculture, housing, utilities, and commercial freight. Oversize and overweight vehicles are subjected to fees up to $10,000. In 2017, Texas collected $159 million in oversize and overweight permits. This is more than the combined revenue for all other western states.

**Utah**

Utah issues three types of permits: single-trip, semi-annual (180 days), and annual permits. The permit fees vary from $30 to $540. Since September 2017, permit fees in Utah include a $50 flat fee plus the additional fee per mile. In 2019, Utah generated a revenue of $8.2 million from oversize and overweight permits.

**Washington**

Washington State issues 21 types of oversize and overweight permits that include single-trip, monthly, and annual permits. Permit fees vary from $14 to $1,000. In 2018, approximately $4 million was collected from oversize and overweight permits in Washington.

**Wyoming**

Ten permit types are issued in Wyoming. The overload fee depends on the actual excess weight (GVW and axle weights). It ranges from $25 for an excess up to 2,000 lbs. to $1,000 for an excess weight greater than 20,000 lbs. There is also an additional charge of $200 per 100 lbs. for weights exceeding 20,000 lbs. In 2009, Wyoming collected $10.9 million from oversize and overweight vehicle permits.

# Chapter 3

# CURRENT PERMIT FEE STRUCTURE

## 3.1 PERMIT FEE REGULATIONS

Alabama provides several laws, regulations, and procedures related to the operation of oversize and/or overweight vehicles, which are listed as follows.

a. An oversize and/or overweight vehicle shall be permitted solely on the condition of payment indemnity bond or proof of insurance protection for $300,000. Additional insurance may also be required to compensate for any damage to public roads, including bridges (Administrative code, chapter 450-3-1). A minimum $300 deposit is also required for annual and single trip permits which are, thereafter, issued by ALDOT Permit Office.
b. In the case of violation of any permitted vehicle, a minimum fine of $100 and no more than $500 is issued, in addition to the possibility of imprisonment or labor for the county of not less than 30 days and no more than 60 days.
c. Also, it is required that permitted vehicles do not travel on holidays such as New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day, and Christmas Day as well as any time on Sundays and during severe weather conditions.
d. The routing of a permitted vehicle shall be described on the permit for single trip and annual permits, and when applicable and shall be the only routing used by the permitted vehicle, under ALDOT jurisdiction. The permitted vehicle shall also comply with all load restrictions placed on bridges and sections of the highway, as well as any road conditions.
e. The annual permit fee is issued for modular homes, sectional houses, boats, any vehicle or combination of vehicles, for heavy commodities and equipment, and mobile homes up to 14 ft wide and 85 ft in length.

## 3.2 PERMIT FEE STRUCTURE IN ALABAMA

In Alabama, permits are issued by the Director of the Alabama Department of Transportation. The Truck Size and Weight regulations are dictated by Sections 32-9-1 to 32-9-32 of the Code of Alabama 1975. The current permit fees in the state were set in the early 1970s and have not been updated since ("A Legislators' Guide to Alabama Taxes" 2019). The collected permit fees are intended to help pay for additional wear and tear caused by overloaded permit vehicles on highways. The current permit fee schedule includes single trip and multi-trip permits. The single trip permits are valid for the specific route from one point of origin to one destination. The annual multi-trip permits are valid for 12 months and an unlimited number of trips.

The current permit fees in Alabama are as follows:

**(1) Single trip permits**

(a) Mobile homes, modular homes, sectional homes, portable buildings, and boats:

(i) $10 - up to and including 12 ft wide and 75 ft long.

(ii) $20 - boats over 12 ft wide; mobile homes, modular homes, sectional houses, and portable buildings over 12 ft wide and/or 75 ft long.

(b) Heavy commodities or equipment:

(i) $10 - over on any limitations as to length, height, or width,

(ii) $10 - over on weight from 80,001 lbs. up to 100,000 lbs.,

(iii) $30 - over on weight from 100,001 lbs. up to 125,000 lbs.,

(iv) $60 - over on weight from 125,001 lbs. up to 150,000 lbs.,

(v) $100 - over on weight from 150,001 lbs. and over.

(c) Miscellaneous:

(i) $20 for houses,

(ii) $10 for off-road equipment,

(iii) $20 for other oversized vehicles, loads, and equipment not otherwise specified,

(iv) $10 for others over height loads not otherwise specified.

**(2) Annual permits**

The annual permit is issued for overweight, oversize, or a combination of overweight and oversize vehicles for 12 months. The flat fee is $100 for the unrestricted number of trips. However, the annual permit is not authorized for a vehicle that:

- gross weight exceeds 150,000 lbs.,
- single axle weight exceeds 22,000 lbs.,
- total length exceeds 75 feet; except mobile homes, whose length limitations, including towing vehicles, which shall be 85 feet,
- total width exceeds 120 inches or whose load width exceeds 144 inches; except mobile homes, whose width limitation shall be 168 inches,
- height exceeds 14 feet.

The permit may not be authorized for a vehicle that exceeds 16 feet in width, 18 feet in height, or exceeds a single axle weight of 27,000 lbs. In addition, the permit may not authorize the operation of the vehicle on any bridge, over or under any overpass, or on an interstate highway.

**(3) Superload permits**

Superload permits are issued by the State Department of Transportation to permit the movement of heavy vehicles on public highways. A refined analysis needs to be conducted to determine if a special superload permit can be granted to the vehicles. The charge for a special permit is similar to charges for miscellaneous (single-trip permits), which is $100 + $10 if over on any limitations as to length, height, or width.

# Chapter 4

# AVAILABLE DATA

## 4.1 PERMIT DATA

Alabama's permits are issued through the automatic permitting system ALPASS – Alabama's Online oversize and overweight (OS/OW). The permit database contains information about all issued OS/OW permits. ALDOT issues several types of permits, which are available in the ALPASS along with the description presented in **Table 4-1**.

Permit data for the years 2013-2021 was shared with Auburn Team by ALDOT. Nine separate Excel files were exported from the Alabama Pass Web application. Permit data includes 295 different attributes of every single permit truck. The data includes permit type, fee, trip origin and destination, authorized routes, axle spacing, axle weight, and the GVW of issued permit vehicles. All permit data records, and selected attributes were processed and transformed into Structured Query Language (SQL)server database.

**Table 4-1: ALDOT permit types.**

| Permit Type | Description |
|---|---|
| A1-Equipment OS | Oversized equipment permits. |
| A1-House | Oversize stick-built house. |
| A2-Equipment OW | Overweight equipment permit. |
| A2-Sealed Container | Overweight shipping container. |
| A3-Equipment OS/OW | Oversized and Overweight equipment permit. |
| MultiState | Not issued by ALDOT. |
| B1-Mobile Homes | Oversized mobile homes. |
| C1-Modular Homes/Boats | Oversized boast or portable buildings. |
| A-Annual | Annual permit for equipment. |
| B-Annual | Annual Permit for mobile home. |
| C-Annual | Annual Permit for boat or portable building. |
| D-Annual | Annual Permit for sealed container. |
| A-Routing Authorization | Routing authorization for oversized and overweight equipment. |
| B-Routing Authorization | Routing authorization for mobile homes. |

The available permit data includes 1,140,564 permit records. Some of the permit data attributes are listed below:

- permit type,
- issue date,
- valid start and end day,
- trip origin and destination,
- trip miles,
- authorized routes per trip,
- rating factor for H15, H20, and HS20,
- permit fee in dollars,
- selected route,
- length, height, and width of a vehicle
- Gross Vehicle Weight,
- axle loads,
- vehicle length,
- number of axles,
- axle spacings,
- truck registration number,
- spacing between tandem and tridem axels,
- type of carried load.

The permit data is an excellent source of information. It provides statistics about permit traffic and its trends. The permit data set is critical to assess the damage caused by permitted vehicles.

Processed permit data sets were used to determine the number of issued permits per year. **Figure 4-1** presents permit statistics for the years 2013 to 2021. The years 2015-2019 indicate an increase in the number of issued permits. In 2020, there is a decrease, which may be a consequence of the COVID-19 pandemic. Still, the number of permits issued in 2020 was lower than in 2017-2019 but significantly higher than in 2013-2016. It confirms the trend is a growing number of permits. The data set for 2021 consists of 6 months of data from January to June.

The number of issued permits in Alabama was filtered by type, and year and presented in **Table 4-2** and **Figure 4-2**. Based on data analysis, it can be concluded, that the most common types of permits in Alabama are:

A1 - Oversized equipment permit.

A3 - Oversized and Overweight equipment permit,

B1 - Oversized mobile homes, and

A - Annual permit for equipment.

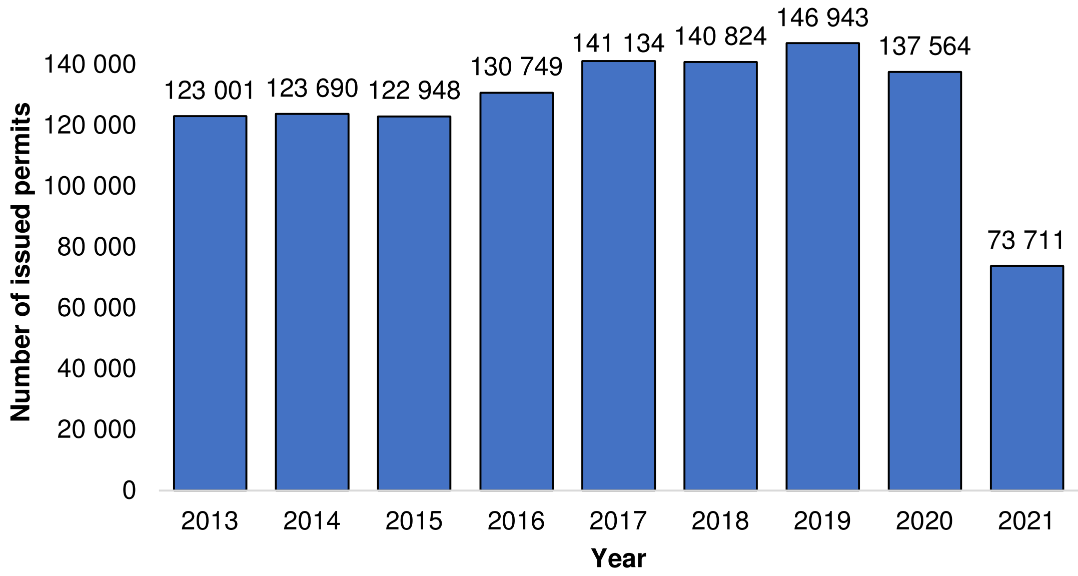



**Figure 4-1: Number of issued permits in Alabama for the years 2013-2021.**

**Table 4-2: Number of permit types for years 2013-2021.**

| Permit Type | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|
| A1-Equipment OS | 42,429 | 41,534 | 40,746 | 40,479 | 38,308 | 40,665 | 42,052 | 36,473 | 18,782 |
| A1-House | 124 | 125 | 86 | 85 | 112 | 93 | 169 | 63 | 34 |
| A2-Equipment OW | 2,416 | 2,953 | 2,703 | 2,749 | 3,575 | 3,604 | 4,072 | 4,200 | 2,185 |
| A2-Sealed Container | 1,410 | 1,219 | 1,372 | 1,358 | 1,171 | 1,126 | 1,092 | 2,264 | 1,265 |
| A3-Equipment OS/OW | 28,998 | 30,254 | 30,888 | 30,989 | 33,898 | 35,354 | 36,675 | 31,540 | 17,561 |
| MultiState | 14 | 10 | 9 | 8 | 7 | 13 | 0 | 0 | 0 |
| B1-Mobile Homes | 18,904 | 20,521 | 22,735 | 24,253 | 25,428 | 25,976 | 27,065 | 28,702 | 16,276 |
| C1-Modular Homes/Boats | 1,003 | 1,311 | 1,475 | 2,768 | 3,124 | 3,006 | 2,957 | 3,267 | 1,550 |
| A-Annual | 7,003 | 7,279 | 7,404 | 7,326 | 7,513 | 7,744 | 7,694 | 7,907 | 4,148 |
| B-Annual | 286 | 232 | 212 | 360 | 380 | 342 | 323 | 334 | 170 |
| C-Annual | 206 | 217 | 222 | 226 | 243 | 250 | 266 | 220 | 131 |
| D-Annual | 1,546 | 1,601 | 1,615 | 1,871 | 1,948 | 2,199 | 2,187 | 1,961 | 873 |
| A-Routing Authorization | 11,334 | 13,242 | 11,732 | 13,276 | 19,355 | 13,115 | 15,388 | 14,270 | 7,125 |
| B-Routing Authorization | 7,328 | 3,192 | 1,749 | 5,001 | 6,072 | 7,337 | 7,003 | 6,363 | 3,611 |

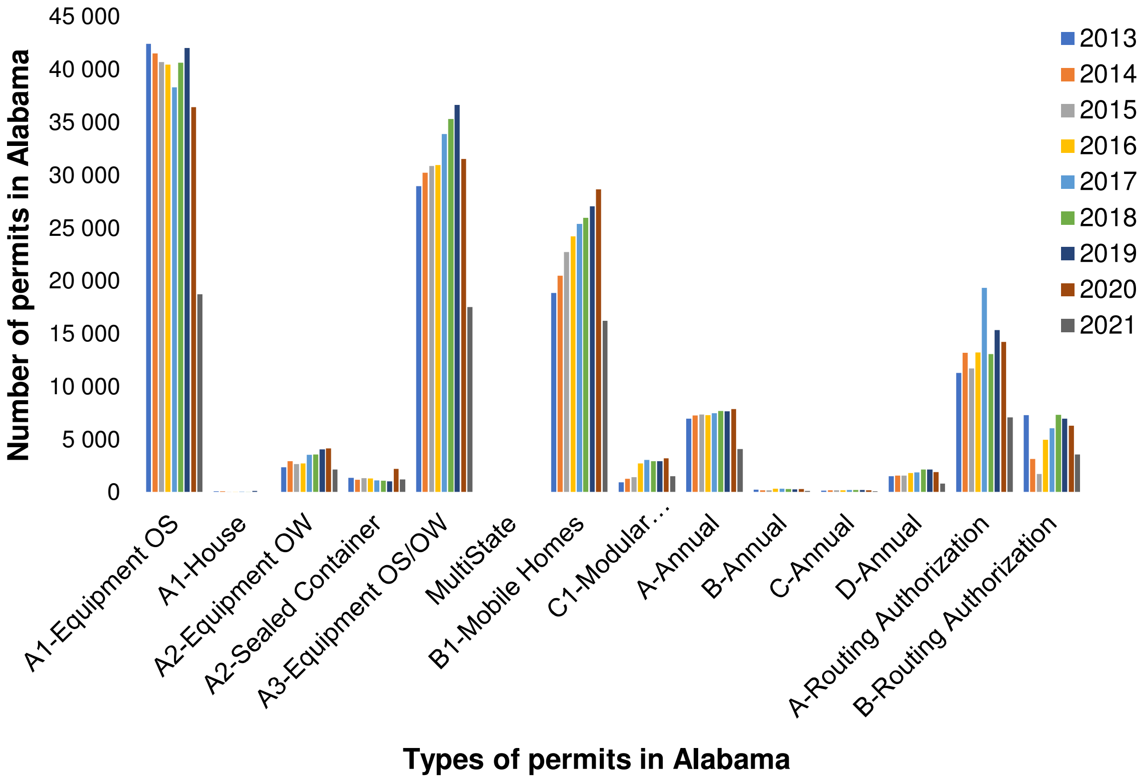



**Figure 4-2: Number of issued permits in Alabama by type and year.**

Based on the available permit database, the annual permit revenue was computed for the years 2013-2021 and is presented in **Figure 4-3**. The project aims to assess the impact of overloaded vehicles on pavements and bridges. Thus, the revenue from the A2 - Overweight equipment permit, and A3 - Oversized and Overweight equipment permits were evaluated. **Table 4-3** presents the dollar revenue for selected permit types. The revenue from A3 - Oversized and Overweight equipment permits brings the highest, whereas A2 - Overweight equipment permit contributes to only 3.3% of the total revenue.

The annual revenue for overloaded vehicles is approximately 2.0 million dollars, and it is expected, the new proposed fee schedule should enable to collect of at least the same amount of money per year.

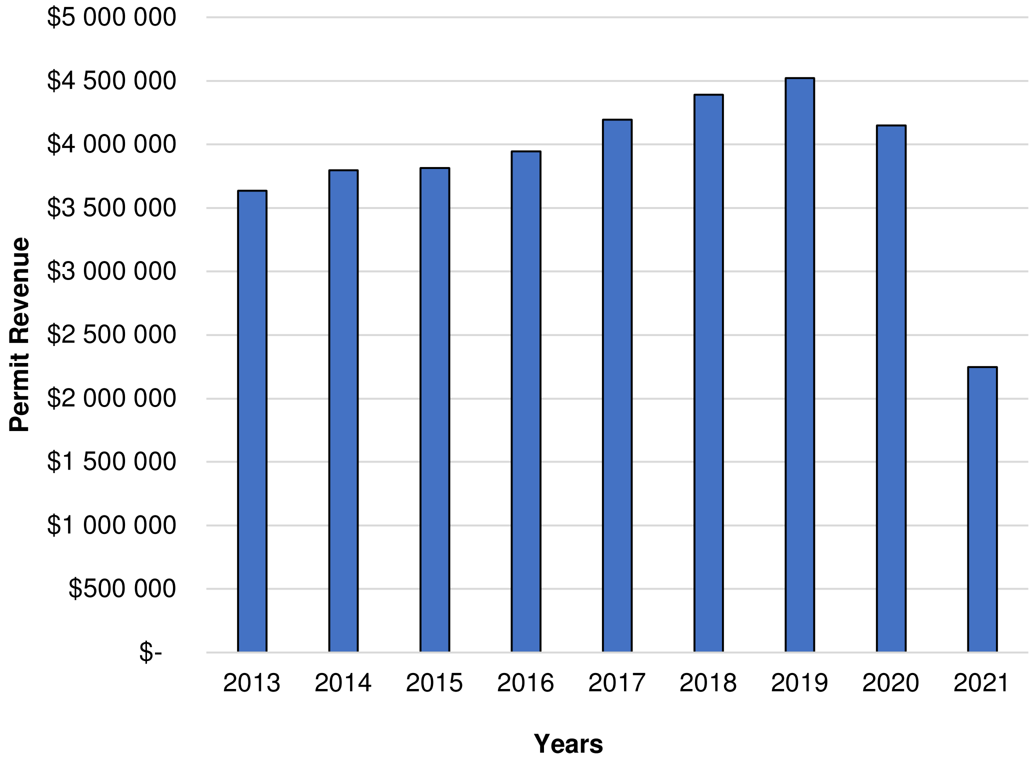



**Figure 4-3: Permit revenue in Alabama by years.**

**Table 4-3: Permit Revenue from overloaded vehicles.**

| Year | A2-Equipment OW | A3-Equipment OS/OW | Total Revenue |
|---|---|---|---|
| 2013 | $ 41,810 | $ 1,485,700 | $ 1,527,510 |
| 2014 | $ 50,350 | $ 1,589,470 | $ 1,639,820 |
| 2015 | $ 46,650 | $ 1,566,680 | $ 1,613,330 |
| 2016 | $ 47,370 | $ 1,606,046 | $ 1,653,416 |
| 2017 | $ 60,230 | $ 1,830,130 | $ 1,890,360 |
| 2018 | $ 67,250 | $ 1,915,510 | $ 1,982,760 |
| 2019 | $ 73,680 | $ 1,992,320 | $ 2,066,000 |
| 2020 | $ 74,200 | $ 1,676,930 | $ 1,751,130 |
| 2021 (Jan.-July) | $ 36,990 | $ 949,750 | $ 986,740 |

## 4.2 WEIGH-IN-MOTION DATA

Weigh-in-Motion (WIM) measurements enable continuous recording of vehicles passing a measurement site. The WIM systems can collect traffic volume, vehicle configurations, and load spectra. It is a powerful system to collect a massive traffic database. Data is recorded for every vehicle, including vehicle configuration, class, measurement date and time, occupied lane, trip direction, moving speed, and truck axle weights and spacings. There are uncertainties involved in the measurement process that must be considered while dealing with big data. To accurately assess traffic-induced load effects, it is required to verify the data quality.

Analysis of the live load effect is essential to maintain infrastructure safety. Hence, it is important to adequately assess the load effects and not underestimate or overestimate them. In Alabama, there are 12 WIM stations. **Figure 4-4** shows the location of the WIM stations in the state of Alabama. The WIM data for the years 2010-2021 was shared by ALDOT.

The first check of WIM data analysis was to determine how many days data were recorded within each year by every WIM site. It was determined based on the number of files stored by every WIM site. **Table 4-4** shows the number of days with records for each WIM site and year. The number of recorded days from 2010 -2017 is close to over 300 days for most WIM sites. In the years 2018 to 2021, the number of days with records is lower. It may be caused by the WIM system malfunction, electrical power failure, lack of calibration, poor temperature compensation, etc. The overall number of recorded days is 34,301 days.

The next step was to decrypt WIM data by converting data sets from binary (RAW) format to user-friendly text format. It was necessary to convert binary data to a text file, e.g., ASCII (American Standard Code for Information Interchange), where every data record is comma-delimited and can be transformed to table format. WIM data decryption required dedicated software. iAnalyze software was used to decrypt data from RAW format. Massive traffic data were decrypted and then transferred to the SQL Server database. **Figure 4-5** presents the number of available records per WIM site.

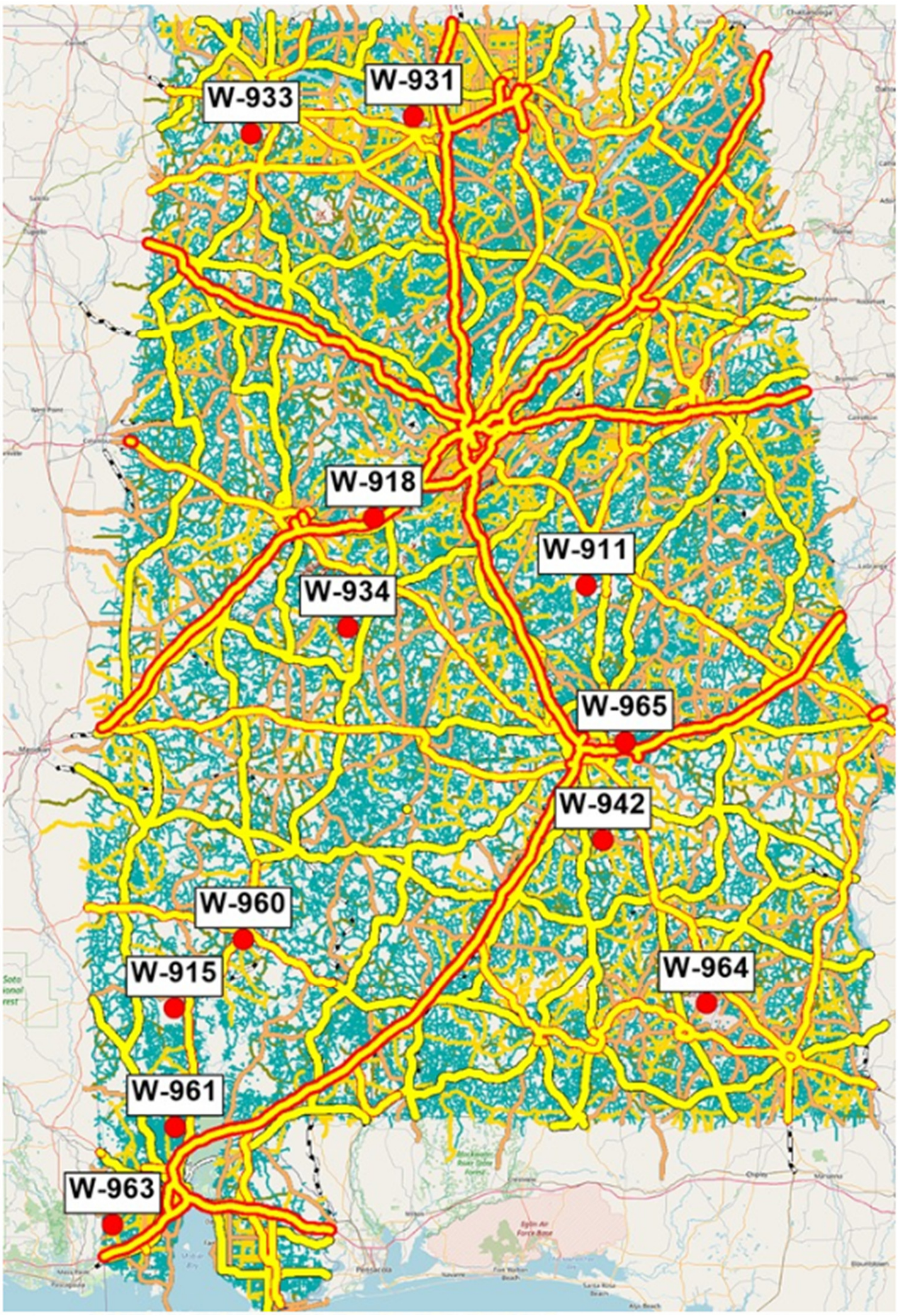



**Figure 4-4: WIM site locations in Alabama.**

WIM data was used to determine the number of available truck traffic records per WIM site and year. **Table 4-5** presents the number of WIM records per site. The number of available records is 323.5 million records.

**Table 4-4: Number of days with WIM records.**

| WIM Site | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 911 Alexander City | 179 | 0 | 364 | 364 | 365 | 365 | 366 | 341 | 0 | 0 | 35 | 230 |
| 915 Sun Flower | 229 | 361 | 195 | 365 | 357 | 365 | 366 | 349 | 365 | 64 | 0 | 259 |
| 918 Bucksville | 359 | 260 | 225 | 320 | 319 | 121 | 0 | 0 | 143 | 116 | 0 | 31 |
| 931 Athens | 362 | 343 | 361 | 364 | 365 | 365 | 366 | 365 | 0 | 116 | 0 | 0 |
| 933 Muscle Shoals | 365 | 365 | 366 | 364 | 365 | 365 | 350 | 353 | 110 | 0 | 0 | 0 |
| 934 Sumiton | 365 | 70 | 339 | 318 | 320 | 363 | 343 | 365 | 0 | 116 | 35 | 234 |
| 942 Pine Level | 365 | 365 | 55 | 364 | 356 | 365 | 366 | 365 | 85 | 116 | 35 | 259 |
| 960 Whatley | 365 | 335 | 221 | 365 | 365 | 365 | 366 | 365 | 365 | 116 | 35 | 31 |
| 961 Mobile | 353 | 31 | 366 | 364 | 364 | 268 | 361 | 365 | 365 | 116 | 35 | 182 |
| 963 Grand Bay | 317 | 15 | 312 | 271 | 365 | 365 | 144 | 75 | 323 | 116 | 35 | 223 |
| 964 Ozark | 365 | 365 | 361 | 362 | 363 | 80 | 363 | 365 | 0 | 116 | 34 | 221 |
| 965 Shorter | 358 | 350 | 125 | 169 | 364 | 241 | 366 | 364 | 0 | 0 | 0 | 192 |

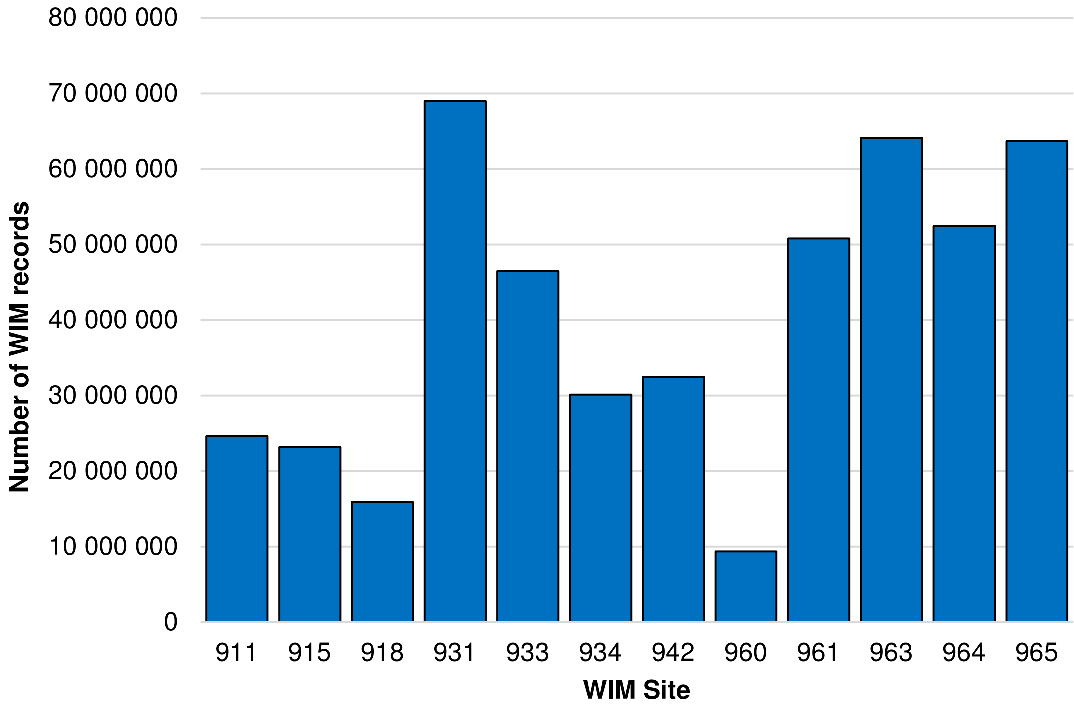



**Figure 4-5: Number available WIM records per site.**

**Table 4-5: Number of WIM records per year and WIM site.**

| WIM Site | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|
| 911 Alexander City | 0 | 0 | 2,306,992 | 3,574,196 | 3,780,091 | 3,924,310 |
| 915 Sun Flower | 0 | 2,733,485 | 1,428,210 | 2,561,484 | 2,531,347 | 2,794,076 |
| 918 Bucksville | 0 | 0 | 0 | 0 | 0 | 0 |
| 931 Athens | 8,262,745 | 7,928,800 | 8,464,767 | 8,751,698 | 8,629,010 | 8,329,086 |
| 933 Muscle Shoals | 6,395,488 | 5,464,791 | 5,939,097 | 5,510,500 | 4,567,171 | 5,312,946 |
| 934 Sumiton | 0 | 0 | 5,496,538 | 4,286,392 | 4,429,635 | 3,433,433 |
| 942 Pine Level | 0 | 0 | 0 | 5,339,850 | 5,335,360 | 4,641,010 |
| 960 Whatley | 0 | 0 | 0 | 1,410,023 | 1,451,953 | 1,441,490 |
| 961 Mobile | 0 | 0 | 7,710,238 | 7,612,469 | 5,344,238 | 686,522 |
| 963 Grand Bay | 0 | 0 | 0 | 7,725,217 | 6,416,531 | 7,899,233 |
| 964 Ozark | 6,455,071 | 6,085,647 | 5,800,463 | 5,872,185 | 6,320,890 | 1,381,203 |
| 965 Shorter | 0 | 0 | 0 | 1,215,322 | 13,534,985 | 9,809,220 |
| **WIM Site** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** |
| 911 Alexander City | 4,114,031 | 3,846,675 | 1,197 | 0 | 353,120 | 2,697,423 |
| 915 Sun Flower | 2,934,894 | 2,645,612 | 2,878,408 | 470,302 | 0 | 2,183,666 |
| 918 Bucksville | 0 | 0 | 7,934,734 | 6,515,306 | 0 | 1,497,840 |
| 931 Athens | 8,208,630 | 7,384,522 | 2,319 | 3,003,186 | 0 | 0 |
| 933 Muscle Shoals | 5,574,739 | 5,935,801 | 1,773,420 | 0 | 0 | 0 |
| 934 Sumiton | 3,770,239 | 3,899,122 | 2,425 | 1,520,727 | 435,219 | 2,853,867 |
| 942 Pine Level | 5,007,004 | 4,271,560 | 1,190,729 | 1,854,501 | 521,168 | 4,295,606 |
| 960 Whatley | 1,481,588 | 1,452,284 | 1,424,590 | 446,174 | 106,542 | 125,713 |
| 961 Mobile | 8,453,736 | 8,139,122 | 8,145,198 | 2,110,445 | 569,297 | 2,014,596 |
| 963 Grand Bay | 3,564,513 | 3,437,664 | 16,175,619 | 5,645,270 | 1,578,868 | 11,680,479 |
| 964 Ozark | 6,582,358 | 6,951,119 | 2,500 | 2,202,325 | 612,972 | 4,189,350 |
| 965 Shorter | 16,049,008 | 15,118,381 | 5,855 | 0 | 0 | 7,913,993 |

Processed WIM has been checked by the Quality Control (QC) procedure to detect any erroneous records. **Table 4-6** presents the developed filtering criteria for the QC procedure to check Alabama WIM data.

**Table 4-6: Filtering criteria for WIM Quality Control procedure.**

| Type | Filtering criteria | Threshold limits |
|---|---|---|
| **WIM description** | Station ID | Null or invalid state I.D. |
| | Lane of travel | ≠ (0-9) |
| | Direction of travel | ≠ (0-9) |
| **Timestamp** | Invalid year | Null or irrespective year |
| | Invalid month | ≠ (1-12) |
| | Invalid day | ≠ (1-31) |
| | Invalid time | ≠ (0-86399) sec. |
| **Duplicates** | Identical records | Exact copy |
| | Same axle weight for consecutive axles | Axle weight = Axle weight n+1 |
| **Vehicle configuration** | Invalid vehicle class | ≠ (1-13) |
| | Zero GVW | = 0 |
| | Zero axle spacings | = 0 |
| | Number of axles is an equal number of recorded axles weights | Number of axles = Number of axle weights |
| | Number of axles spacings | ≠ (1-21) |
| | The number of axles is equal to the number of axles spacings + 1 | Number of axles ≠number of axles spacing +1 |
| | Sum of axle weights is equal to GVW ± 10% | ± 10% of GVW |
| | Minimum first axle spacing | < 6 ft |
| | Minimum axle spacing | < 3.3 ft |
| | Steering axle weight | > 18 kips |
| | Single axle weight | ≠ 1.2-60 kips |
| | Tandem axle weight | > 60 kips |
| | Tridem axle weight | > 80 kips |
| | Left and right wheel weight difference | ± 20% |
| **Speed limits** | Vehicle speed | ≠ 10-90 mph |

The QC procedure begins with the basic checks concerning WIM station ID, traffic lane, and direction of the trip. If the data record does not pass the data description check, it is flagged. WIM data are validated for the correct year, month, day, and time. It is also checked for duplicated records with identical vehicle weights and configurations. Duplicated and null records are discarded. From previous experience with WIM data analysis, it was observed that data duplication or null records are common errors.

After WIM data records were checked for description, time, nulls, and duplicates, the major step was to identify errors in the vehicle configuration, which includes analyzing the gross vehicle weight (GVW) and axle weights and spacings. All data with zero weight recorded was discarded. The number of axles and axle spacings was checked to determine if the vehicle had been recorded correctly. Moreover, the sum of axle weight was also compared to the GVW, with ±a 10% tolerance. Left and right wheel weights were compared for every axle, with ± 20% tolerance. The WIM records were checked for the minimum first axle spacing and minimum axle spacing based on the literature review and traffic analysis. Also, the threshold was verified for steering axle weight and for single, tandem, and tridem axle weight.

### 4.3 INFRASTRUCTURE DATA

Data on bridge and pavement infrastructure is needed to evaluate the effects of permit-induced loading on Alabama infrastructure. In the case of bridges, there is a public domain database, National Bridge Inventory (NBI), and InfoBridge databases, which contains information about the bridges from 1983-2021. The NBI database was used to determine Alabama bridge characteristics, including structural and material type, maximum span length, and total span length. The location of the bridges with given longitude and latitude was used to determine bridges utilized by the permit vehicles.

Based on the 2020 NBI database, there are approximately ten thousand bridges in Alabama. The typical bridge materials in Alabama are shown in **Figure 4-6**. The most typical are concrete bridges with almost 40% of the bridge population in Alabama, where steel bridges are second (30%), and prestressed concrete bridges (23%).

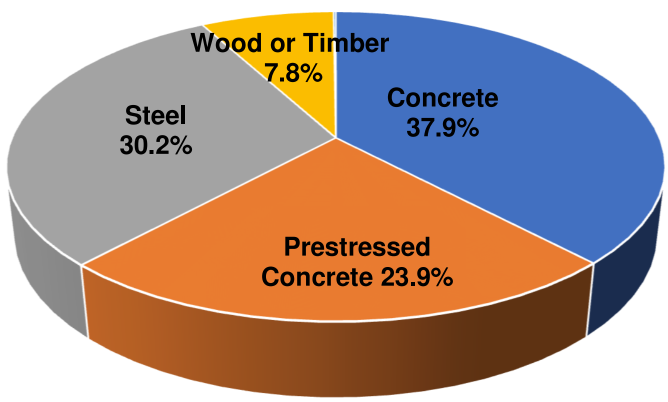



**Figure 4-6: Bridge by material type in Alabama.**

Steel girder bridges (27.2%), T-Beam concrete bridges (19.5%), and prestressed concrete bridges (13.9%) are the most typical bridges in terms of material and structural types. The number of Alabama typical bridge types is shown in **Figure 4-7**.

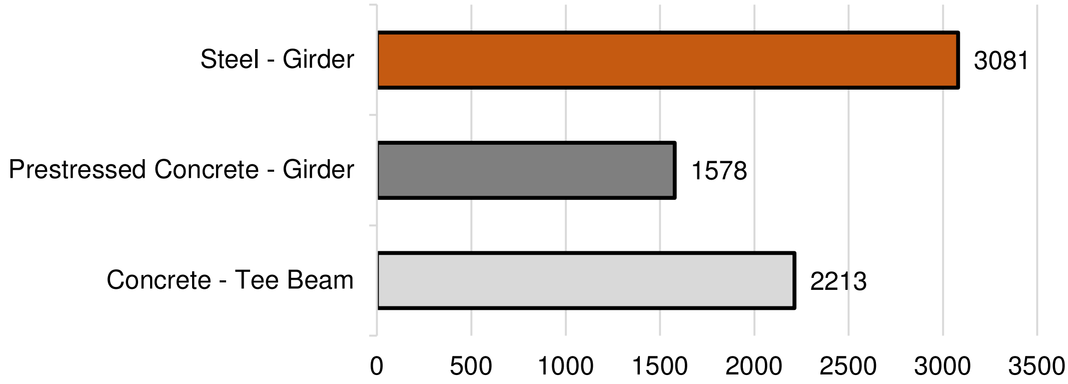



**Figure 4-7: Number of the most typical bridge material and structural types in Alabama.**

Moreover, the deck and superstructure condition ratings were checked for the bridges in Alabama. The percentage of bridges in Alabama for each condition rating category is shown in **Figure 4-8** and **Figure 4-9**. Over 50% of decks are rated at least a good condition, while almost 17% are below a satisfactory condition. Similarly, the superstructure condition rating indicates 49.2% with good or better condition and 18% below satisfactory condition.

The pavement database is not available. The typical pavement structure was reviewed in the analysis and assumed based on road category and the average daily truck traffic (ADDT).

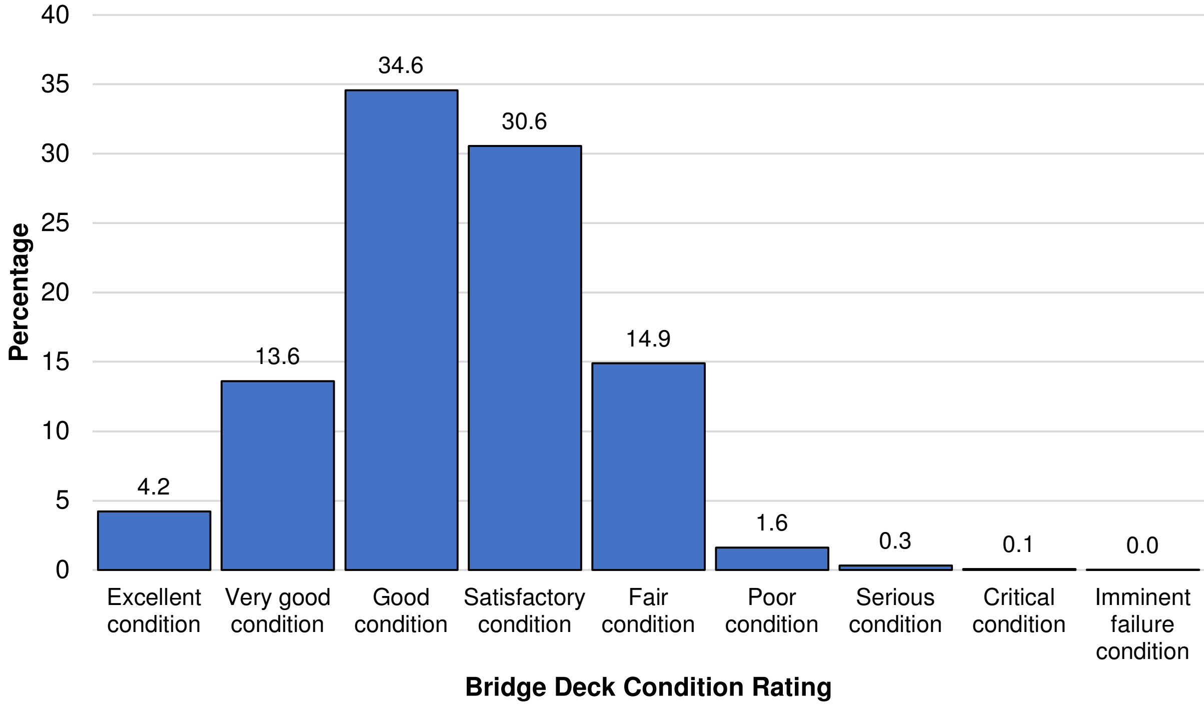



**Figure 4-8: Bridge deck condition rating for Alabama.**

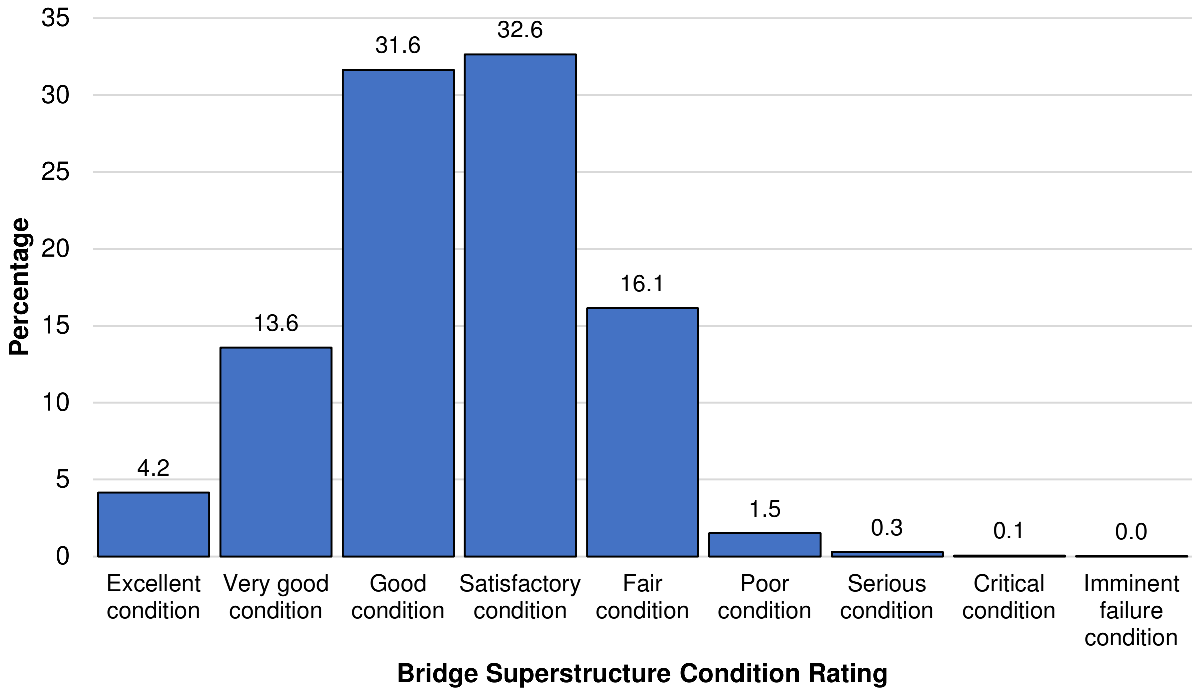



**Figure 4-9: Bridge deck condition rating for Alabama.**

## 4.4 ROAD NETWORK

Alabama road network data is required to determine the Alabama traffic distribution and heavy permit corridors. The Alabama road network system is presented in **Figure 4-10**. It was developed based on public domain data, where OpenStreetMaps (https://download.geofabrik.de/north-america/us.html) and Alabama DOT web portal (https://aldotgis.dot.state.al.us/TDMPublic/) were used.

The basic road network attributes include:

- link length [miles],
- road name,
- road category (motorway, trunk, primary, secondary, tertiary, unclassified, residential),
- vehicle free flow speed [miles/h],
- capacity [veh/hour],
- road users (cars, trucks, buses, bikes, pedestrians),
- geometry (polyline defined by succeeding coordinates),
- bridge numbers along the link (according to the 2020 NBI databases).

Moreover, the data on Alabama traffic volume was determined by using Automatic Traffic Counters. Data for 205 count locations in Alabama for the years 2017 to 2020 were shared by ALDOT. The locations of Automatic Traffic Counters are present in **Figure 4-11**. The Automatic Traffic Count data was used to find Average Daily Traffic (ADT) and percentage of Average Daily Truck Traffic (ADTT) in the Alabama location.

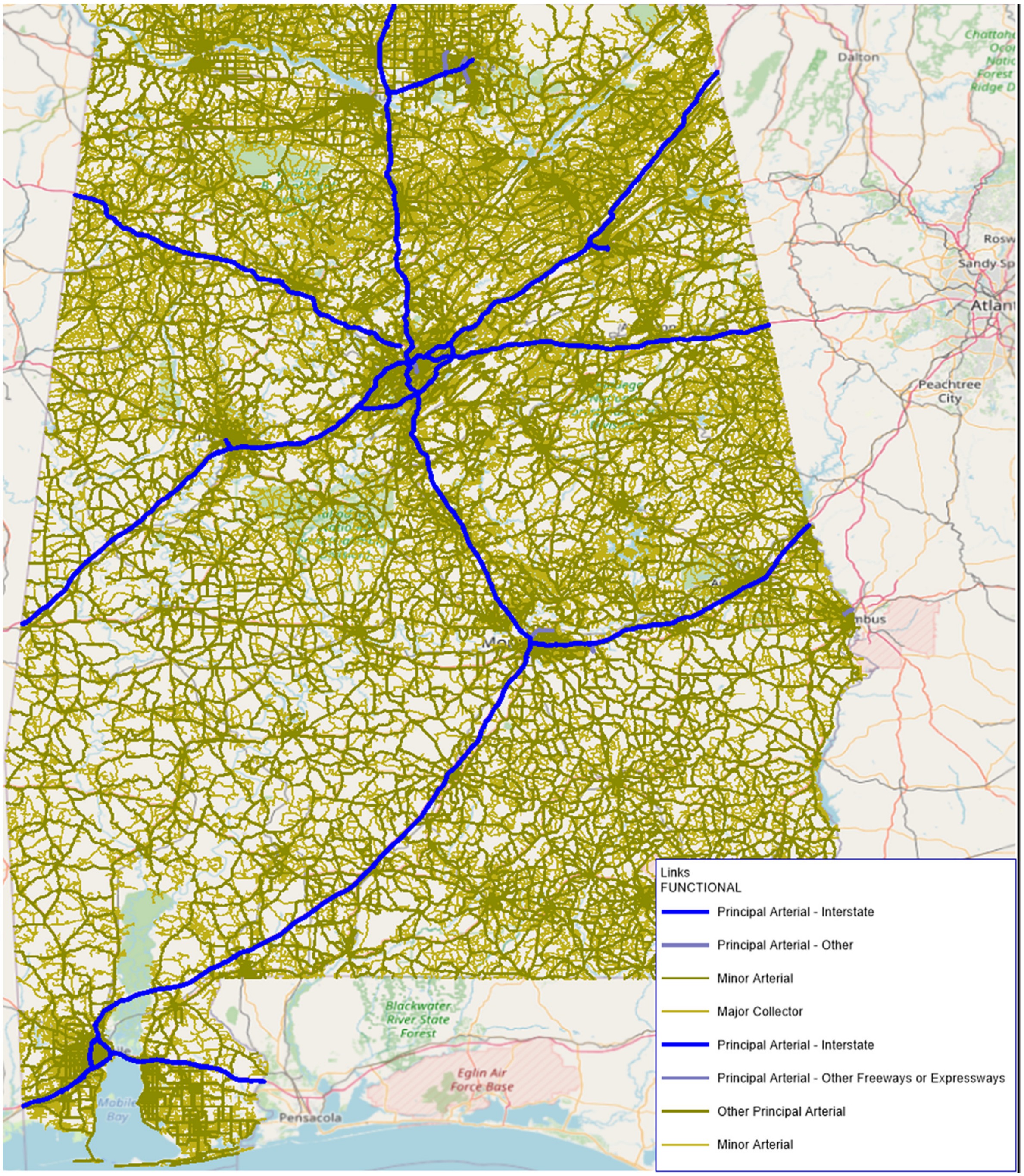



**Figure 4-10: Alabama GIS road network system.**

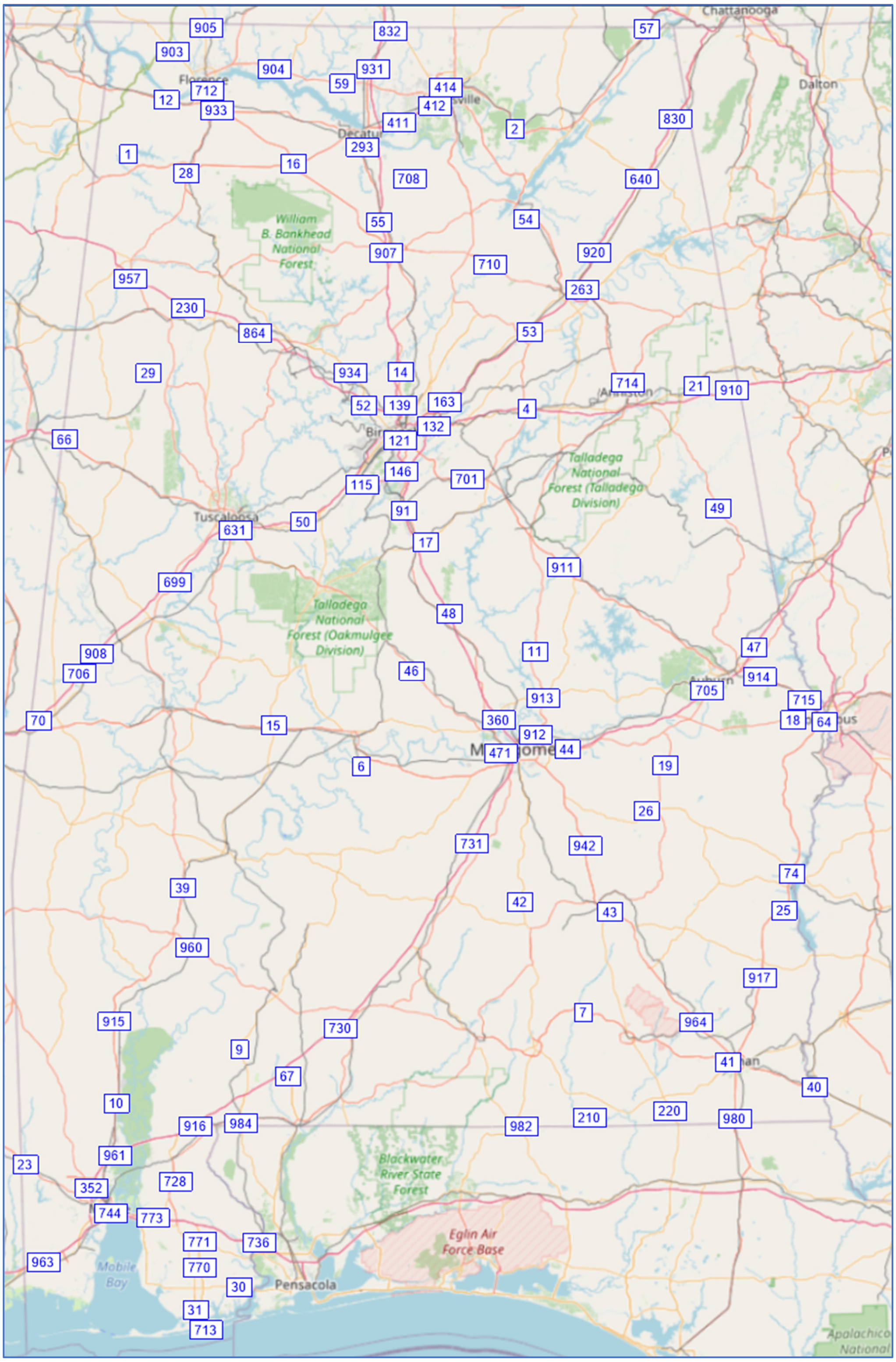



**Figure 4-11: Alabama Traffic Count Locations.**

The NBI 2020 NBI database was used to determine the percentage of bridges by functional route. **Figure 4-12** presents the percentage of bridges for each road category.

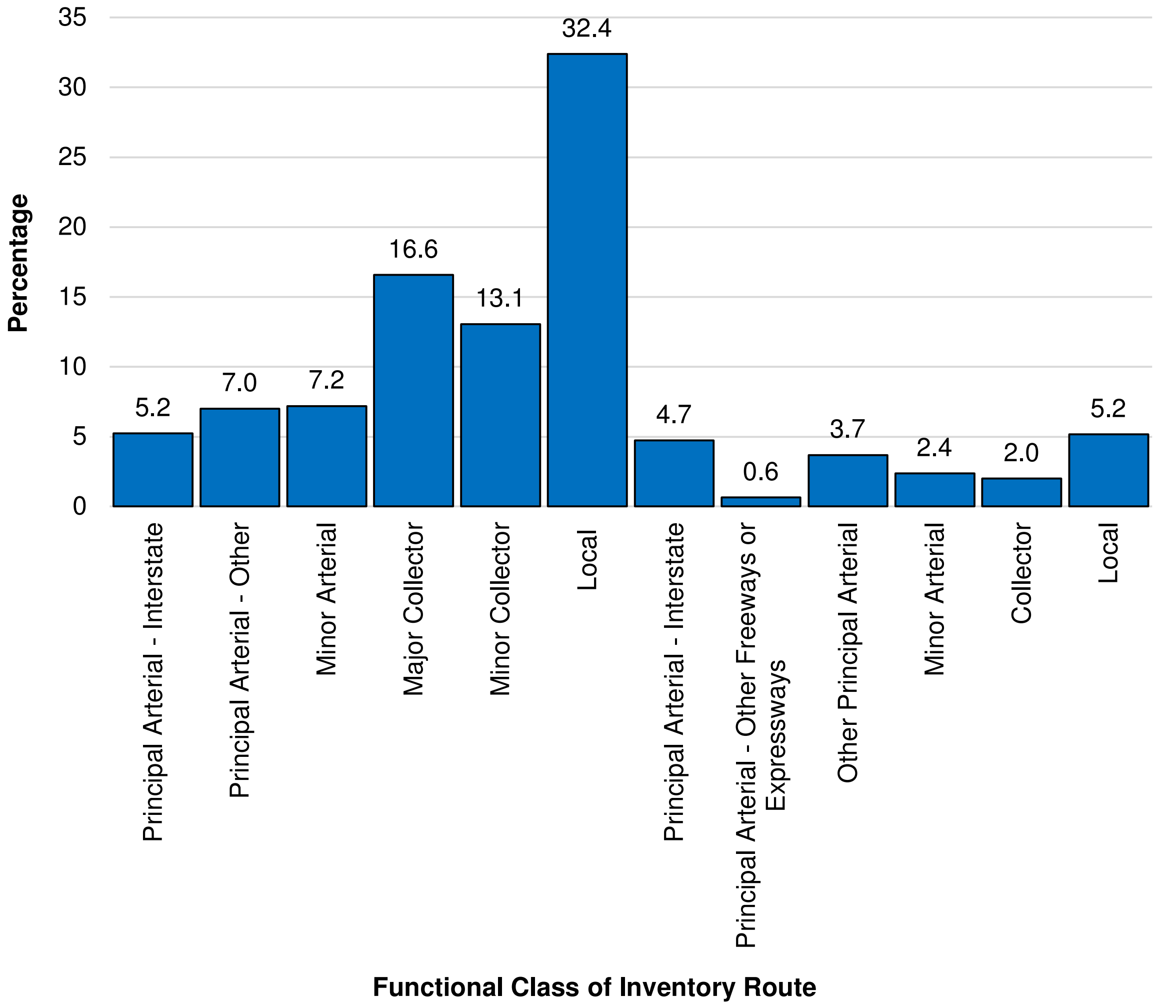



**Figure 4-12: Percentage of bridges by functional route class in Alabama.**

# Chapter 5

# METHODOLOGY

## 5.1 INTRODUCTION

Permit regulations and monitoring procedures are developed to provide safety to the road and bridge infrastructure. The permit law intends to protect motorists from traffic hazards caused by the movement of overweight vehicles on state highways, and to minimize damage to infrastructure, thus protecting the investment in the highway system. The operation of permit vehicles is vital for efficient transportation and economic growth. However, overweight permit vehicles contribute to road and bridge damage. The permit fee schedule is not intended to redeem the total damage, but to cover administration, construction, reconstruction, maintenance, and repair costs of roads and bridges, as well as control the overweight and oversize traffic to prevent accelerated damage. The developed permit fee schedule needs to provide a fair and equitable fee for various types of vehicles. The ALDOT permit fee schedule was developed a few decades ago. The traffic and the value of money have changed, therefore there is a need to update the Alabama permit fee schedule.

To assess the damage caused by the overweight permit trucks in Alabama, the available traffic and infrastructure data are utilized. The permit data from the automated permitting system ALPASS is used to capture heavy traffic weights and configurations and use them to assess the permit-induced load effects. Permit database also contains information about the allowed permit routes used by heavy trucks. Trip origin and destination, along with the authorized route are available and can be used to determine the types of roads and bridges utilized by permit traffic. The goal of this project is to use the existing permit traffic data and develop a methodology to determine the damage caused by overloaded permit vehicles to Alabama bridges and roads. Permit database is a major source of information on permit vehicle weight and configuration, as well as the permit routes. The permit data is used to determine damage caused by excessive load. The developed damage assessment methodology is presented in this chapter.

## 5.2 DAMAGE ASSESSMENT APPROACH

Damage assessment of heavy permit vehicles on Alabama bridges requires a comprehensive knowledge of state-specific permit traffic, as well as road and bridge infrastructure. Therefore, the development of the damage methodology requires several steps, which are listed as follows:

1) Process Alabama permit data and select the overweight vehicles.
2) Define permit vehicles' trip origin and destination coordinates.

3) Build GIS system with Alabama road network, including road sections, intersections, and bridges.
4) Develop an algorithm to determine heavy permit corridors based on authorized permit routes.
5) Find roads and bridges on Alabama heavy permit corridors.
6) Assess the damage caused by permit trucks on utilized roads and bridges.
7) Calculate the bridge and pavement damage for the representative permit dataset.
8) Determine the total damage for each permit and its route.
9) Group permit vehicles by the selected attributes and provides the average total damage.

The overall approach requires the development of the bridge damage assessment approach, and pavement damage assessment approach, as well as the development of the GIS system to determine heavy permit corridors. The permit database is a key input to the analysis; thus, it contains the information necessary to determine the damage. The mathematical definition of the permit database attributes required for the damage analysis is presented in **Equation (5-1)**:

$$P = \{i \in N;\ \ x_i\, , l_i, t_i, a_i, O_i, D_i, R_i, GVW_i, A_i, S_i\} \quad \textbf{(5-1)}$$

where:

| | | |
|---|---|---|
| *N* | – | number of issued permits |
| *i* | – | a permit vehicle |
| *x* | – | permit trip ID |
| *l* | – | trip distance [miles] |
| *t* | – | a trip type (O – oversized, W – overweight, O&W – oversized and overweight) |
| *a* | – | permit fee |
| *O* | – | a permit trip origin |
| *D* | – | a permit trip destination |
| *R* | – | an authorized route |
| *GVW* | – | gross vehicle weight |
| *A* | – | axle load |
| *S* | – | axle spacing |

Set ***P*** outlines the most important permit data attributes, which are necessary to calculate the damage caused by heavy permit vehicles to Alabama bridges and pavements. In this analysis, over 1.1 million permit data records were used. The permit vehicle weight and configuration are readily available, but the heavy permit routes, and the types of bridges and roads utilized by the permit traffic need to be found. So, there is a need to use permit trip origin to the destination, and its authorized route description to determine heavy permit corridors. The development of the heavy permit corridors is described in Chapter 6 “Permit Corridors in Alabama.” Based on the available permit data, the authorized routes were found for individual permit trucks. It was observed that several permits have the same trip origin and destination; therefore, the same authorized route is approved, and the permits were grouped by the same trip origin and destination. The authorized routes set *OD* was defined as follows:

$$OD = \{i \in N;\ L_i = \{l \in LL;\ L_l\,(C, L, P)\}, B_i = \{b \in BB;\ B_b(m, L, L_{max})\}\} \quad \textbf{(5-2)}$$

where:

| | | |
|---|---|---|
| $K$ | – | number of authorized routes |
| $i$ | – | a permit route |
| $L_i$ | – | a subset of road links on authorized route |
| $LL$ | – | number of links in the authorized route |
| $l$ | – | a route link in $L_i$ set |
| $C, L, P$ | – | a road class, link length, and pavement type |
| $BB$ | – | number of bridges on the authorized route |
| $b$ | – | a bridge in $B_i$ set |
| $m, L, L_{max}$ | – | bridge attributes: material and structural type, bridge total length, maximum bridge span length |

In the analysis over 3,700 different permit routes were developed, with 750 thousand road links, and 195 thousand bridges. The permit set was supplemented by the permit routes, and bridge and road types. So, the permit set P can be defined, as follows:

$$P = \{i \in N;\ \ x_i\,, l_i, t_i, a_i, O_i, D_i, R_i, GVW_i, A_i, S_i, OD_i\} \quad \textbf{(5-3)}$$

Permit database with overweight vehicle characteristics and the permit routes with known bridge and road types is used in the development of the damage assessment methodologies.

### 5.3 BRIDGE DAMAGE ASSESSMENT

The bridge damage caused by overloaded permit vehicles in Alabama requires an evaluation of the traffic-induced load. Thus, the damage is calculated in terms of the bending moment effect caused by a permit truck on a bridge. It is a measure used to design and evaluate bridges. Every permit truck that passes over a bridge creates a bending moment at points along the span, and the bending moment at each point changes as the truck crosses. This change in bending moment results in different magnitudes depending on the weight and configuration of the truck and bridge geometry. Influence line analysis was used to determine the maximum bending moment caused by the permit truck on the bridges assigned permit authorized routes. Permit data along with Alabama NBI database are used to determine the permit live load effects.

The influence line analysis was run to find moment effects, which determine damage based on vehicle GVW, axle configuration, and axle weight. For each permit truck in the database, there is an assigned authorized route with a known number and types of bridges. Every bridge has over 130 attributes available from NBI. However, bridge information used in this analysis is the maximum span length, which is needed for influence line analysis runs, and the type of the bridge. This study considered simple span and continuous span bridges. The influence line analysis for each bridge is conducted based on the span length and support condition. For continuous span bridges, the maximum moment is considered as a maximum positive and negative moment for two equal continuous span bridge.

The bridge damage analysis included 160 thousand permit trucks that crossed over 195 thousand bridges. The permit-induced load effects were developed for each permit truck and every Alabama bridge used by the overloaded permit truck. The bridge damage is then represented by the bridge damage ratio:

$$B = \frac{M_{permit}}{M_{legal\ truck}} \tag{5-4}$$

where:

| | | |
|---|---|---|
| $B$ | – | bridge damage ratio |
| $M_{permit}$ | – | moment effect due to a permit vehicle [kip-ft] |
| $M_{legal}$ | – | moment effect due to a typical legal vehicle [kip-ft] |

To determine the bridge damage, the permit-induced load effects need to be compared with the typical legal vehicle. The bridge damage ratio represents the relative increase of the damage in comparison to the legal vehicles. This analysis requires finding the Alabama legal truck. Weigh-in-Motion data was used to determine representative typical legal trucks. Available WIM data was used to analyze the truck traffic composition in Alabama. WIM data was filtered out to find the number of vehicles by class to determine the most common type. The data showed that class 9, 5-axle trucks are dominating in Alabama. The analysis of 5-axle trucks was conducted to determine the typical configuration of legal 5-axle trucks. Several configurations were considered and run over influence line analysis for a wide range of bridge span lengths. Moreover, the Auburn Team conducted a literature review, and it was found that the typical WIM truck for U.S. national WIM data for several states, was closely aligned with Alabama WIM data analysis(Wassef and WSP USA Inc. 2021). The representative typical legal truck needs to follow Federal Truck Weight and Size law as well as Federal Bridge Formula B. WIM data analysis determined the representative 5-axle truck with the configuration shown in **Figure 5-1**.This truck is used to determine bridge damage ratio. The results of the bridge damage assessment analysis are shown in Chapter 7 “Infrastructure Damage”.

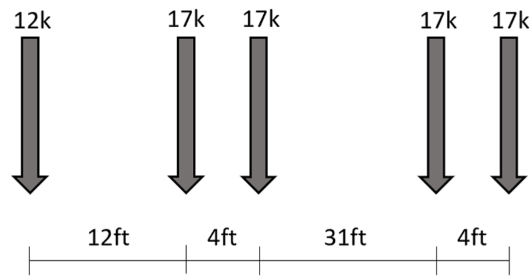



**Figure 5-1: Representative typical legal vehicles for Alabama traffic.**

### 5.4 PAVEMENT DAMAGE ASSESSMENT

Pavement design is based on the Equivalent Single Axle Load (ESAL), which is a concept developed from data collected at the American Association of State Highway Officials (AASHO) Road Test to establish the damage relationship for comparing the effects of axles carrying different loads. Design ESALs convert vehicle axle load into an equivalent number of 18,000 lb. single axle load. Therefore, this study used the permit database to find for each permit truck the single, tandem, tridems, quad, and penta axle configurations. Vehicle axle configurations are used to determine Equivalent Axle Load Factor (EALF) per each axle configuration, then summed to determine ESAL per truck. **Equations (5-3)**, and **(5-4)** present the EALF, and ESAL analysis.

**Equations (5-5)** to **(5-9)** show the supplementary equations for the parameters required to determine ESAL.

The ESAL calculation was conducted for flexible and rigid pavements. Based on the analysis, it was decided to only use the flexible pavement ESAL for further damage assessment as the goal is to determine the relative damage of pavement in comparison to Alabama's typical legal truck.

$$EALF = \left(\frac{L_{18} + L_a}{L_p + L_a}\right)^{4.79} \left(\frac{10^{\frac{G}{\beta_x}}}{10^{\frac{G}{\beta_{18}}}}\right) (L_a)^{4.33} \quad \textbf{(5-5)}$$

$$ESAL = \frac{1}{EALF} \quad \textbf{(5-6)}$$

where:

*ESLF* – Equivalent Single Load Factor

| | | |
|---|---|---|
| *ESAL* | – | Equivalent Single Axle Load |
| $L_p$ | – | axle being evaluated in kips |
| $L_a$ | – | code for axle evaluation:<br>1 – single axle<br>2 – tandem axle<br>3 – triple axle<br>4 – quad axle<br>5 – penta axle |
| $L_{18}$ | – | standard axle load in kips |
| *G* | – | function of the ratio of loss in serviceability at time t, see Eq. **(5-7)** |
| $\beta_x$ | – | function which determines the relationship between serviceability and axle load applications for permit vehicle axles |
| $\beta_{18}$ | – | function which determines the relationship between serviceability and axle load applications for standard axle |

$$G = log\left(\frac{4.2 - pt}{4.2 - 1.5}\right) \quad \textbf{(5-7)}$$

$$\beta_x = 0.04 + \left(\frac{0.081\left(L_p + L_a\right)^{3.23}}{(SN+1)^{5.19}{L_a}^{3.23}}\right)^{4.79} \quad \textbf{(5-8)}$$

$$\beta_{18} = 0.04 + \left(\frac{0.081\left(L_{18} + L_a\right)^{3.23}}{(SN+1)^{5.19}{L_a}^{3.23}}\right)^{4.79} \quad \textbf{(5-9)}$$

where:

| | | |
|---|---|---|
| $p_t$ | – | terminal serviceability index |
| $SN$ | – | structural number per pavement cross section |

This study follows the flexible pavement design to determine the relative damage caused by different permit axle loadings. This method provides a procedure to calculate the damage caused by mixed vehicle loadings. The pavement damage is represented by the pavement damage ratio, **Equation (5-10)**.

$$P = \frac{ESAL_{permit}}{ESAL_{legal\ truck}} \quad \textbf{(5-10)}$$

where:

| | | |
|---|---|---|
| $P$ | – | pavement damage ratio |
| $M_{permit}$ | – | moment effect due to a permit vehicle [kip-ft] |
| $M_{legal}$ | – | moment effect due to a typical legal vehicle [kip-ft] |

The ESAL calculations were conducted for approximately 160 thousand permit trucks and 750 thousand road links. Every permit truck has an assigned authorized route with a known ADTT per lane. Road links are categorized based on the ADDT per lane, where the variable parameter, $p_t$ – terminal serviceability index, is taken as 2.0 for ADDT <250, 2.5 for ADTT 250-500, 3.0 for ADTT 500-1000, and 3.5 for ADTT >1000. The structural number per pavement section was taken as 5.0. A sensitive analysis was conducted to determine the impact of variable SN, and it was concluded that it has a minor impact on the developed damage.

The permit induced ESALs were developed for each permit truck and every detected road link in Alabama. The pavement damage is represented by the pavement damage ratio, results are shown in Chapter 7.

## 5.5 TOTAL INFRASTRUCTURE DAMAGE

Based on the developed bridge and pavement damage assessment methodology using the bridge and pavement damage ratio, the total permit damage calculation is proposed. The permit database supplemented by the developed permit corridors allowed to quantify the relative infrastructure damage caused by Alabama permit traffic. The total infrastructure damage is shown in **Equation (5-11)**.

The total damage is developed for every permit truck as the weighted average damage caused by a single truck to all the bridges and road links crossed based on the assigned authorized permit route. The damage calculated for each bridge is then summed up and weighted by the total length of the bridge. Similarly, pavement damage is found based on the summation of ESAL for all road links. The total damage provides a basis to determine a new equitable permit fee schedule for Alabama.

$$Damage = \frac{\sum_{b=1}^{BB} \frac{M_{b,permit} \cdot L_b}{M_{b,legal}} \cdot}{\sum_{b=1}^{BB} L_b} + \frac{\sum_{l=1}^{LL} \frac{ESAL_{l,permit} \cdot L_l}{ESAL_{i,legal}} \cdot}{\sum_{l=1}^{LL} L_l} \qquad \textbf{(5-11)}$$

where:

| | | |
|---|---|---|
| $Damage$ | – | total permit damage |

| | | |
|---|---|---|
| *BB* | – | number of bridges crossed by a single permit vehicle |
| *LL* | – | number of road links crossed by a single permit vehicle |
| *b* | – | a bridge on the permit route |
| *l* | – | a route link on the permit route |
| $M_{b,permit}$ | – | Maximum bending moment on *b* bridge caused by permit vehicle [kip-ft] |
| $M_{b,legal}$ | – | Maximum bending moment on *b* bridge caused by legal vehicle [kip-ft] |
| $ESAL_{l,permit}$ | – | Equivalent Single Axle Loads on *l* road link caused by permit vehicle |
| $ESAL_{l,legal}$ | – | Equivalent Single Axle Loads on *l* road link caused by legal vehicle |
| $L_b$ | – | total length of the *b* bridge |
| $L_l$ | – | total length of the *l* road link |

# Chapter 6

# PERMIT CORRIDORS IN ALABAMA

## 6.1 TRANSPORT DEMAND MODEL

Developed damage methodology requires analysis of Alabama permit corridors. The roads and bridges utilized by the permit traffic need to be identified to be used in the damage assessment. Therefore, permit data is used to extract information about the trip origin and destination. The authorized permit routes are used to find the infrastructure utilized by permits. This chapter presents the development of the Transport Demand Model (TDM) which is a tool to find heavy permit corridors in Alabama.

To determine permit routes, the origin and destination along with the trip description are used, but finding the probable route, based on the above-mentioned input parameters, requires dedicated software and the algorithm to find the route. To find permit trip corridors a GIS application needs to be used. There are several options available including web services such as GoogleMaps, OpenStreetMaps, or ESRII ArcGIS Online, and GIS desktop applications ESRII ArcGIS, qGIS, Hexagon Geomedia, and more. The GIS system allows to conduct a limited transportation analysis and may require extra support or modules to achieve the necessary functionality. Therefore, in this project, a more advanced tool was developed to combine the GIS system with the possibility to calculate bridge and pavement damage.

The Alabama Transport Demand Model was developed in 2017 as a part of the Alabama 2040 Statewide Transportation Plan. It is an excellent tool for determining existing and future congestion levels and projecting the overall travel demand. TDM was developed using CUBE voyager software, the U.S. Census data, and Longitudinal Employer-Household Dynamics data. The Alabama TDM was not available to be used in this project, because of the restricted access to its numerical data. Thus, the project specific Transport Demand Model was developed. PTV VISUM software was used to develop Alabama TDM. VISUM is a computer-aided transport planning program, which serves to analyze and plan transportation systems. Transportation systems include private (PrT), public transport supplies (PuT), and travel demands. VISUM supports transportation planners to develop measures to better predict and manage transportation systems. VISUM also provides basic transport information and planning systems, which can be managed and maintained with the network editor. Unlike simple GIS systems, VISUM allows complex relationships within single or several transport systems allowing the creation of suitable transport models. VISUM TDM allows importing and combining network data from different data sources and deals with private and truck traffic. Moreover, VISUM can be supplemented by other data sources required for analysis.

This chapter provides background information on the development of Alabama TDM for pavement and damage assessment. The main objective is to present the major steps required to build the model. The purposes of Alabama TDM are to:

- detect heavy permit vehicle corridors,
- determine all road links and their attributes within the corridors,
- find bridges and their attributes within the corridors,
- compute pavements and bridge damage caused by Alabama permit vehicles.

The data required to build the model includes road and bridge data and the traffic data with average daily traffic (ADT), and average daily truck traffic (ADTT). Extensive databases were utilized to build TDM and develop heavy permit corridors. The following datasets were used:

- Road network:
  - nodes – junctions, road network start and end points, with a spatial location defined by coordinates (latitude, and longitude)
  - road sections – links between nodes, with geometry defined by coordinates (latitude, and longitude), road category and length attributes,
  - bridges with a spatial location defined by coordinates (latitude, and longitude), bridge material and structural type, total length, and maximum span length attributes.
- Traffic data – ADT and ADTT
- Permit data – trip origins and destinations, authorized route description
- Traffic analysis zones (TAZ) – virtual areas defined by boundary coordinates, with land-use attributes (based on the US census)

The development of the TDM model requires the development of demand, network, and impact models, and validation of the model. **Figure 6-1** shows the required operation models to build the TDM. These models are correlated, and they constitute the TDM base body supported by the impact model, which allows various analyses.

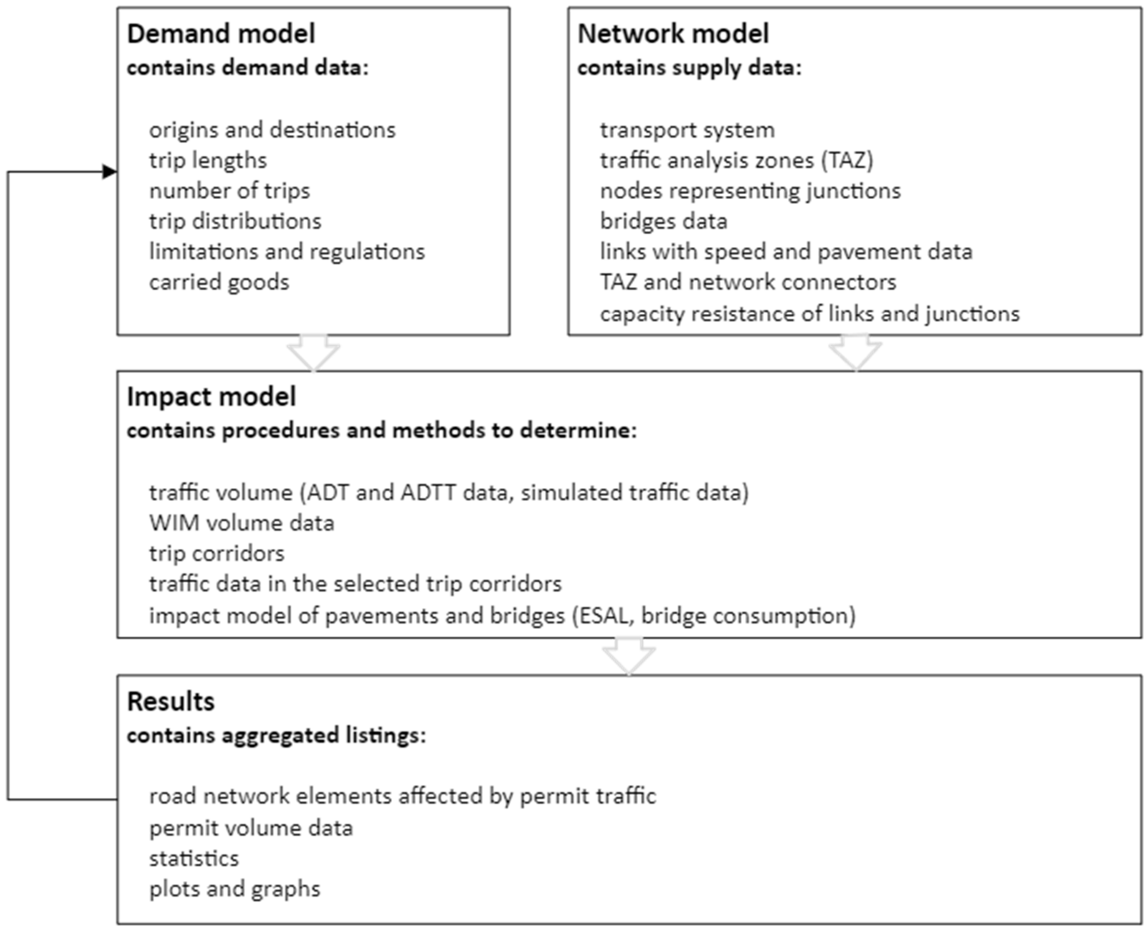



**Figure 6-1: Transport Demand Model with required operation models.**

## 6.2 NETWORK DEVELOPMENT MODEL

Alabama road network was selected to represent a transportation system for TDM. The transportation system **T** is typically represented via network graphs defined by links (one-way homogeneous sections of transportation infrastructure or service) and nodes (link endpoints, typically intersections or points representing changes in link attributes). Both links and nodes have associated attributes (e.g., length, speed, and capacity for links and turn prohibitions and penalties for nodes). The road network model was developed to determine permit vehicle corridors, road links, and bridges utilized by the permitted traffic.

The road network model is based on the graph theory, where nodes represent:

- interchanges and junctions
- network start and end points
- point of changes in link types (pavement, cross-section, capacity free flow speed, etc.)

Road network links represent sections of pavement, and they are defined as directed vectors between a pair of nodes. The opposite link represents the second direction of the traffic if it exists.

OpenStreetMap datasets (Geofabrik download server, 2021) were used to build a network model. Public transportation network was not included in the analysis, only road network datasets were uploaded to the model. The available road network attributes include:

- link type
- free flow speed
- capacity
- lanes number
- traffic volume

The developed Alabama TDM model consists of 97 thousand miles of road network with 7,000 miles of motorways and trunks (**Figure 6-2**). The link lengths were defined based on link geometry as defined in the OpenStreetMap database. The link geometry is defined in TDM by succeeding points described by pair of (X, Y) coordinates, which is presented in **Figure 6-3**.

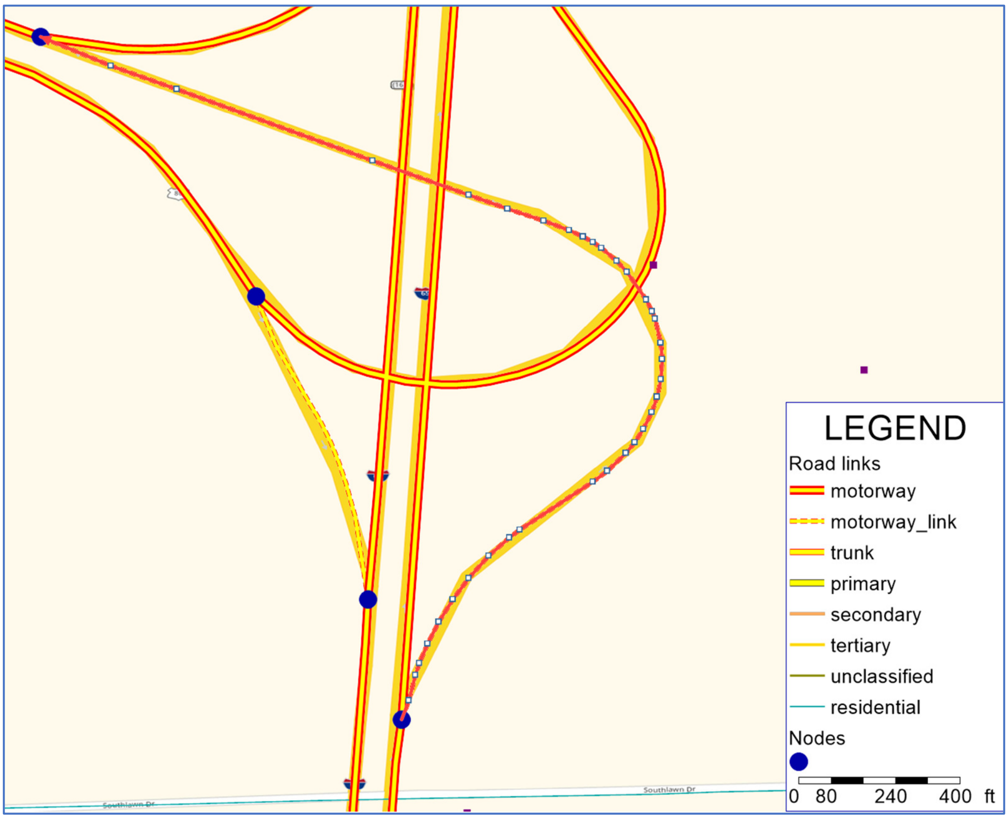



**Figure 6-2: Road links definition in Alabama TDM.**

Road link types, traffic counts, and mileage statistics included in TDM are presented in **Table 6-1**. Over 70% of the total road network length is covered by residential and unclassified links, whereas the basic road network, represented by motorways and trunks (interstate and state roads), carries 7.2% of traffic. As the residential roads act as the first and last mile of permit vehicle trips, they need to be included in the TDM.

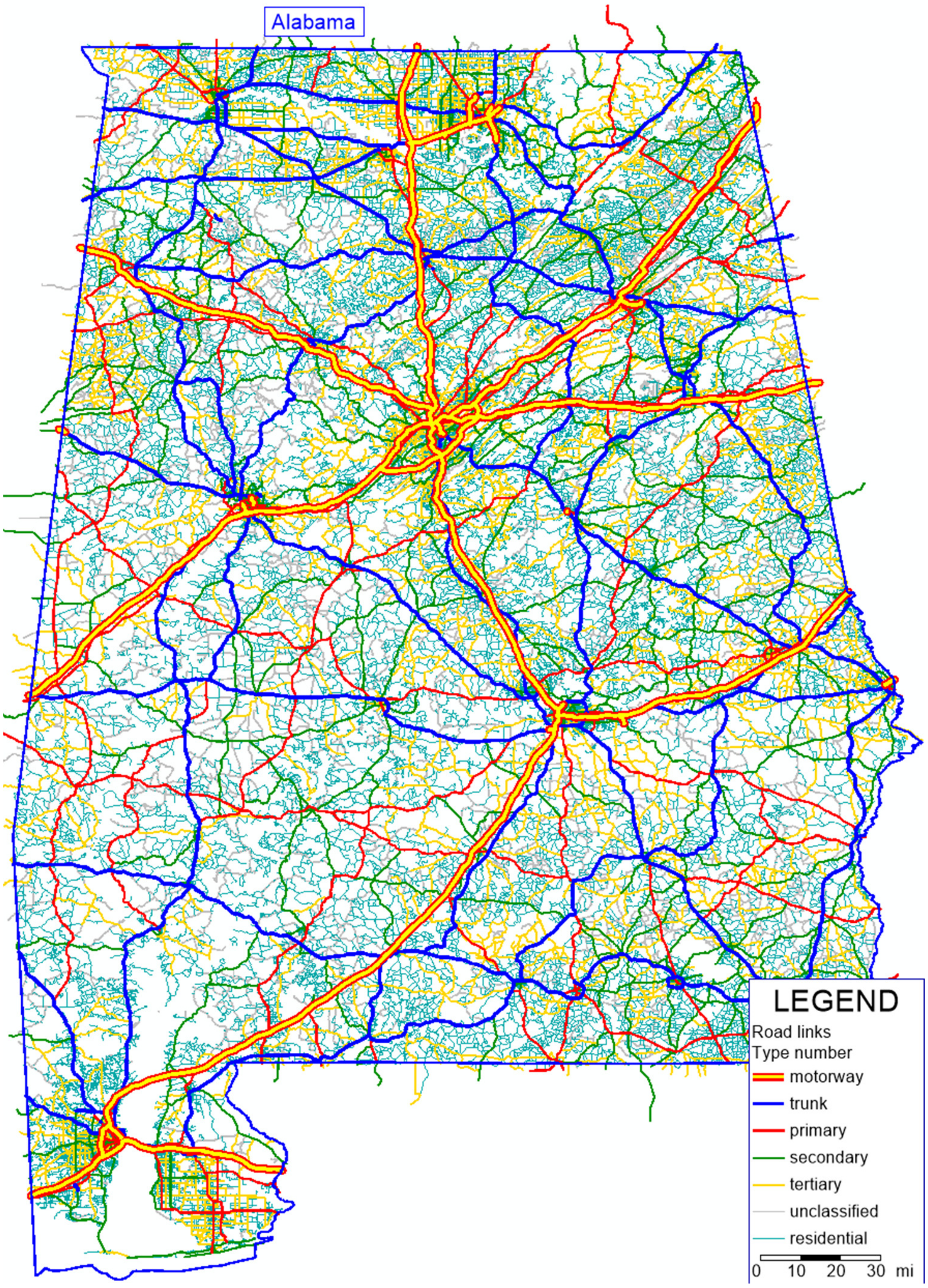



**Figure 6-3: Alabama GIS road network system for Alabama.**

**Table 6-1: Road network typical sections in Alabama TDM**

| Road Network Section | Number of lanes | Capacity | Model speed [mph] | Number of sections | Total length [miles] |
|---|---|---|---|---|---|
| Motorway, | 1 | 1,500 | 81 | 8 | 1 |
| Motorway | 2 | 3,000 | 81 | 778 | 1,373 |
| Motorway | 3 | 4,500 | 81 | 518 | 566 |
| Motorway | 4 | 6,000 | 81 | 181 | 152 |
| Motorway Link | 1 | 1,100 | 50 | 2,625 | 360 |
| Motorway Link | 1 | 1,200 | 50 | 433 | 82 |
| Trunk | 1 | 1,500 | 62 | 140 | 16 |
| Trunk | 2 | 3,000 | 62 | 15,465 | 3,763 |
| Trunk | 3 | 4,500 | 62 | 3,879 | 565 |
| Trunk Link | 1 | 1,100 | 50 | 2,257 | 93 |
| Trunk Link | 2 | 1,200 | 50 | 138 | 11 |
| Primary | 1 | 1,300 | 62 | 12,188 | 2,944 |
| Primary | 2 | 2,600 | 62 | 3,040 | 362 |
| Primary | 3 | 3,900 | 62 | 578 | 70 |
| Primary Link | 1 | 1,000 | 25 | 1,638 | 59 |
| Secondary | 1 | 1,000 | 50 | 24,878 | 5,726 |
| Secondary | 2 | 2,000 | 50 | 2,944 | 294 |
| Secondary Link | 1 | 1,000 | 12 | 980 | 44 |
| Tertiary | 1 | 800 | 43 | 48,358 | 12,007 |
| Tertiary | 2 | 1,600 | 43 | 1227 | 135 |
| Tertiary Link | 1 | 800 | 12 | 677 | 30 |
| Unclassified | 1 | 800 | 43 | 24,089 | 8,976 |
| Residential | 1 | 400 | 31 | 329,386 | 59,250 |
| Living Street | 1 | 200 | 19 | 53 | 5 |
| Ferry | 1 | 100 | 3 | 1 | 2 |
| | | | **Total** | **476,459** | **96,887** |

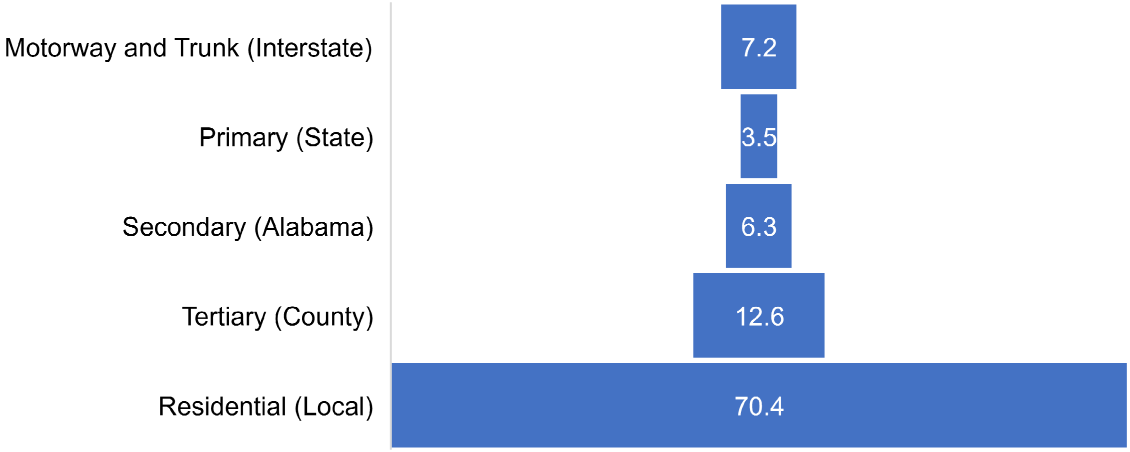



**Figure 6-4: Percentage of road network types in Alabama.**

The classification of the road network in Alabama was adopted based on data recorded in OpenStreetMap. There is no paving data on the road network in Alabama. Therefore, this road and traffic volume classification is used to define pavement characteristics for road sections. It is assumed that the higher the class of the road and the heavier the traffic volume.

The developed TDM model requires information about the heavy permit corridors, and the types of roads and bridges to calculate the damage caused by permit trucks. The network model includes the road characteristics with the defined road classes. For the bridge data, the TDM model was supplied by the public domain National Bridge Inventory Database (NBI) database. The 2022 NBI data was utilized in the TDM. The Alabama bridge coordinates were used in Alabama TDM. There are over ten thousand bridges and six thousand culverts in Alabama according to the NBI databases. NBI data contains over 130 bridge attributes for every bridge. Alabama bridge records were imported to TDM as points of interest (POI) with the latitude and longitude to locate them to the road network. **Figure 6-5** presents Alabama road network and available attributes for selected bridges. **Figure 6-6** presents the map of the Alabama road network and all bridges important to the TDM. Bridges are located along the road network links and can be assigned to heavy permit corridors. In addition to bridge coordinates, the name of the carried roads was used to ensure the correctness of the bridge location to the road links. All bridge attributes were imported to the model to be used in the bridge damage analysis. Some of the bridges were located outside the Alabama road network. Corrective action was taken to verify and adjust the location of the bridges to align with the links. Over 320 bridge locations were verified and corrected. Only 12 bridge locations were unidentified and discarded from the TDM.

NBI data for Average Daily Traffic (ADT) and Average Daily Truck Traffic (ADTT) were used and assigned to the road network links. This traffic data was a supplementary source of traffic volume information added along with the traffic count data.

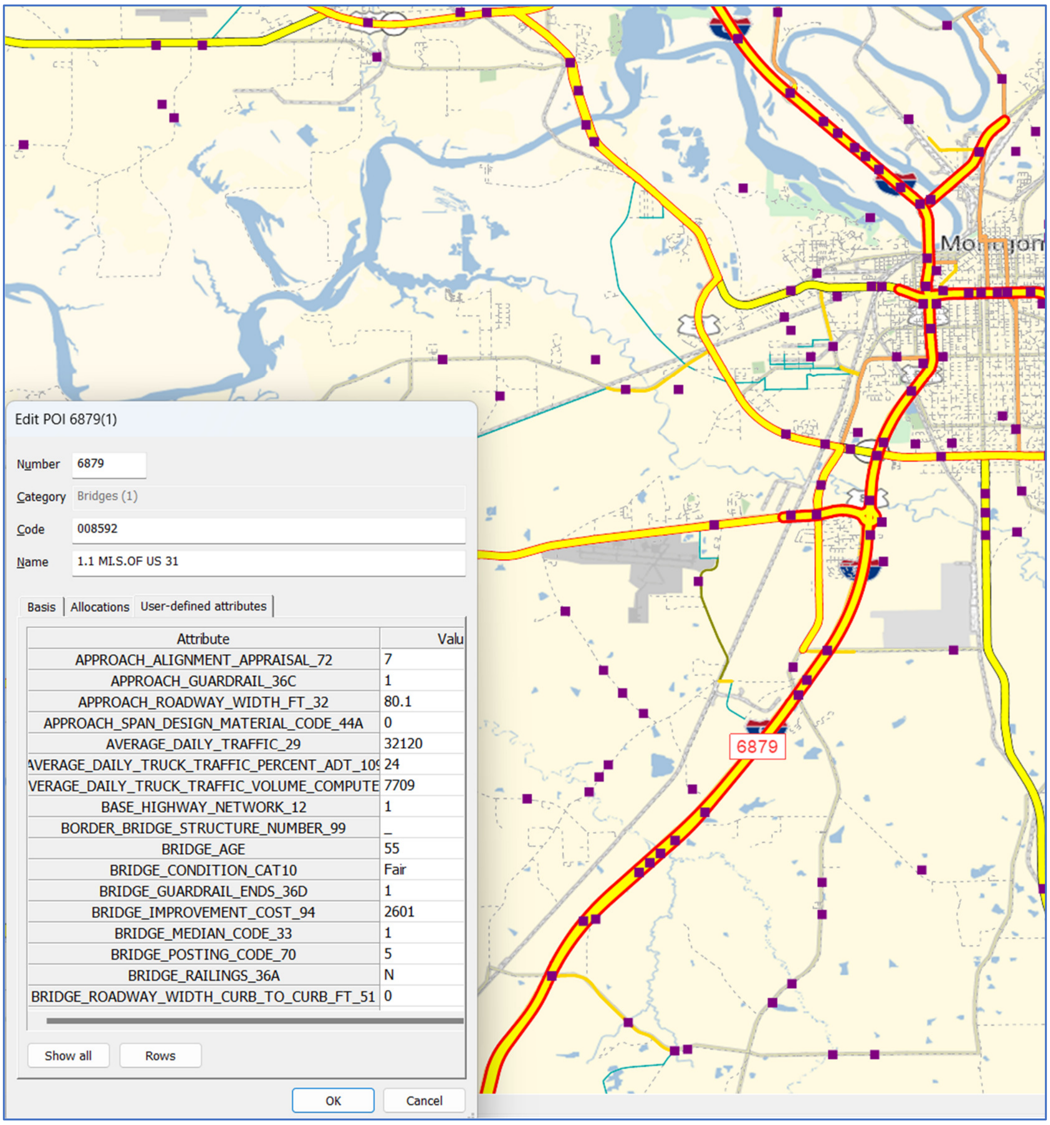



**Figure 6-5: Bridge attributes available in Alabama Transport Demand Model.**

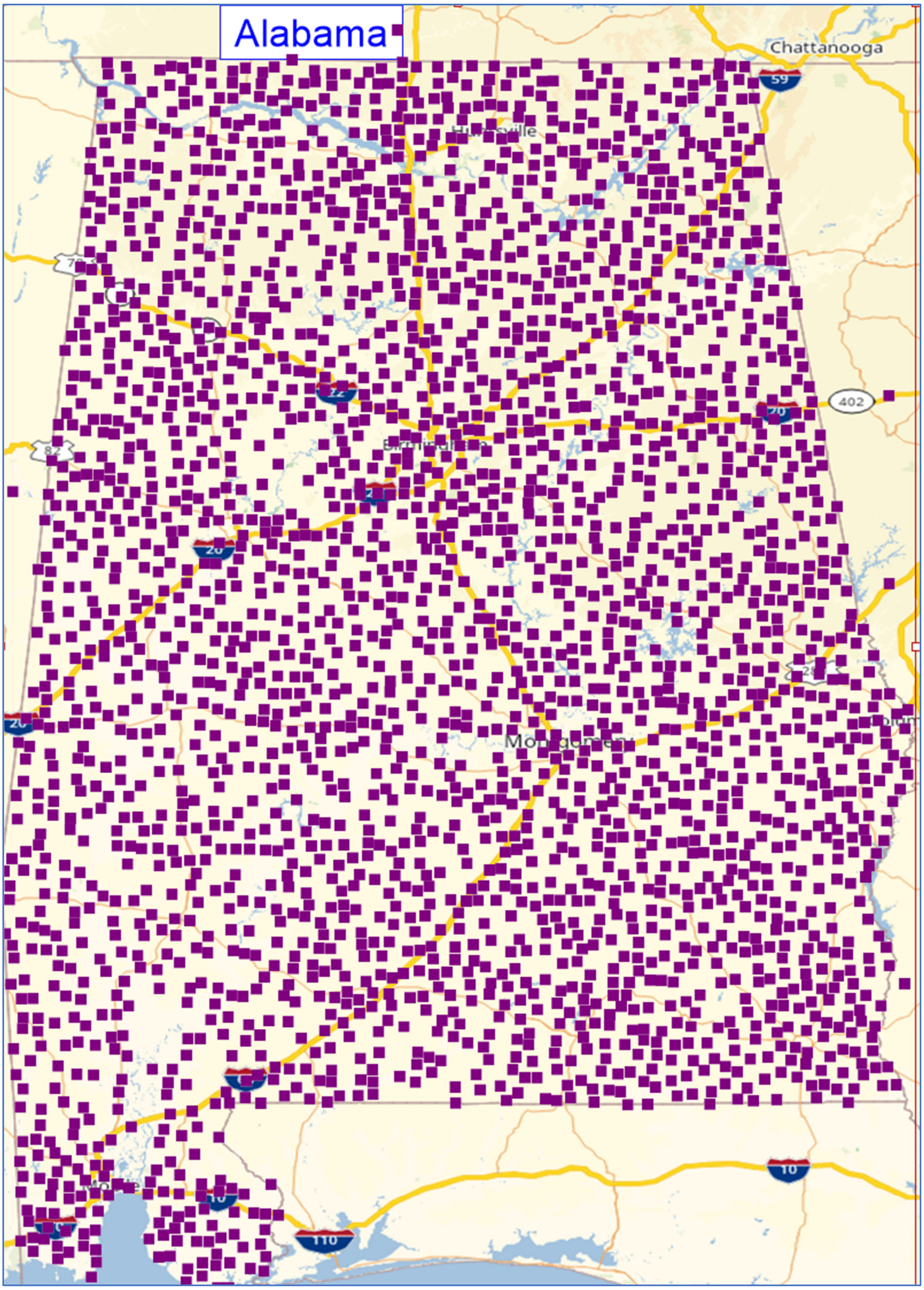



**Figure 6-6: Alabama bridges in Transport Demand Model.**

## 6.3 HEAVY PERMIT CORRIDORS

### 6.3.1 Traffic Analysis Zones

TDM is limited by state borderlines (cordons) which define a study area. The area within the cordon is composed of Traffic Analysis Zones (TAZ) and is subjected to explicit modeling and analysis. The internal activity system **A** is typically represented by socio-economic, demographic, and land use data defined for TAZs or other convenient spatial units. The activity of system **A** is interfaced with transportation system **T** via centroid connectors which are abstract links connecting TAZ centroids to realistic access points on the physical road network.

The developed TDM for Alabama is a classic 4-stage model where the trip origin and destination are defined by TAZ. Census Tracts were used to define 1,473 inner TAZs (see **Figure 6-7**), and socioeconomic data were utilized based on the U.S. Census population and household numbers for 2010. The Longitudinal Employer-Household Dynamics data set available from the U.S. Census for the employment data served as the main source of transportation behavior characteristics. The collected data included the number of households, average income for the households, retail employment, and non-retail employment.

The statewide traffic count database was used to define Alabama traffic attributes, where 121 additional external TAZs were defined. All TAZs were connected to the transportation network by connectors, which define possible road network access nodes. No less than 5 and no more than 16 connectors were defined for every TAZ, and all connectors were attributed to the attractiveness factor. This factor defines the percentage of traffic used by the given connector. This solution allows a definition of trip origins and destination distribution within every single TAZ, and thus, to a better assignment of traffic into the road network. An example of connectors defined for TAZs is presented in **Figure 6-8**.

Based on the developed TDM, a single square matrix of daily trips was generated. The sum of the rows for a given TAZ represents the total traffic generated by that TAZ, and the sum of the columns represents the traffic absorbed. The diagonal of the matrix characterizes the movement in the inner zone, but it is not the subject of this analysis.

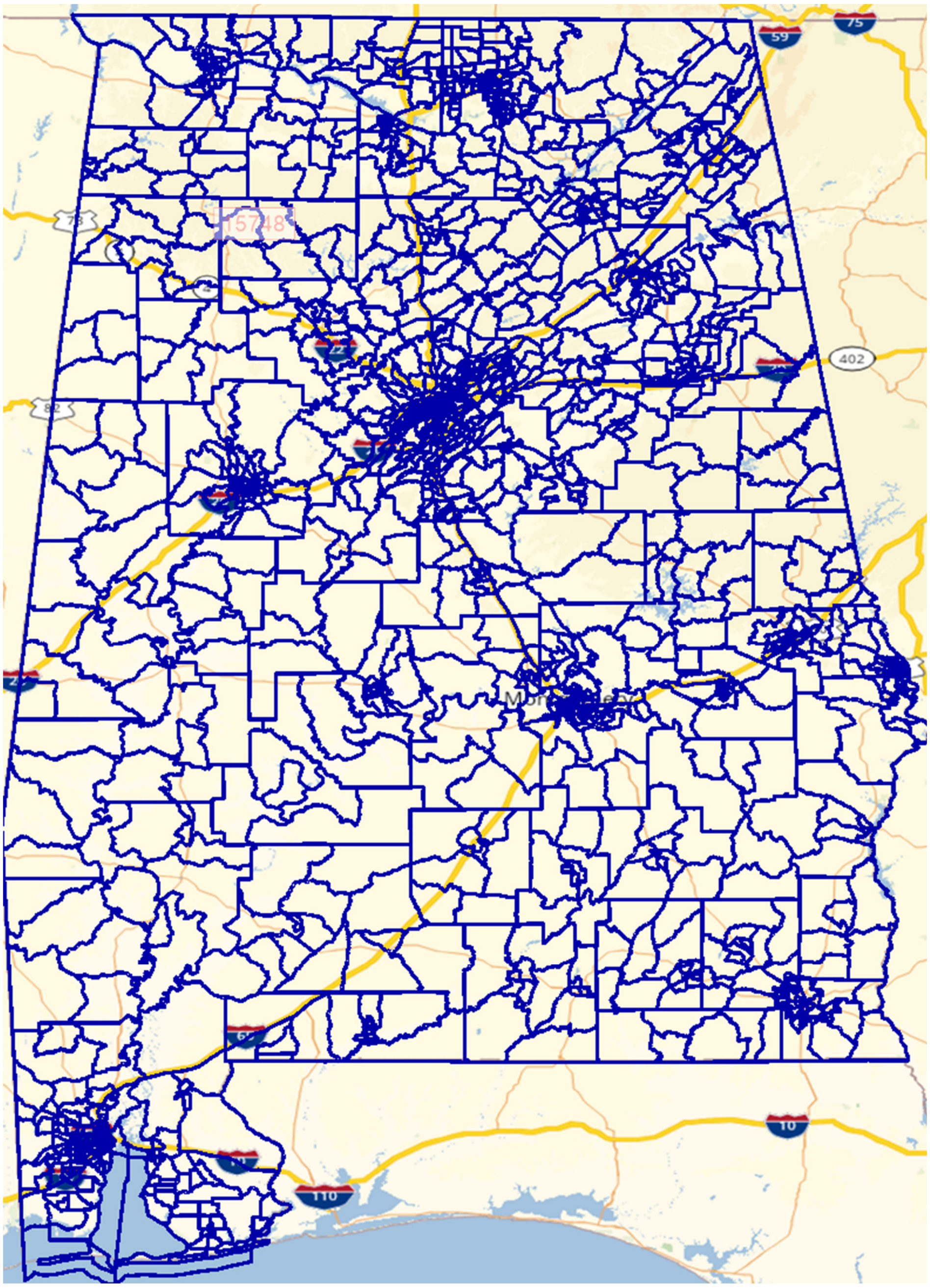


**Figure 6-7: Traffic Analysis Zones Using Census Tracts.**

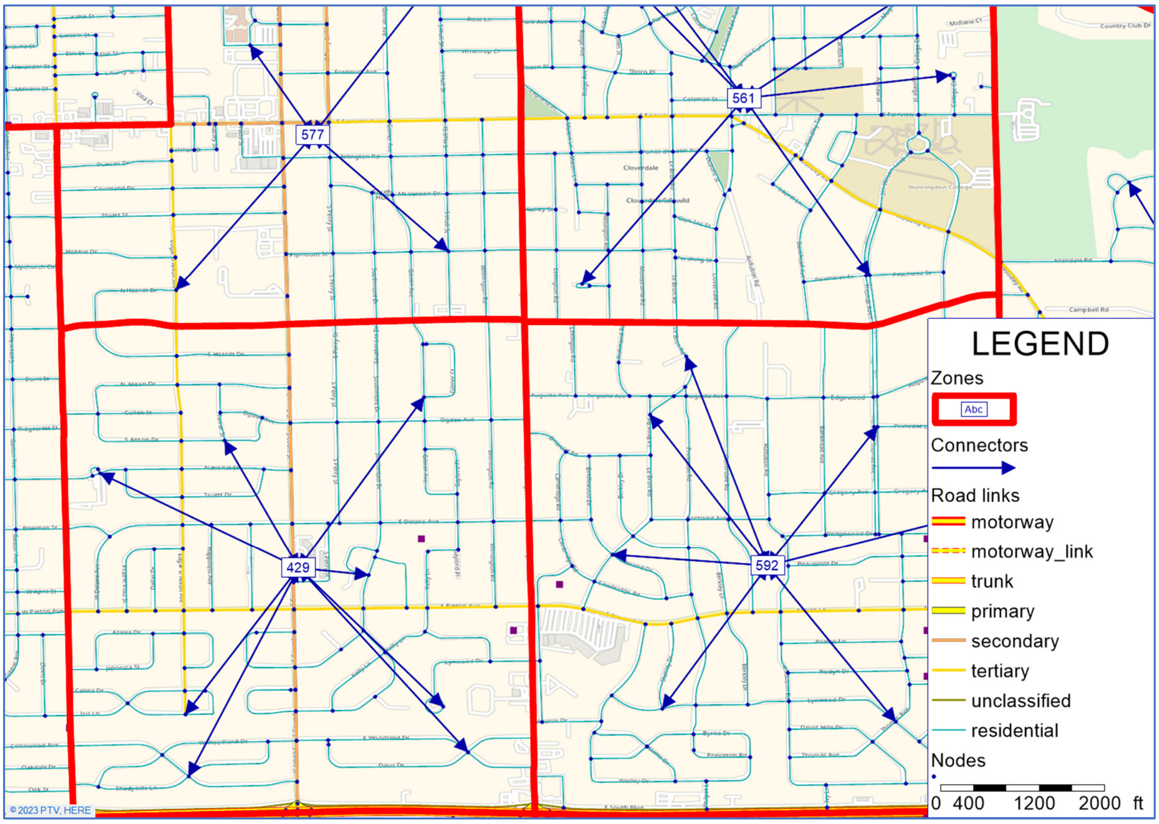



**Figure 6-8: Traffic Analysis Zones Connectors for Alabama TDM.**

### 6.3.2 Permit Traffic Demand

Permit traffic is a major input data to the Transport Demand Model. It has been observed that overloaded traffic keeps growing. Based on WIM data analysis and the federal weight and size law, over 11% of trucks are overloaded.

Permit vehicle operations are restricted because not all infrastructure is prepared to carry overweight traffic. Typically, the basic road infrastructures, represented by motorways, trunks, and primary links, are utilized for permit truck operations. The trip's origin and destination in most cases are located on the primary road infrastructures; however, the local road networks are used in the first and last mile. This study provides a methodology to determine the damage caused to bridges and pavements by permitted vehicles. Thus, permit traffic needs to be represented as the separate demand part of the TDM.

The Alabama Maintenance Bureau issues about 500-600 permits per day. About 200 of them are issued for overweight, as well as oversize and overweight vehicles. The Alabama permit database was filtered for overweight, and overweight and oversized permits, which were then transferred to the Structured Query Language (SQL) Server database. Available permit trip origins and destinations were used in the trip generation analysis. Every permit trip is specified by its unique origin and destination which defines the most attractive areas for permit traffic – permit analysis zones. In total, over 235 thousand trips between origin and destination were found. The most attractive zones for permit traffic generation and absorption were listed in **Table 6-2**. The total number of permit traffic generation and permit traffic absorption are 54,441 and 55,962, respectively. The permit trips origins and destinations were used to determine heavy corridors for the damage assessment analysis.

**Table 6-2: Permit analysis zones – trip generation and trip absorption.**

| Id | Permit generator and absorber | Trips generation | Trips absorption |
|---|---|---|---|
| 1 | PENSACOLA FL | 13,629 | 928 |
| 2 | GARDEN CITY KS | 492 | 10,520 |
| 3 | 4301 IVERSON BLVD | 5,873 | 3,117 |
| 4 | 3525 RICHARD ARRINGTON BLVD | 0 | 6,837 |
| 5 | COLUMBUS MISSISSIPPI | 5,252 | 223 |
| 6 | DADEVILLE | 2,558 | 1,898 |
| 7 | CUSSETA, AL | 2,600 | 1,734 |
| 8 | NEW SITE, AL | 1,557 | 2,724 |
| 9 | 1201 AL 20 | 3,117 | 0 |
| 10 | CHATTAHOOCHEE, FL | 596 | 1,664 |

### 6.4 IMPACT MODEL

ALPASS - Alabama's Online OS/OW Permitting System collects information about the trip's origin and destination, as well as the description of the trip. Permit data analysis captured repetitive trip origins and destinations, with the same trip descriptions. Therefore, trips with similar characteristics were used in the TDM. Permits were grouped by trip origins and destinations and marked with a unique ID number. It was found that the top 3,300 most common permit trip routes represent approximately 12% of all permits issued by Alabama DOT.

The impact model is defined in TDM to run the desired analysis. The algorithm to find the optimal route from trip origin to trip destination requires the so-called trip resistance function and its parameters. Both road sections' length and speed limitation impacts travel time, and traffic volume can cause an additional delay in trips. Thus, the volume-delay function (VDF) is defined in the impact model. Travel times for traffic are determined by the saturation of links and turns, which result from the traffic volume and the capacity of these network objects. Travel times vary and need to be considered while detecting routes utilized by permit traffic.

To detect road sections and bridges on permit routes, a corridor needs to be identified in TDM. The corridor is defined by a list of road links and bridges along a permitted route. Permit vehicle trips are usually planned based on popular map services, like Google Maps or OpenStreetMap. While checking permit database records, it is observed that the trip directions provided by those services are directly included in the permit data as the authorized routes. Therefore, OpenStreetMap API service was used to detect vehicle trip corridors.

OpenStreetMap requires detailed coordinates (latitude and longitude) of trip origins and destinations, to determine possible routes from trip origin to destination. The Geolocator service was used to collect coordinates from OpenStreetMap API service. This service provides a procedure to list directions and coordinates for a trip from origin to destination. A detailed list of coordinates was used to create the geometry of the permit vehicle trip (a list of succeeding pairs of coordinates linked by lines) for each corridor. Then the trip directions were compared to the authorized routes to verify the correctness of the corridor definition. If they did not match it, the alternative routes were checked. The example list of permit trip coordinates is present in **Figure 6-9**. It can be observed that the linestring perfectly matches links representing the Alabama road network. Therefore, links of the Alabama road network can be matched with corridors.

In the Impact Model, approximately 4,000 most common corridors representing overweight permit vehicles in Alabama were found and attributed to over 90,000 permit trips. **Figure 6-9** presents detected permit corridor coordinated, and **Figure 6.10** shows Alabama heavy permit corridors with assigned permits. The busiest roads and their associated number of issued permits from 2013-2021 are listed as follows:

- I10, East Mobile – 9600 permits
- Government Street, Mobile – 7,100 permits
- AL98, Moffett Road – 7,000 permits
- Spring Hill Avenue and Springhill Avenue, Mobile – 7,000 permits

Detected permit corridors were assigned to Alabama permit trucks. In TDM all road network links are attributed with the basic data necessary to calculate pavement damage, and the NBI bridge data is used to determine the bridge damage.

A) Pavement damage requires:
- Road section length
- Road category, name, county,
- Number of lanes
- Traffic volume in terms of ADTT

B) Bridge damage requires:
- Bridge total length
- Maximum span length
- Bridge material, and structure type

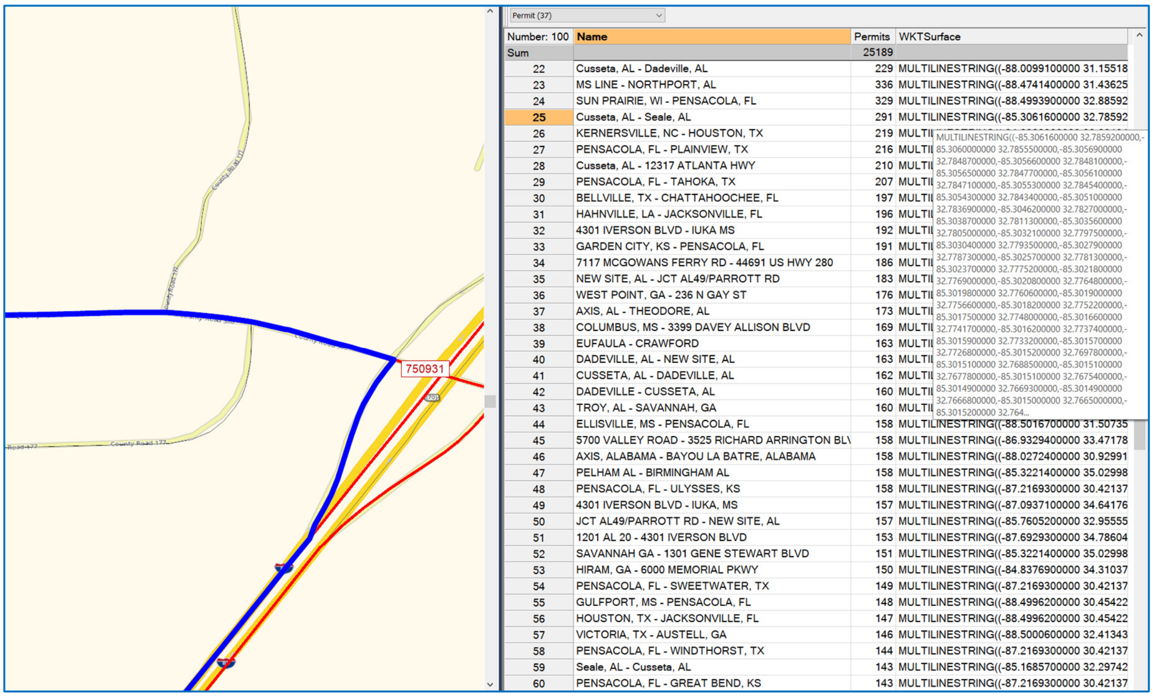



**Figure 6-9: Permit route coordinates in Alabama TDM.**

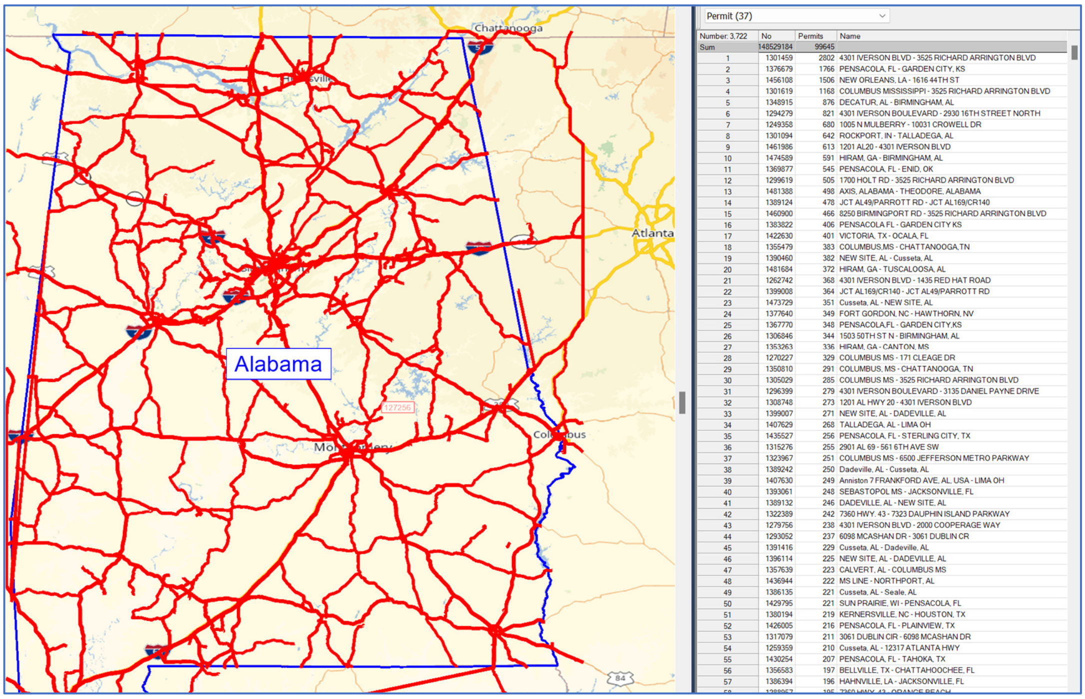



**Figure 6-10: Alabama heavy permit corridors with assigned permits.**

This chapter presented the development of the Alabama Transport Demand Model to determine the damage caused by overloaded permit trucks to roads and bridges. TDM was used to determine the heavy permit corridors, and consequently determine the bridge and road types utilized by the heavy traffic. The heavy permit corridors with the details about the Alabama bridges and roads were used to evaluate the damage for bridges in terms of the bending moment and ESAL for pavements. The results of the damage analysis are presented in the next chapter.

# Chapter 7

# INFRASTRUCUTRE DAMAGE

## 7.1 DAMAGE ASSESSMENT

The developed Transport Demand Model detected the heavy permit corridors in Alabama. The authorized permit routes were assigned to approximately 160 thousand permit vehicle records. The representative set of permit data was used to assess the damage caused by overloaded trucks to bridges and pavements. The bridge damage is represented by the ratio of the maximum bending moment caused by the permit vehicles to standard legal truck. Similarly, the pavement damage ratio is calculated in terms of permit ESAL to standard legal ESAL. The developed methodology provides a basis to determine the relative damage caused by the existing Alabama permit traffic.

The developed damage assessment methodology calculated the damage caused by every detected permit route and vehicle. An example of a damage calculation for a single permit truck is presented in **Table 7-1**. A 7-axle permit truck with a GVW of 134 kips, crosses 13 bridges, and 44 road links, the permit trip length is 66 miles. The damage is calculated for every bridge and road link utilized by the permit truck. The total damage is calculated as a weighted average by the length of the bridges and roads as shown in **Equation (7-1)**. The example calculations show the pavement damage is 2.97, and the bridge damage 1.25. The weighted damage of one means that the permit vehicle did not cause any additional damage, but the damage ratio above one indicated incremental damage to the infrastructure. Thus, the total unit damage can be expressed as:

$$Total\ damage = 1 + (Bridge_{damage} - 1) + (Pavement_{damage} - 1) \qquad \textbf{(7-1)}$$

To continue with the example presented in **Table 7-1,** the total infrastructure damage is 1+(1.25-1) + (2.97-1), which gives total damage of 3.22. The value of 3.22 is the damage multiplier that indicates what is the additional damage caused by a permit truck in comparison to the standard legal truck.

The damage analysis was conducted for 160 thousand permit records, which account for 18% of permits received from ALDOT for the years 2013-2021. The analysis of the infrastructure damage provides a basis to determine a new permit fee schedule for Alabama permit traffic. **Table 7-2** presents a list of the selected permit trucks with calculated pavement and bridge damage.

**Table 7-1: Example of damage calculation by a permit vehicle.**

| | | | |
|---|---|---|---|
| **Permit ID:** | 2855656 | **Trip Length [miles]:** | 66.17 |
| **GVW [kips]:** | 134 | **Axle loads [kips]:** | 14, 20, 20, 20, 20, 20, 20 |
| **Axle Number:** | 7 | **Axle spacings [ft]:** | 15.4, 4. 6, 4.6, 30.0, 4.6, 14.0 |

| | No | Element | Length [miles] | Damage |
|---|---|---|---|---|
| | 1 | link | 0.471 | 2.95 |
| | 2 | link | 12.091 | 2.95 |
| | 3 | link | 0.422 | 2.95 |
| | 4 | link | 3.017 | 2.95 |
| > < | 5 | bridge | 0.009 | 1.16 |
| > < | 6 | bridge | 0.013 | 1.16 |
| | 7 | link | 0.694 | 3.34 |
| > < | 8 | bridge | 0.010 | 1.16 |
| | 9 | link | 5.017 | 2.95 |
| | 10 | link | 0.294 | 2.95 |
| | 11 | link | 5.003 | 2.95 |
| | 12 | link | 0.399 | 2.95 |
| | 13 | link | 2.992 | 2.95 |
| | 14 | link | 0.329 | 2.95 |
| > < | 15 | bridge | 0.091 | 1.51 |
| | 16 | link | 4.560 | 2.95 |
| | 17 | link | 0.557 | 3.34 |
| | 18 | link | 2.122 | 3.34 |
| | 19 | link | 0.337 | 3.17 |
| | 20 | link | 0.852 | 2.95 |
| > < | 21 | bridge | 0.033 | 1.44 |
| | 22 | link | 0.330 | 2.95 |
| | 23 | link | 0.216 | 2.95 |
| > < | 24 | bridge | 0.033 | 1.44 |
| | 25 | link | 0.152 | 2.95 |
| | 26 | link | 0.349 | 2.95 |
| | 27 | link | 0.442 | 2.95 |
| | 28 | link | 0.414 | 2.95 |
| > < | 29 | bridge | 0.064 | 1.07 |

| | | | | |
|---|---|---|---|---|
| | 30 | link | 1.152 | 2.95 |
| | 31 | link | 0.091 | 2.95 |
| | 32 | link | 0.227 | 2.95 |
| | 33 | link | 0.226 | 2.95 |
| | 34 | link | 0.710 | 2.95 |
| | 35 | link | 0.109 | 2.95 |
| | 36 | link | 0.356 | 2.95 |
| > < | 37 | bridge | 0.004 | 1.16 |
| | 38 | link | 1.450 | 2.95 |
| | 39 | link | 0.667 | 2.95 |
| | 40 | link | 2.079 | 2.95 |
| | 41 | link | 1.217 | 2.95 |
| | 42 | link | 0.637 | 2.95 |
| > < | 43 | bridge | 0.052 | 1.07 |
| | 44 | link | 0.308 | 2.95 |
| | 45 | link | 0.255 | 2.95 |
| > < | 46 | bridge | 0.005 | 1.16 |
| | 47 | link | 1.865 | 2.95 |
| > < | 48 | bridge | 0.007 | 1.16 |
| | 49 | link | 0.562 | 2.95 |
| | 50 | link | 1.876 | 2.95 |
| | 51 | link | 0.845 | 2.95 |
| | 52 | link | 5.867 | 2.95 |
| > < | 53 | bridge | 0.064 | 1.07 |
| | 54 | link | 0.490 | 2.95 |
| > < | 55 | bridge | 0.009 | 1.16 |
| | 56 | link | 3.917 | 2.95 |
| | 57 | link | 0.204 | 2.95 |

| | |
|---|---|
| Average pavement damage: | 2.97 |
| Average bridge damage: | 1.25 |

**Table 7-2: Example of the bridge and pavements damage calculations for selected permit vehicles.**

| Permit ID | Trip Length | GVW [kips] | Axles | Axle spacing [ft] | Axle Load [kip] | Damage | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Bridge | Pavement | Total |
| 2600925 | 1.091 | 149.65 | 8 | 8.0,5.5,8.0,5.5,13.3,5.0,5.0 | 19.9,18.65,18.35,18.7,18.15,18.15,18.05 | 1.92 | 2.98 | 4.90 |
| 2600986 | 4.749 | 150 | 8 | 15.10,4.3,4.3,34.8,4.9,4.9,10.7 | 19.5,19.5,19.5,20,20,20,19.5 | 1.57 | 3.36 | 4.93 |
| 2600996 | 4.664 | 132 | 7 | 18.6,4.4,4.7,34.4,4.9,4.9 | 20,20,20,20,20,20 | 1.45 | 2.94 | 4.38 |
| 2601088 | 2.229 | 92 | 5 | 18.2,4.6,32.0,4.6 | 20,20,20,20 | 1.05 | 2.08 | 3.12 |
| 2601149 | 2.429 | 112 | 7 | 19.7,4.4,15.11,10.2,10.2,4.2, | 18,18,14,14,18,18 | 1.27 | 1.79 | 3.06 |
| 2601158 | 6.963 | 140 | 8 | 11.9,4.5,4.4,36.4,4.7,4.7,14.1 | 14,20,20,19,19,19,19, | 1.44 | 2.81 | 4.25 |
| 2601186 | 2.010 | 82 | 5 | 21.0,4.4,29.0,10.0 | 15,15,20,20 | 1.00 | 1.62 | 2.62 |
| 2601203 | 0.559 | 110 | 6 | 5.4,8.0,5.4,13.2,4.5 | 20,20,20,15,15, | 1.61 | 2.14 | 3.75 |
| 2601222 | 2.369 | 122 | 6 | 18.8,4.4,31.0,4.0,4.0 | 22,22,22,22,22, | 1.43 | 3.30 | 4.74 |
| 2601235 | 2.443 | 122 | 6 | 18.8,4.4,31.0,4.0,4.0 | 22,22,22,22,22, | 1.44 | 3.30 | 4.75 |
| 2601260 | 5.944 | 101 | 6 | 23.1,4.4,38.9,4.6,4.6 | 18,18,17.4,17.3,17.3, | 1.07 | 1.53 | 2.60 |
| 2601261 | 1.160 | 112.26 | 7 | 6.6,5.6,10.1,4.6,4.6,4.0 | 18.5,18.5,14.45,14.45,14.45,13.41 | 1.63 | 1.65 | 3.28 |
| 2601287 | 0.765 | 106.842 | 6 | 5.1,5.1,9.1,5.0,5.0 | 17.354,17.354,18.26,18.26,18.26, | 1.66 | 1.88 | 3.54 |
| 2601372 | 1.193 | 96 | 5 | 15.0,4.6,50.0,4.6 | 21,21,21,21 | 1.07 | 2.46 | 3.53 |
| 2601376 | 0.881 | 123 | 6 | 17.0,4.6,53.0,4.6,4.6 | 22,22,22,22,22, | 1.15 | 3.18 | 4.33 |
| 2601409 | 8.538 | 96 | 5 | 15.0,4.6,50.0,4.6 | 21,21,21,21 | 1.04 | 2.46 | 3.50 |
| 2601419 | 8.619 | 96 | 5 | 15.0,4.6,50.0,4.6 | 21,21,21,21 | 1.04 | 2.46 | 3.50 |
| 2601466 | 4.764 | 150 | 8 | 15.10,4.3,4.3,34.8,4.9,4.9,10.7 | 19.5,19.5,19.5,20,20,20,19.5, | 1.57 | 3.36 | 4.93 |
| 2601487 | 4.719 | 150 | 8 | 15.10,4.3,4.3,34.8,4.9,4.9,10.7 | 19.5,19.5,19.5,20,20,20,19.5, | 1.57 | 3.36 | 4.93 |
| 2601501 | 4.715 | 132 | 7 | 18.6,4.4,4.7,34.4,4.9,4.9 | 20,20,20,20,20,20 | 1.45 | 2.94 | 4.38 |
| 2601515 | 1.950 | 122 | 7 | 16.8,4.0,4.2,35.5,4.2,4.2 | 16.666,16.667,16.667,20,20,20 | 1.16 | 2.22 | 3.38 |
| 2601555 | 0.899 | 137.9 | 7 | 9.2,5.5,6.6,5.5,12.4,4.6 | 20,20,20,20,20,20 | 1.92 | 3.24 | 5.16 |
| 2601559 | 0.899 | 111.52 | 6 | 5.5,7.8,5.5,10.9,4.6 | 19.76,19,19,17,17, | 1.71 | 2.14 | 3.85 |
| 2601641 | 0.305 | 108 | 7 | 12.6,4.6,4.6,27.0,4.6,4.6 | 16,16,16,16,16,16 | 1.26 | 1.34 | 2.60 |
| 2601655 | 0.266 | 111 | 7 | 12.6,4.6,4.6,27.0,5.0,5.0 | 16,16,16,17,17,17 | 1.26 | 1.50 | 2.76 |
| 2601699 | 4.634 | 112 | 6 | 19.7,4.4,37.5,4.2,4.6 | 20,20,20,20,20, | 1.24 | 2.34 | 3.58 |
| 2601913 | 2.258 | 136 | 8 | 4.8,10.4,4.6,4.8,10.3,4.6,4.6 | 19.85,20,15.8,15.5,14.85,15.35,15, | 1.84 | 2.08 | 3.92 |
| 2602975 | 1.255 | 124 | 6 | 17. 0,4. 4,32. 0,4. 6,4. 6, | 22,22,22,22,22, | 1.38 | 3.36 | 4.74 |
| 2603896 | 0.445 | 150 | 7 | 9.10,5.5,6.7,6.1,19. 0,4. 3, | 22,21,22,22,21,21.5 | 1.84 | 4.36 | 6.20 |
| 2603900 | 2.612 | 115.003 | 8 | 21.3,5.0,38.7,4.8,4.8,14.3,4. 8 | 14.429,14.429,14.429,14.429,14.429,14.429,14.429 | 1.09 | 1.18 | 2.27 |
| 2603901 | 0.432 | 150 | 8 | 10.0,3.8,4.6,35.0,4. 6,4.6,6.0 | 10,22,22,22,22,21,19, | 1.46 | 3.65 | 5.11 |
| 2603948 | 3.185 | 174 | 10 | 15.2,4.3,4.3,14.5,5.0,38.0,5.0,16.0,5.0 | 15,15,15,19,19,20,20,19.5,19.5 | 1.41 | 3.17 | 4.58 |

## 7.2 BRIDGE AND PAVEMENT DAMAGE

The damage assessment analysis for bridges and pavements was conducted for a representative dataset. **Table 7-3** shows the permit data sample size for various GVW considered in the analysis. The current permit fee schedule in Alabama is based on the vehicle GVW. Therefore, calculated damage was grouped by the GVW ranging from 80 kips up to 200 kips in 10 kips increments. The limit of 200 kips was considered, thus vehicles above 200 kips are superload permits and require a refined analysis to get the permit.

The bridge damage distribution is presented for all GVW groups (see **Figure 7-1**)**.** The bridge damage varies for each GVW group and depends on the total weight of the vehicle, and the vehicle configuration. The weight distribution of the length of the vehicle impacts the bending moment calculation. Also, the geometry and support condition of the vehicles influence the calculated damage. All these parameters are considered in the developed bridge damage approach.

Pavement damage distribution based on ESAL calculations are presented in **Figure 7-2**. The pavement damage produces a larger damage ratio in comparison to the bridge damage, because of the ESAL formula, and the exponential increase of the damage with the axle weight. In pavement damage, the GVW is not a critical parameter, compared to the axle load that is distributed over single, tandem, tridem, and larger groups of axles.

Based on the abovementioned, the GVW may not be a great indicator of the damage. Therefore, calculations for the permit damage were grouped by the combination of GVW and the number of axles. Based on the Alabama permit database and the available sample size, the vehicles were divided into four groups with less than 6 axles, 6, 7, and more than 7 axles. **Figure 7-3** presents the histograms of bridge damage based on the number of axles. There are certain limitations in the number of axles and the GVW. Therefore, it is recommended to use both the number of axles and GVW in the damage assessment analysis, and the basis for the new permit fee schedule.

**Figure 7-4** shows the CDF plot of the bridge damage for different number of axles. There is a correlation between the number of axles and damage. For the lighter vehicles, the damage is the lowest for the vehicles with the largest number of axles, but as the vehicle weight increase, it can be noticed that damage for vehicles with seven or more axles is the largest. This is because heavy trucks with a weight over 150 kips most likely have a greater number of axles.

Similarly, pavement damage was considered in terms of the number of axles. **Figure 7-5** presents the histograms, and **Figure 7-6** shows the CDF plots with pavement damage. There is an analogous conclusion that for lighter trucks the damage is the lowest for the vehicles with the larger number of axles, but as the GVW increases the damage increase for trucks with a greater number of axles. The pavement damage for vehicles with 6 and 7 axles is very similar, there is no noticeable decrease in the damage for vehicles with 7 axles.

The next section introduces the total damage caused by overloaded permit trucks based on the GVW, and the combination of GVW, and the number of axles. The calculated damage will be used to establish a new permit fee structure.

**Table 7-3: Permit data sample size by GVW.**

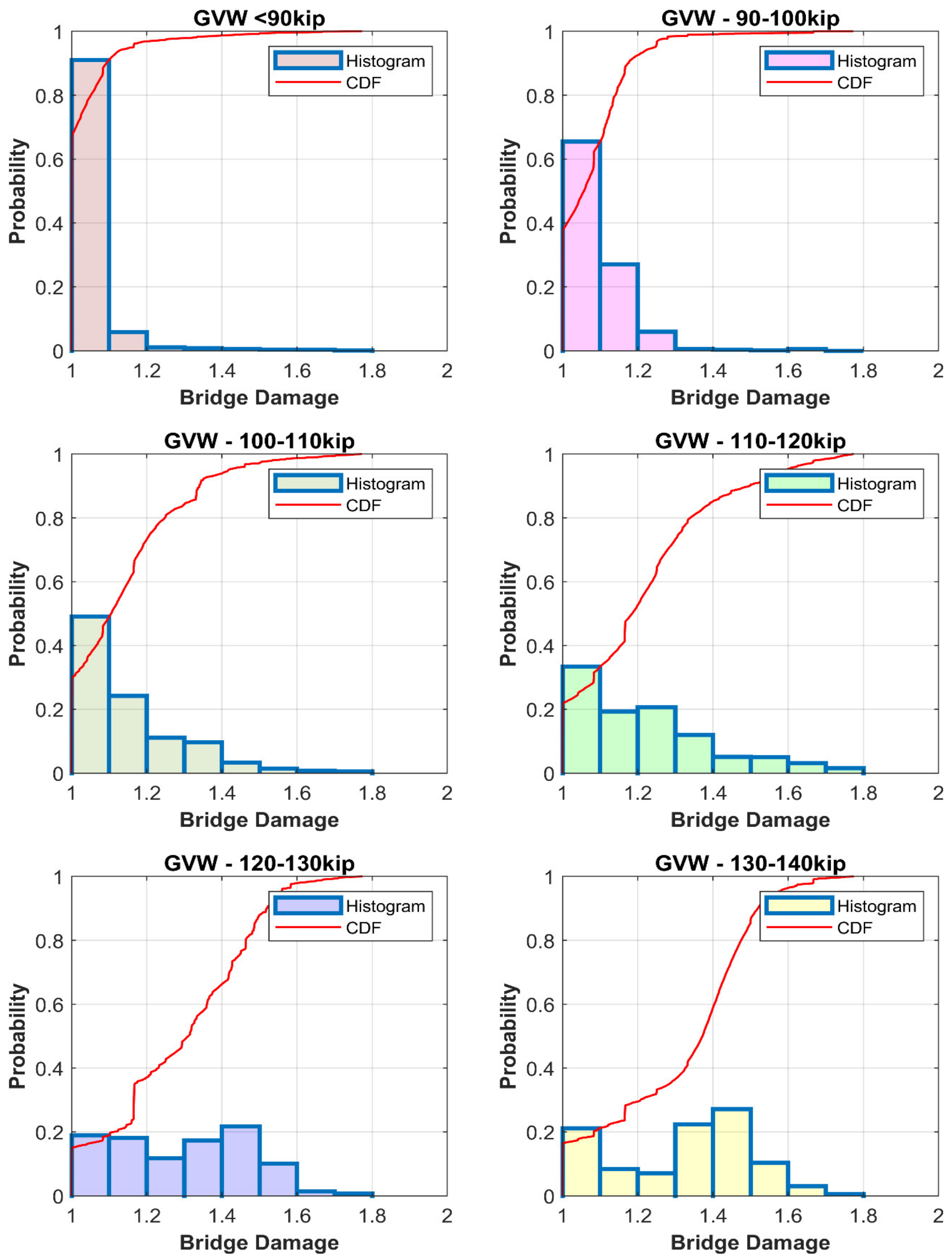
| GVW [kips] | Permit Sample Size |
|---|---|
| 80 | 532 |
| 90 | 12,327 |
| 100 | 24,911 |
| 110 | 21,639 |
| 120 | 26,021 |
| 130 | 28,249 |
| 140 | 19,984 |
| 150 | 10,698 |
| 160 | 10,195 |
| 170 | 1,690 |
| 180 | 1,703 |
| 190 | 771 |
| 200 | 1,104 |
| **Total** | **159,821** |

## 7.3 TOTAL DAMAGE

The total damage was calculated based on the developed bridge and pavement damage methodology. The total damage based on the GVW is presented on histograms in **Figure 7-7. Figure 7-8** shows the CDF plot of the total damage based on all thirteen GVW groups. There is a noticeable trend that the damage increase with the GVW, but there are some instances where it is not the case. It may be due to the specific vehicle configuration used for a certain weight, as well as the sample size. **Table 7-4** lists the calculated average damage for various GVW groups. The damage increases from 80 to 100 kips, drops for vehicles with 110 kips, then increases again for vehicles up to 150 kips. There is also a decrease in damage for vehicles with a GVW of 170 and 190 kips. The overall average damage is 1.77, meaning that an average permit truck causes almost two times more damage than a standard legal truck.

Another analysis considered the damage in terms of GVW and the number of axles. **Figure 7-9** presented histograms with the total damage for vehicles with less than 6 axles, 6, 7, and more than 7 axles. **Figure 7-10** shows the CDF plot of the total damage based on the number of axles.

**Figure 7-11** presents the total damage vs. GVW and the number of axles. It clearly shows that the damage depends on the GVW and the number of axles. The damage contribution from bridges and pavements is shown in **Figure 7-12.** The damage contribution changed with the GVW, and vary from 35-68% for pavements, and 32-65% for bridges.



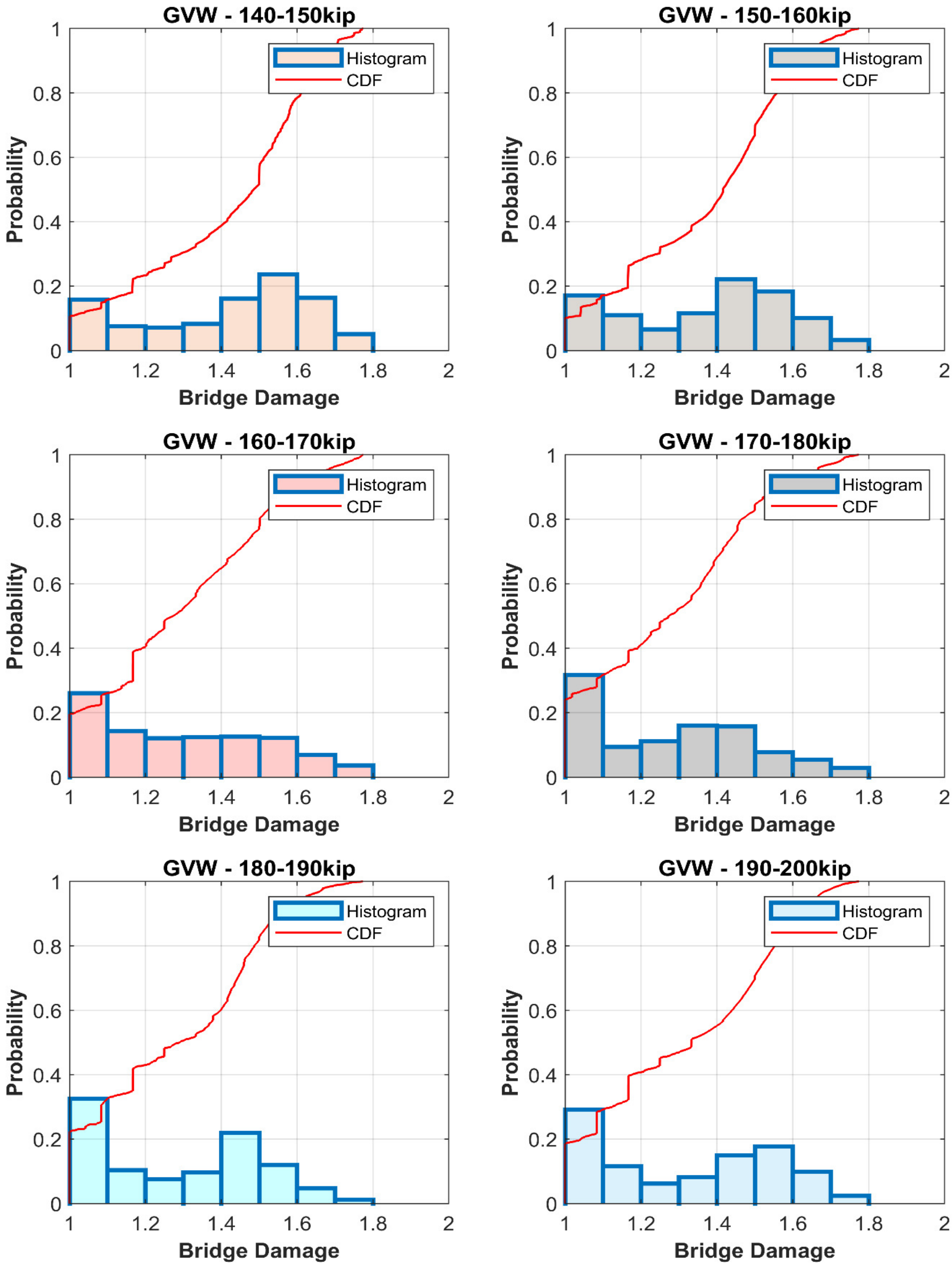
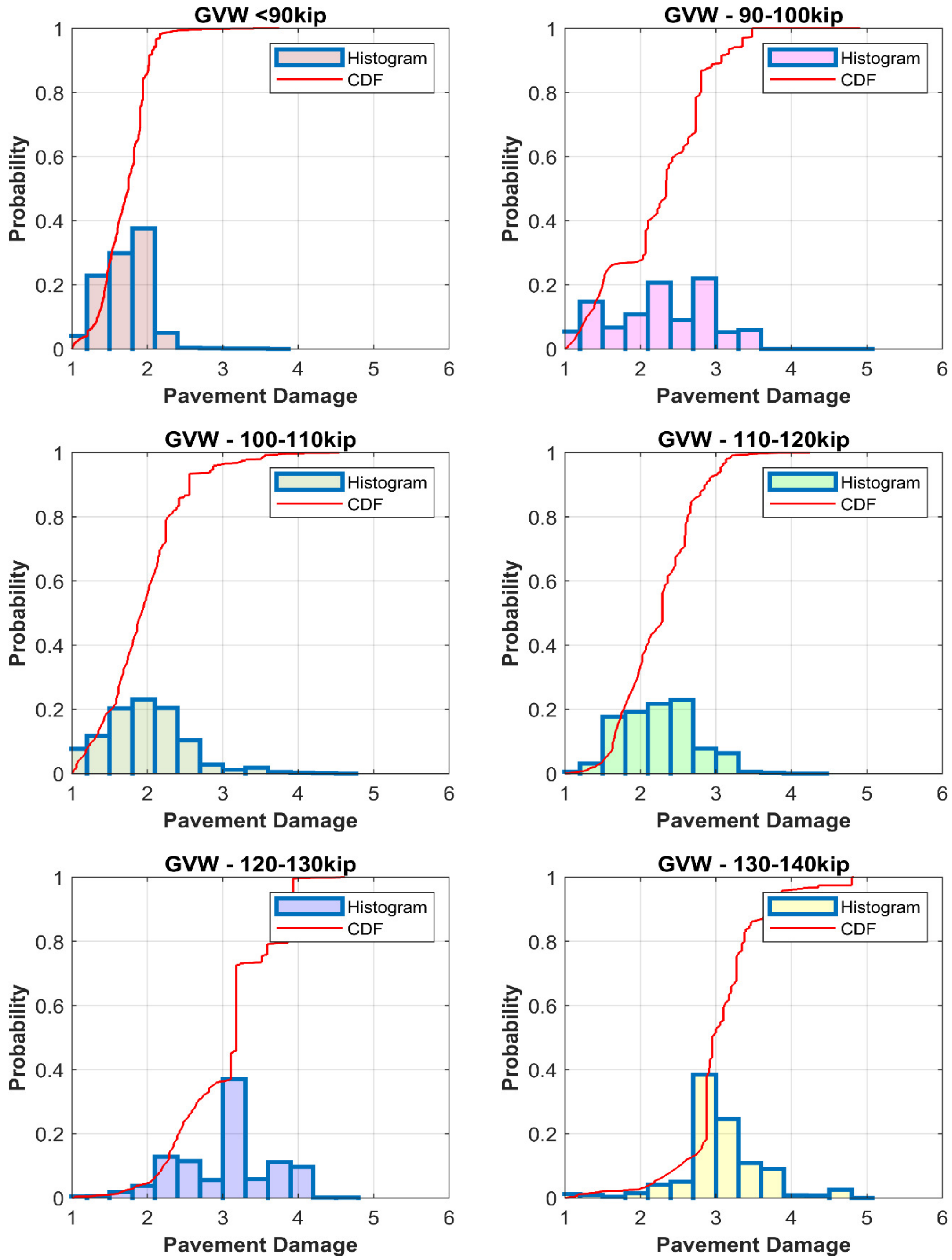



**Figure 7-1: Bridge damage based on GVW.**


GVW <90kip
GVW - 90-100kip
GVW - 100-110kip
GVW - 110-120kip
GVW - 120-130kip
GVW - 130-140kip
Histogram
CDF
Probability
Pavement Damage
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
6

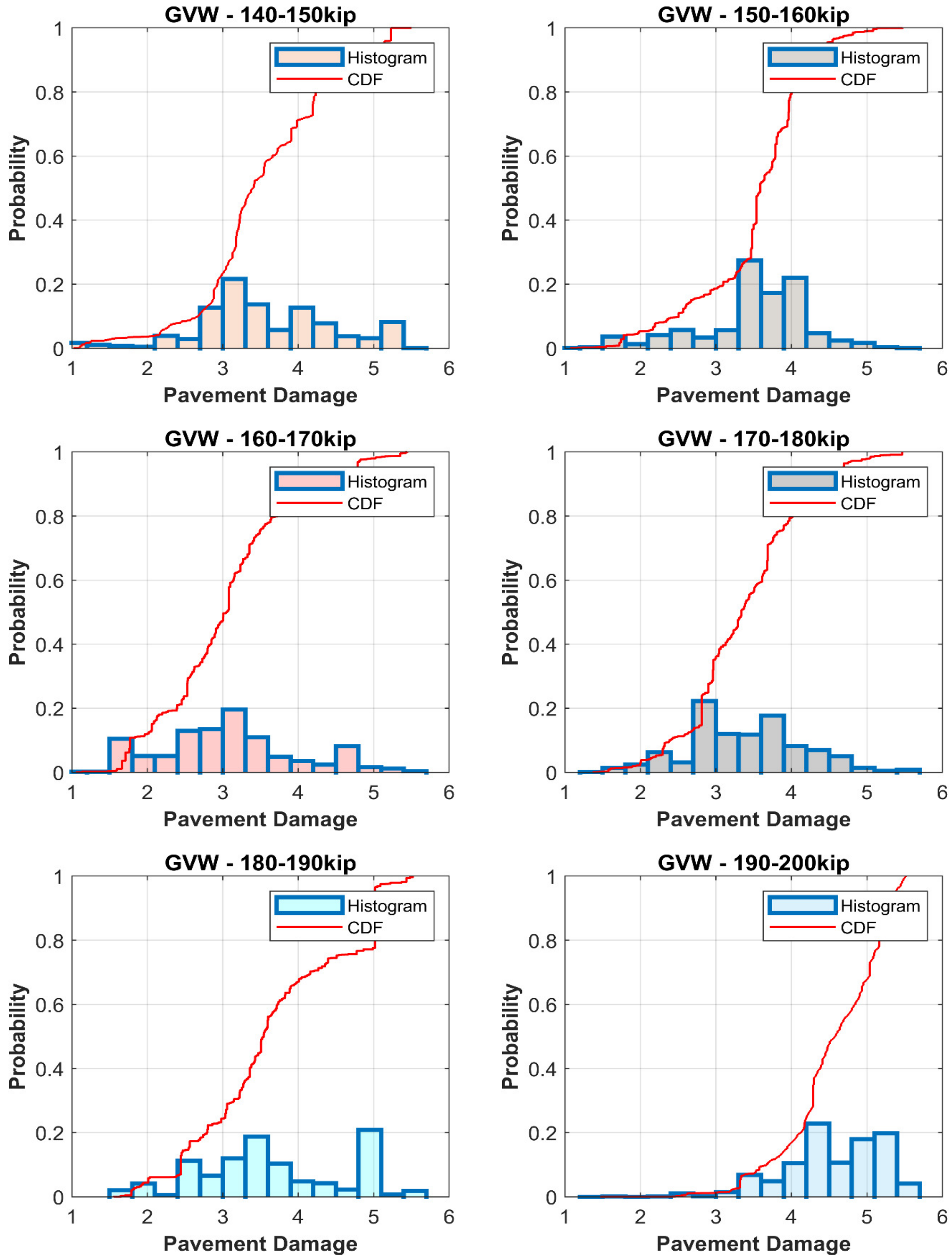



**Figure 7-2: Pavement damage based on GVW.**

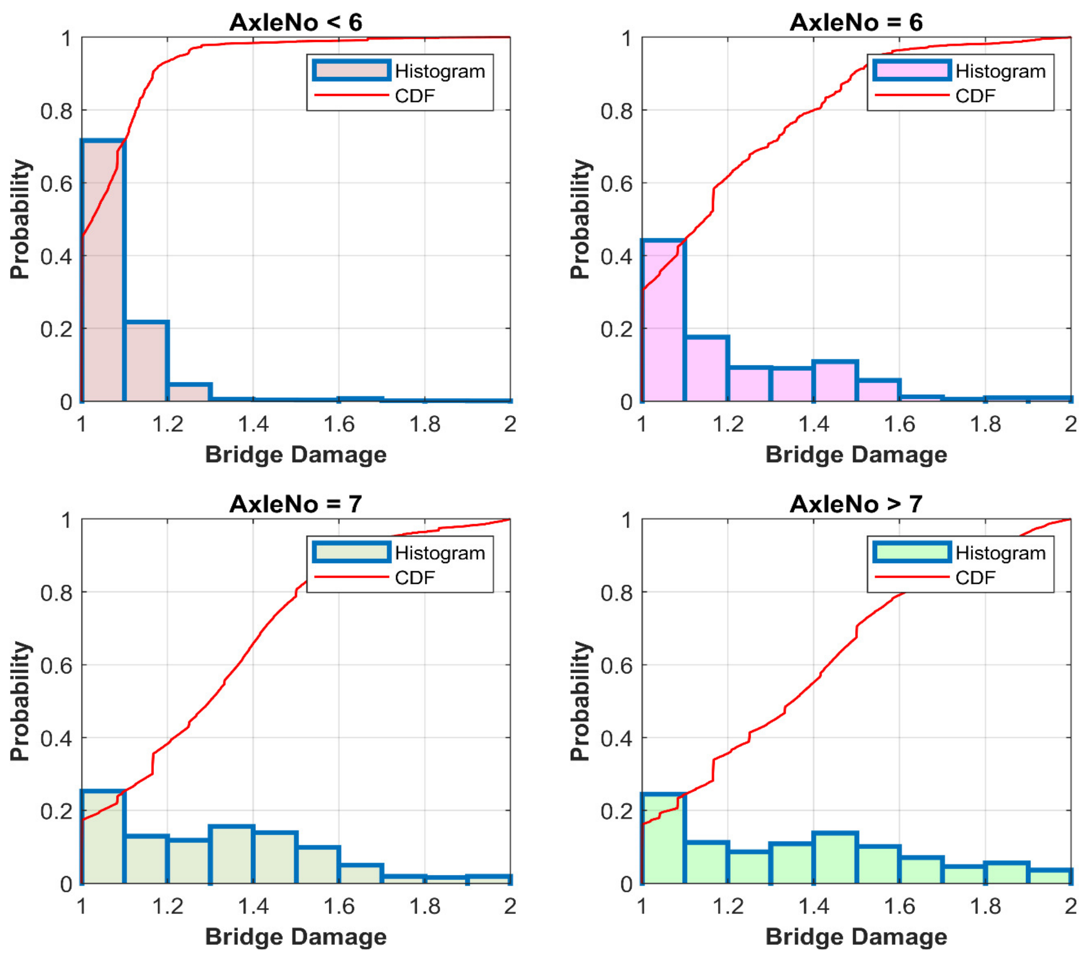



Figure 7-3: Bridge damage based on the number of axles.

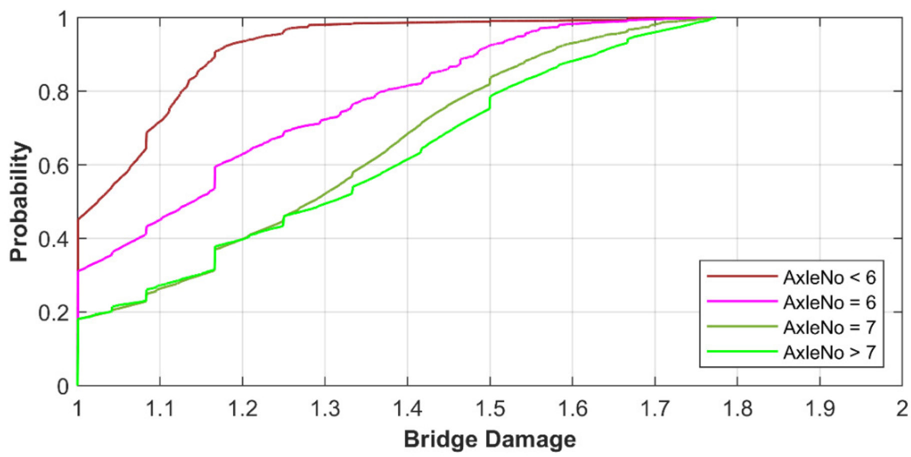



Figure 7-4: CDF plots for bridge damage based on the number of axles.

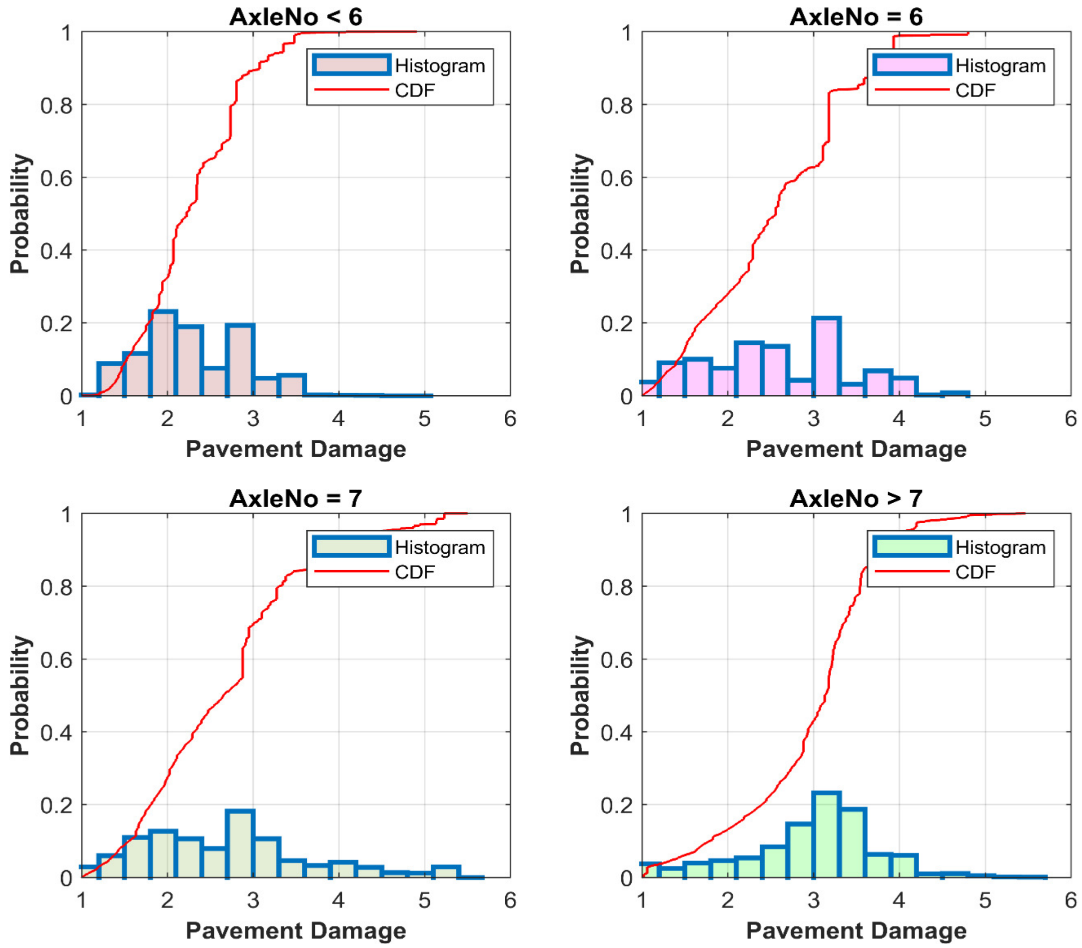
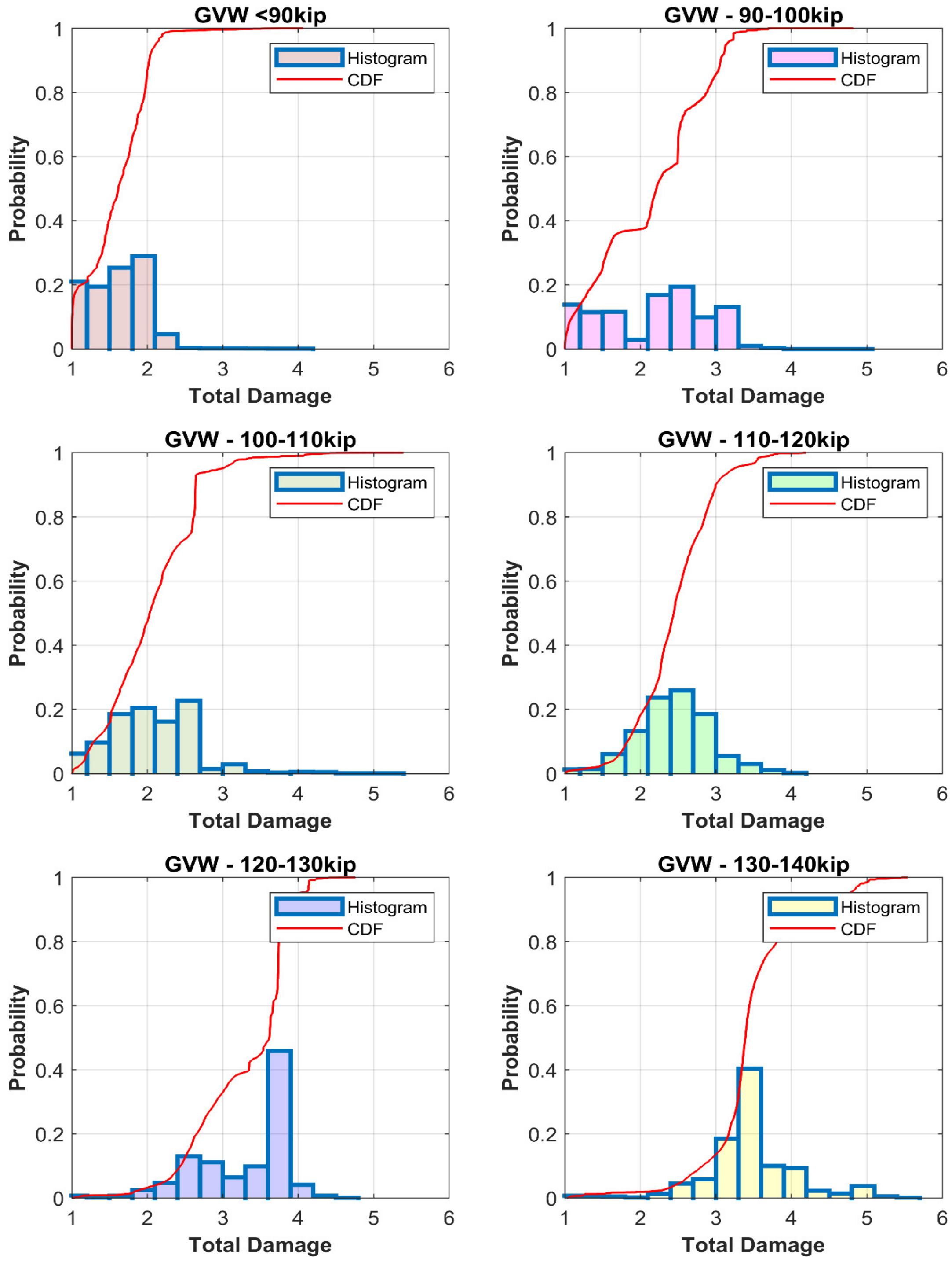



**Figure 7-5: Pavement damage based on the number of axles.**


**Figure 7-6: CDF plots for pavement damage based on the number of axles.**


GVW <90kip
GVW - 90-100kip
GVW - 100-110kip
GVW - 110-120kip
GVW - 120-130kip
GVW - 130-140kip
Histogram
CDF
Probability
Total Damage

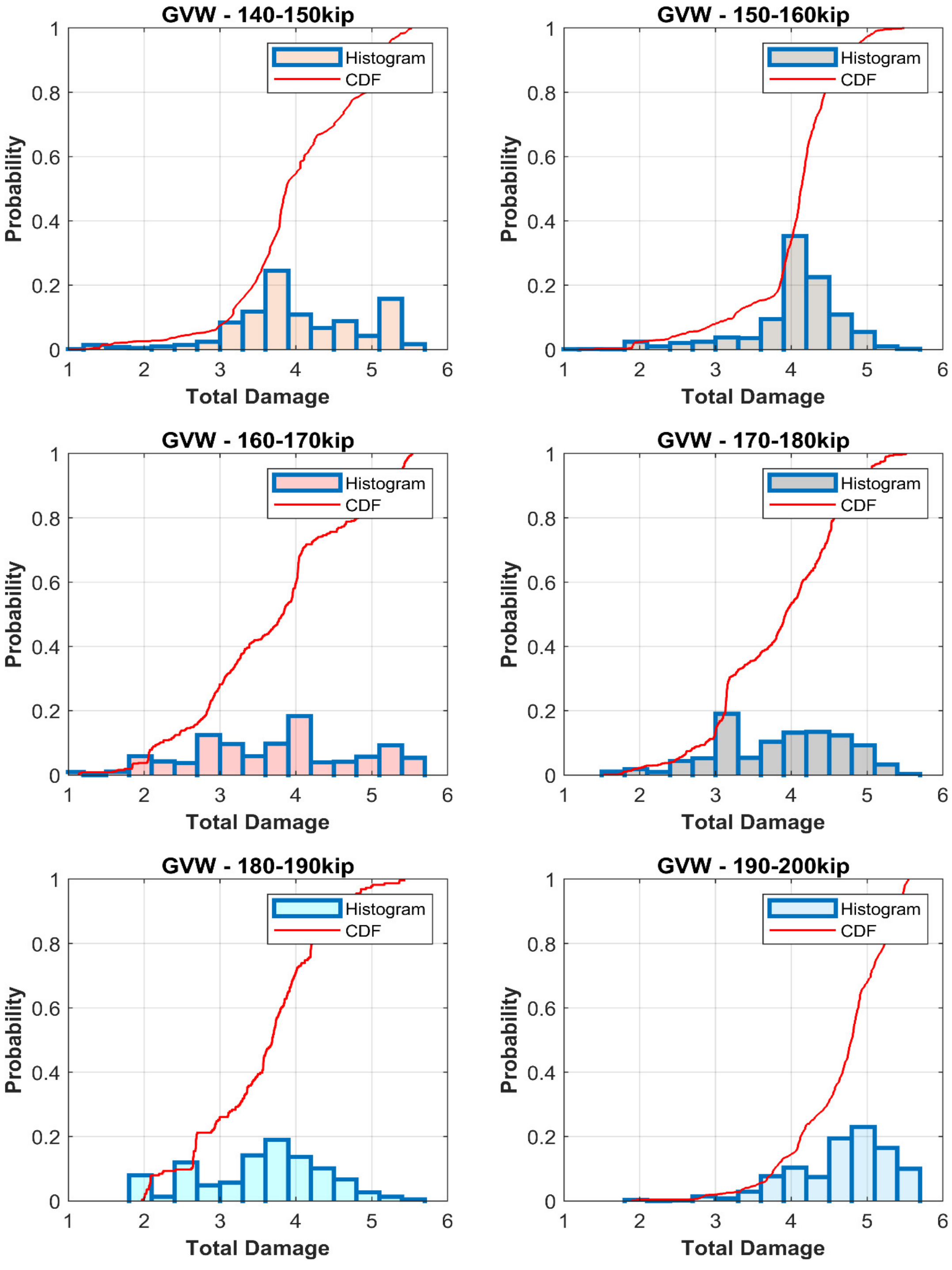



**Figure 7-7: Total damage based on GVW.**

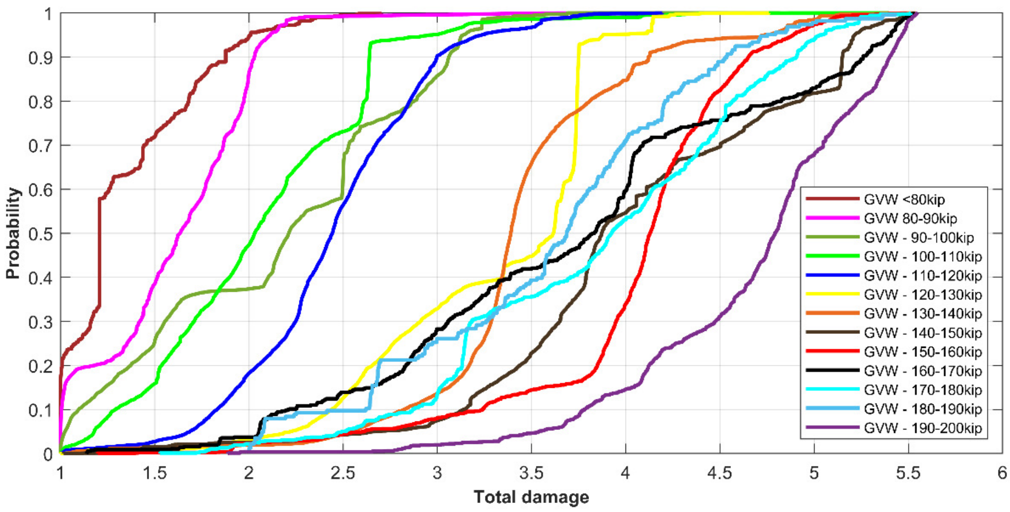



**Figure 7-8: CDF plots for total damage based on GVW.**

**Table 7-4: Total damage based on GVW.**

| GVW [kip] | Average total damage |
|---|---|
| 80 | 1.35 |
| 90 | 1.61 |
| 100 | 2.14 |
| 110 | 2.06 |
| 120 | 2.45 |
| 130 | 3.28 |
| 140 | 3.45 |
| 150 | 4.02 |
| 160 | 4.04 |
| 170 | 3.72 |
| 180 | 3.85 |
| 190 | 3.57 |
| 200 | 4.67 |
| **Average** | **2.77** |

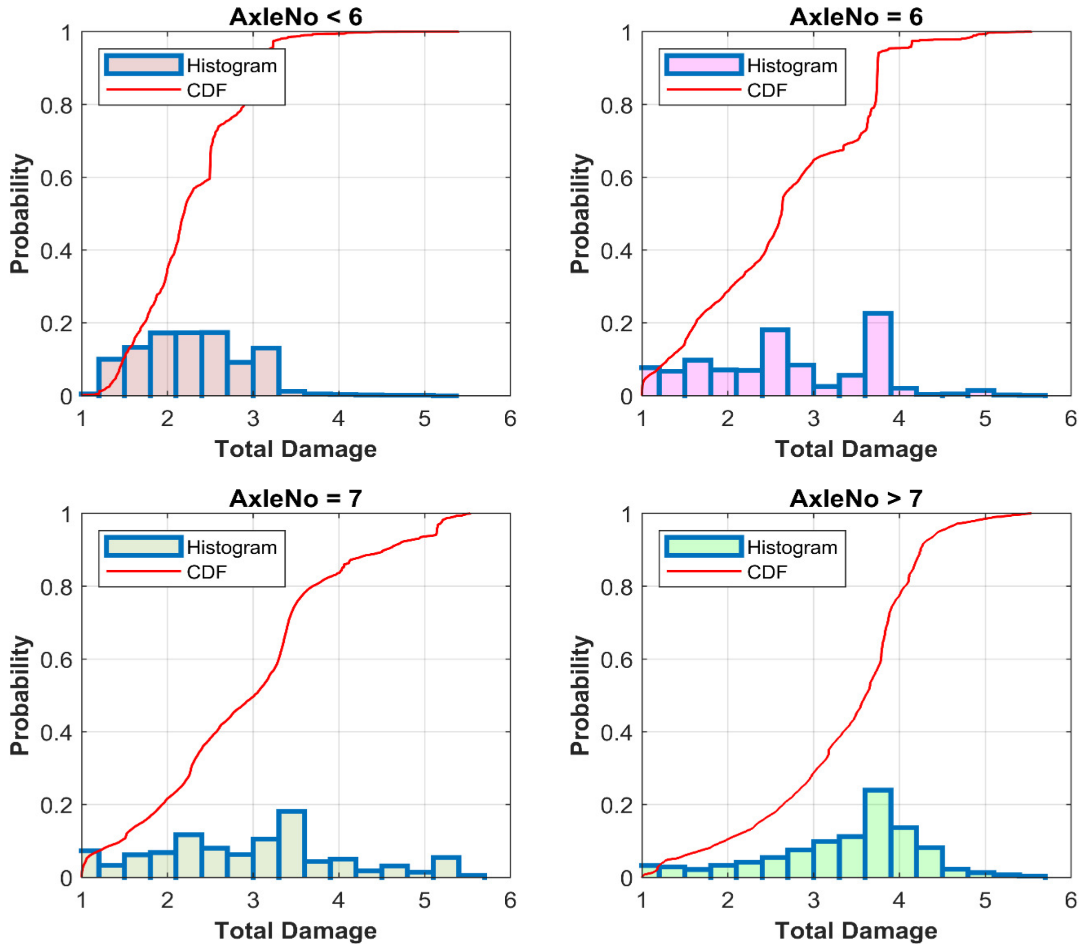



**Figure 7-9: Total damage based on number of axles.**

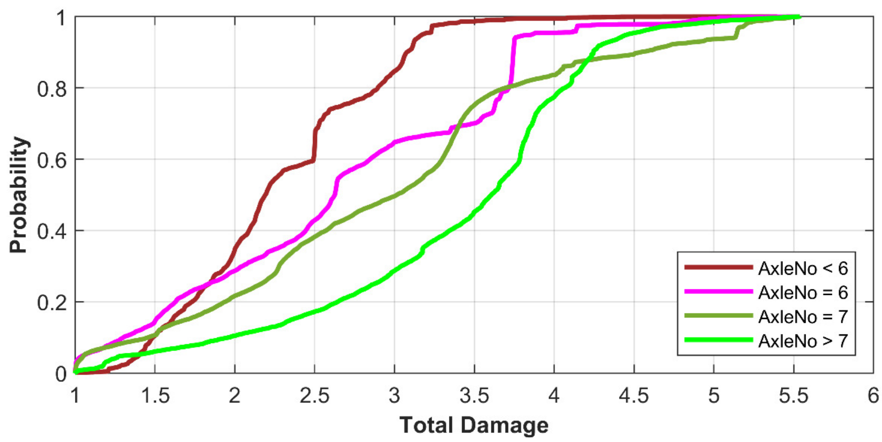



**Figure 7-10: CDF plots for total damage based on the number of axles.**

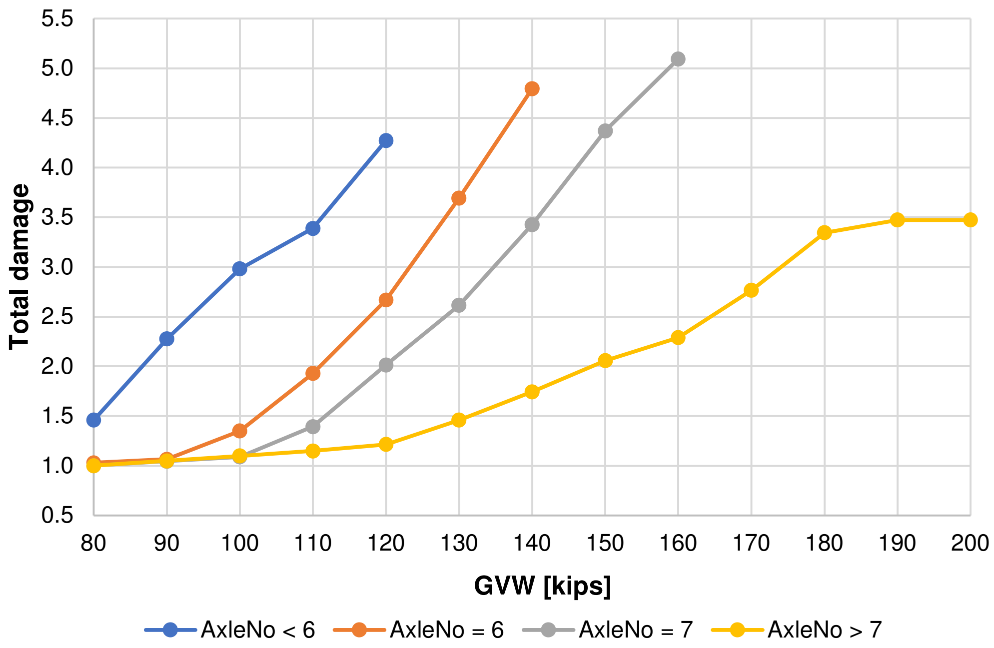



**Figure 7-11: Total damage based on GVW and the number of axles.**

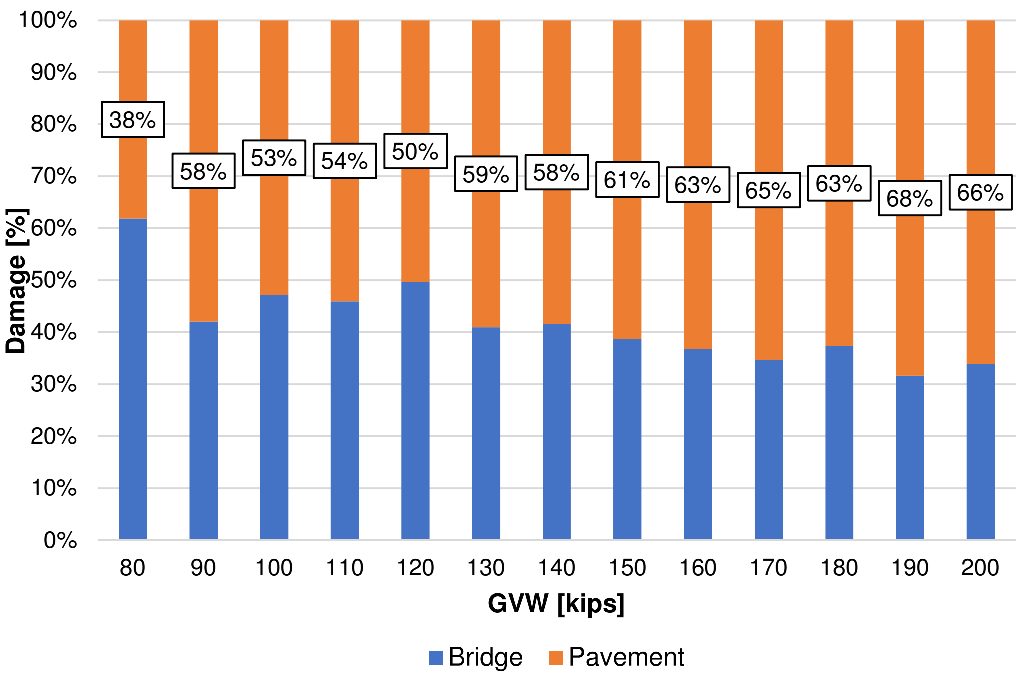



**Figure 7-12: Total damage contribution from bridges and pavements.**

### 7.4 PERMIT TRIP LENGTH

The Transport Demand Model was used to determine the infrastructure utilized by permit vehicles in Alabama. **Figure 7-13** presents the distribution of the trip length for different GVWs. Based on the CDF plot distribution, the average trip length was calculated, and presented in **Table 7-5**. It is noticed that the heavier the permit truck the shorter the trip. The average trip length for Alabama permit vehicles is 120.5 miles.

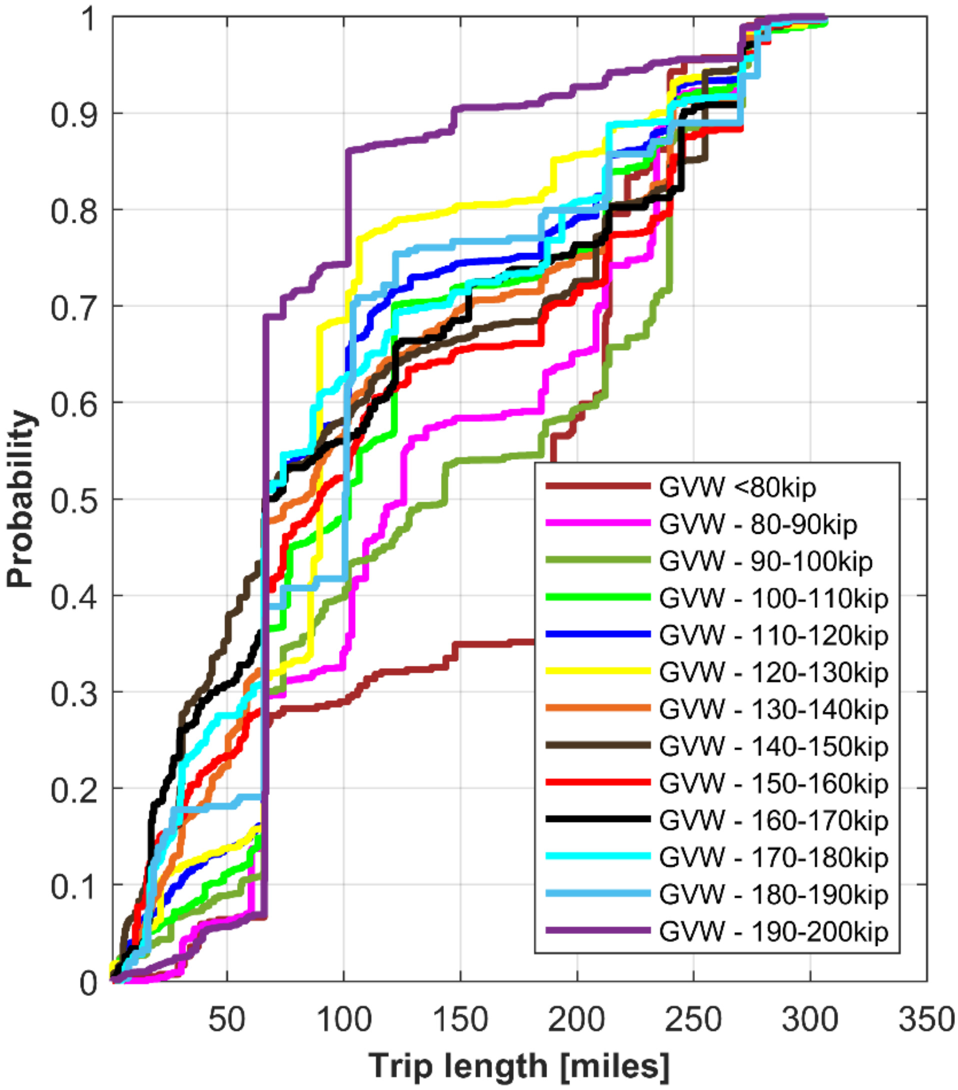



**Figure 7-13: CDF plot for permit vehicle trip length.**

**Table 7-5: The average permit vehicle trip lengths.**

| GVW up to | Trip Length |
|---|---|
| 80 | 163.37 |
| 90 | 144.16 |
| 100 | 150.34 |
| 110 | 121.87 |
| 120 | 110.32 |
| 130 | 105.46 |
| 140 | 115.23 |
| 150 | 111.76 |
| 160 | 122.58 |
| 170 | 111.28 |
| 180 | 106.51 |
| 190 | 112.46 |
| 200 | 88.56 |
| **Average** | **120.50** |

### 7.5 INTERIM CONCLUSIONS

The developed damage assessment methodology allows to determine the relative damage caused by overloaded permit trucks to pavements and bridges in Alabama. The Transport Demand Model detected heavy permit corridors, and the types of bridges and pavements utilized by the permit trucks. Permit vehicles' weight and axle configuration are used to calculate the damage. Bridge damage assessment uses influence line analysis to calculate the maximum bending moment caused by the permit trucks to all the bridges on the authorized permit routes. The pavement damage is based on the ESAL calculations for different road classes, and traffic volumes. The damage is computed to all road links utilized by the permit trucks. The bridge and pavement damages are then summed up to obtain the total damage for every permit truck and its authorized route.

Computed total damage provides a basis to establish the new permit fee schedule for Alabama. The total damage for individual permit vehicles is grouped by GVW and the combination of GVW and the number of axles. The two permit fee scenarios will be proposed for the ALDOT consideration. The permit cost scenarios are presented in the next chapter.

The following observations regarding the total damage calculations can be made:

- The damage depends on the GVW, but also the load distribution over the length of the truck. Therefore, the total damage for individual permit trucks is grouped by GVW and the combination of GVW and the number of axles.

- Permit damage is presented for 13 groups of GVW from 80 kips to 200 kips in 10 kips increments.
- The number of axles groups was determined based on the permit data sample size, and distribution of the vehicles. Four groups were selected including vehicles with less than 6 axles, 6 axles, 7 axles, and more than 7 axles.
- The maximum GVW for permit vehicles with six or more axles, six axles, and seven axles are 120, 140, and 160 kips accordingly. There are some limitations to permit truck configurations to carry the excessive load. Thus, a combination of the GVW and the number of axles provides a fair justification of the total damage caused by permit trucks to the road and bridges.
- The maximum damage for bridges was calculated as 1.80, and 5.5 for pavements.
- The maximum total unit damage is 4.5, meaning that the permit vehicles contribute over four times more to the bridge and pavement damage than standard legal vehicle.
- The average total damage caused by permit traffic is 2.77, which means that average permit trucks cause almost three times more damage than standard legal truck.
- The total damage depends on the number of axles. For lighter permit vehicles, the damage is the lowest for the vehicles with the largest number of axles, but as the vehicle weight increase, the number of axles increases to carry the excessive loads, so then the total damage for vehicles with seven or more axles is the largest.
- It is recommended to include the number of axles as the second parameter in the permit fee schedule development.
- The contribution of pavement damage varies from 38-66% of the total damage depending on the GVW. The larger the permit vehicle weight the more contribution of pavement damage in the total damage.
- The average permit trip length in Alabama was calculated as 120.5 miles. It was noticed that the heavier the permit truck the shorter the trip.

The developed damage analysis serves as the framework to quantify the damage caused by overloaded permit vehicles with variable weights and configurations. The total damage for the permit vehicle is grouped by GVW, and a combination of GVW and the number of axles is used to determine the cost for additional damage to overloaded trucks. The proposed methodology is an efficient tool to assess the damage caused by the permit vehicles operating in Alabama. It gives a rational basis to develop fair and justifiable permit fees.

# Chapter 8

# PERMIT FEE SCHEDULE

Permit regulations and monitoring procedures are developed to provide safety to the road and bridge infrastructure. The permit fee schedule is developed to control heavy traffic and maintain the good condition of bridges and roads and provide a possibility for efficient and economically justified transport. Therefore, it is necessary to provide a method to assess the monetary damage caused by overloaded vehicles on bridges and pavements.

The total damage was assessed for over 160 thousand permit trucks in Alabama. Computed total damage was grouped by GVW and a combination of GVW and the number of axles. Damage calculations serve as a basis to develop monetary damage for Alabama permits. The goal of the study is to determine a new permit fee schedule. This chapter presents a proposed new permit fee structure for Alabama.

## 8.1 PERMIT DAMAGE

Permit damage was calculated in terms of the total damage contributed by bridge and pavement damage. The damage results are presented in Chapter 7. For the development of the permit fee schedule, the total damage was adjusted to provide fair damage which increases with the GVW of the vehicle. For some GVW groups the damage was not growing with the weight, thus the calculated damage and the best fit function were used to represent the damage behavior based on GVW and GVW with the number of axles. **Table 8-1** presents the adjusted damage for all considered cases. It can be noticed that for the damage based solely on GVW, the total damage increases up to 150 kips and remains constant up to 200 kips. For the total damage based on GVW and the number of axles, some of the combinations are not available, which represent unrealistic vehicle configurations. Adjusted total damage values provide a basis to determine a permit fee schedule. **Figure 8-1** illustrates the total damage vs. GVW for all considered cases. The plot clearly shows the impact of the number of axles on total damage. These results will be reflected in the proposed permit fees.

**Table 8-1: Adjusted total damage by GVW and the number of axles.**

| GVW [kips] | All Axles | < 6 axles | 6 axles | 7 axles | > 7 axles |
|---|---|---|---|---|---|
| **80** | 1.46 | 1.46 | 1.03 | 1.00 | 1.00 |
| **90** | 1.52 | 2.28 | 1.07 | 1.05 | 1.05 |
| **100** | 1.90 | 2.98 | 1.35 | 1.09 | 1.10 |
| **110** | 2.24 | 3.39 | 1.93 | 1.39 | 1.15 |
| **120** | 2.39 | 4.27 | 2.67 | 2.01 | 1.22 |
| **130** | 3.20 | | 3.69 | 2.62 | 1.46 |
| **140** | 3.39 | | 4.80 | 3.42 | 1.75 |
| **150** | 3.79 | | | 4.37 | 2.06 |
| **160** | 3.96 | | | 5.09 | 2.29 |
| **170** | 3.96 | | | | 2.77 |
| **180** | 3.96 | | | | 3.35 |
| **190** | 3.96 | | | | 3.47 |
| **200** | 3.96 | | | | 3.47 |

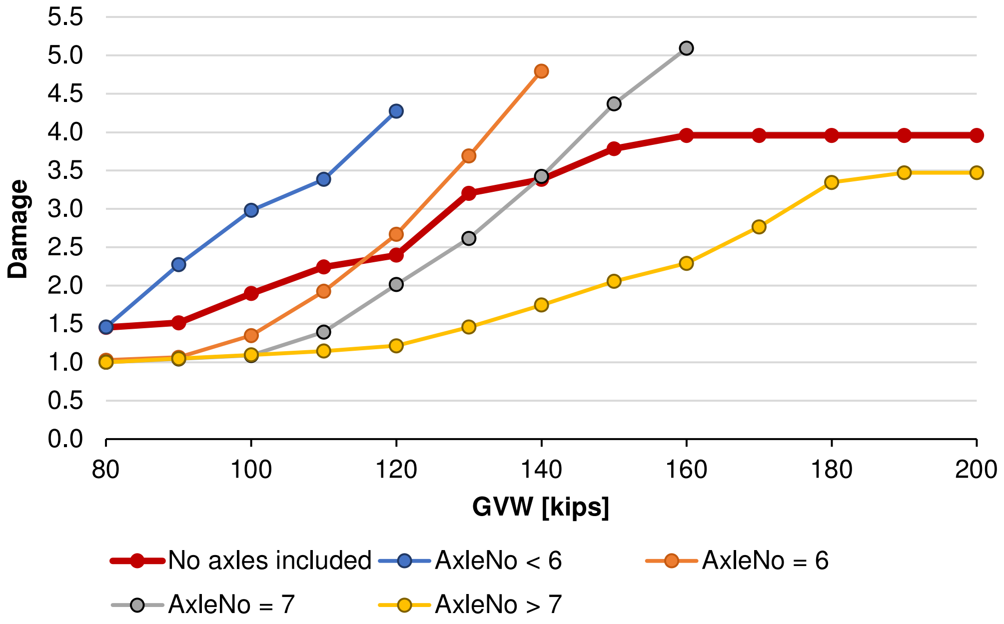



**Figure 8-1: Adjusted total damage for all considered cases.**

## 8.2 PERMIT FEE SCENARIOS

The service life of roads and bridges depends on many factors such as climate, traffic loads, natural hazards, defects in material production, extreme events, etc. The damage assessment of permit vehicles only considers the impact of excessive loading, including the permit load effects above the federal weight and size limits. So, the monetary consumption by a permit vehicle is calculated only for the overloaded part of the vehicle's weight since roads and bridges are not designed for regular excessive permit loading. The climate impact and natural hazards are not considered in the permit damage assessment since unpredictable events contribute to the infrastructure damage, independently of the traffic. Similarly, material, production, and analysis assumptions are not considered because the uncertainty of random variables is included in design safety factors.

The infrastructure asset value, and the state-specific funding for bridge and pavement replacement, repair, or maintenance fluctuate on a yearly basis. Therefore, it is difficult to determine the permit fee schedule based on the annual funds. The available money, most likely, will not be equivalent to the infrastructure's needs to improve the condition. Thus, it proposed to use a developed total permit damage ratio with an adjustable base fee. The base fee can be decided by the legislators and DOT representatives depending on state expectations. In this study, the base permit fee will be proposed based on a thorough review of the permit fees in the U.S. and the analysis of the permit fee revenue. The proposed approach allows for flexibility, and eventual changes based on the economic situation, inflation, etc. The analysis of permit fees is shown in section 8.2.3.

### 8.2.1 Single Trip Permit

Alabama issues single trip permits based on the GVW of the truck. The permit is valid from one point of origin to one destination, and the hauler is allowed to complete only one trip with the permit. Single trip permits are analyzed for GVW weight, and the route provided by an applicant.

To determine a single trip permit fee in Alabama based on the developed total damage, there are two required input data, which are a base fee and an administration fee.

The base fee is used as a reference point; in other words, it is a fee equivalent to a damage ratio of one. The base fee utilizes the total damage multiplier to determine an actual permit fee. Additionally, there may be an administrative fee which is constant for every permit to cover the cost of the administrative processing of permits, personnel, and system maintenance.

### 8.2.2 Multi-Trip Permit

Alabama issued multi-trip permits based on the GVW of the truck for 12 months and an unlimited number of trips. The multi-trip fee calculations require setting an average number of trips. The number of trips is not available in the permit database. Therefore, it was established based on the available literature and DOT input. The annual multi-trip permit assumes on average 25 trips.

A new permit fee schedule for Alabama proposes to expand the types of multi-trip permits to 1 month, 3 months, 6 months as well as annual - 12 months permits. It provides more flexibility for the permittees to adjust the permit for their needs, in case of the seasonal need to carry excessive loads. **Table 8-2** presents the assumed number of trips for the considered multi-trip permits.

**Table 8-2: Proposed number of trips for multi-trip permits.**

| Multi Trip Permit period | No of trips |
|---|---|
| **1 month** | 4 |
| **3 months** | 9 |
| **6 months** | 15 |
| **12 months** | 25 |

In general, the multi-trip permits include a discount in comparison to the single trip permits. The discount depends on the DOT preferences and can be adjusted. It is proposed to consider 35%, 40%, 45%, and 50% for the 1 month, 3 months, 6 months as well as 12 months permits, accordingly.

### 8.2.3 Permit Fee

The permit fee schedule in the U.S. varies significantly from state to state. The permit fees and permit criteria are very different and can be based on axle weight, gross vehicle weight, distance, weight and distance, and flat fee. State agencies seek to establish a rational and fair permit fee structure based on damage assessment analysis. The permit fee schedule is developed to control heavy traffic and maintain the good condition of bridges and roads. Therefore, it is necessary to provide a method to assess the monetary consumption of overloaded vehicles on infrastructure.

There are typically single and annual multi-trip permits. In this project, the proposed permit fee structure consists of single and multi-trip permits for four different periods including 1, 3, 6, and 12 months. The permit fee is developed based on the total damage presented for permit vehicle GVW and a combination of GVW and a number of axles. Two permit fee types are presented 1) flat fee – fixed dollar amount for a permit, and 2) $/mile fee – depending on the permit route length. For the single trip permit, two permit options are available to ALDOT considering a flat fee independent of the trip length and based on the miles traveled. Similarly, for the multi-trip permit, there is a flat fee for different periods, as well as a proposal for the $/mile fee for a specific restricted route. The results of the analysis for a flat fee and $/mile fee scenarios are shown in the next sections.

To determine the $/mile fee the average trip length is required for the selected permit GVW groups. Transport Demand Model allowed to determine permit routes and their lengths. Thus, an average permit trip length was calculated for all GVW groups. The trip length was adjusted to provide fair damage which increased with the GVW of the vehicle. The permit trip length for vehicles above 130 kips is constant. Calculated average permit trip length for these groups varied significantly, therefore it was decided to consider the average for GVW groups from 130-180 kips.

**Table 8-3** presents the adjusted permit length by the GVW categories, used to calculate the dollar per mile fee. To determine the base fee for a new permit fee structure, Alabama permit revenue for the years 2019-2021 was analyzed. From ALPASS permit data all overweight, and both oversize and overweight permits were grouped by GVW. **Table 8-4** shows the total number of issued permits in 2019-2021 by GVW and permit fee. The total number of overweight permits issued in Alabama is presented in **Table 8-5** for the years 2019 – 2021. The permit data for the year 2021 was only available for 6 months, therefore, to account for the annual data, the values were simply multiplied by two to determine the total number of issued permits. **Table 8-6** shows the permit revenue for the years 2019 – 2021.

**Table 8-3: Adjusted permit trip length by GVW.**

| GVW [kip] | Trip Length [miles] |
|---|---|
| **80** | 163.4 |
| **90** | 152.0 |
| **100** | 146.0 |
| **110** | 121.9 |
| **120** | 110.3 |
| **130** | 109.2 |
| **140** | 109.2 |
| **150** | 109.2 |
| **160** | 109.2 |
| **170** | 109.2 |
| **180** | 109.2 |
| **190** | 109.2 |
| **200** | 109.2 |

**Table 8-4: Number of permits issued by GVW and permit fee.**

| GVW up to | $10 | $20 | $30 | $40 | $60 | $70 | $100 | $110 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **80** | 12,381 | 15,547 | 2 | 6 | - | 1 | - | 1 | 27,939 |
| **90** | 56,598 | 570,215 | 3 | 17 | 1 | 1 | 83,735 | 7 | 710,578 |
| **100** | 8,131 | 11,698 | 5,070 | 19,070 | 1 | 4 | 1 | - | 43,975 |
| **110** | - | 27 | 5,695 | 32,200 | 1 | 7 | - | - | 37,930 |
| **120** | 4 | 15 | 2,697 | 17,880 | 557 | 6,429 | - | 3 | 27,585 |
| **130** | - | 5 | 1 | 18 | 2,484 | 35,163 | 1 | 8 | 37,680 |
| **140** | - | 1 | - | 4 | 957 | 20,010 | - | 16 | 20,988 |
| **150** | - | 3 | - | - | 271 | 6,831 | 382 | 11,094 | 18,581 |
| **160** | - | 2 | - | 1 | - | 4 | 152 | 7,440 | 7,599 |
| **170** | - | - | - | - | - | | 225 | 4,820 | 5,045 |
| **180** | - | - | - | - | - | 1 | 104 | 3,092 | 3,197 |
| **190** | - | 1 | - | - | - | 1 | 8 | 4,380 | 4,390 |
| **200** | - | 2 | - | - | - | 1 | 14 | 17,474 | 17,491 |
| **Total** | **77,114** | **597,516** | **13,468** | **69,196** | **4,272** | **68,453** | **84,622** | **48,335** | **962,978** |

**Table 8-5: Number of issued permits by GVW in Alabama for years 2019-2021.**

| GVW [kip] | 2019 | 2020 | 2021 |
|---|---|---|---|
| **80** | 3,649 | 3,344 | 3788 |
| **90** | 97,306 | 93,039 | 100048 |
| **100** | 6,862 | 7,212 | 7002 |
| **110** | 7,482 | 6,570 | 6842 |
| **120** | 7,288 | 7,136 | 7324 |
| **130** | 8,950 | 7,834 | 8736 |
| **140** | 5,378 | 4,845 | 5136 |
| **150** | 4,569 | 2,985 | 3408 |
| **160** | 1,043 | 1,126 | 1232 |
| **170** | 575 | 539 | 634 |
| **180** | 453 | 518 | 484 |
| **190** | 641 | 684 | 624 |
| **200** | 2,747 | 1,732 | 2164 |
| **Total** | **148,962** | **139,584** | **151,464** |

**Table 8-6: Permit revenue for permits in 2019-2021.**

| GVW [kips] | 2019 | 2020 | 2021 |
|---|---|---|---|
| **80** | $55,320 | $50,020 | $56,000 |
| **90** | $2,554,960 | $2,477,370 | $2,606,880 |
| **100** | $167,950 | $173,160 | $167,140 |
| **110** | $208,110 | $163,120 | $184,300 |
| **120** | $174,030 | $164,290 | $182,760 |
| **130** | $322,500 | $251,250 | $310,880 |
| **140** | $223,130 | $178,970 | $194,900 |
| **150** | $224,390 | $198,670 | $236,600 |
| **160** | $113,340 | $122,340 | $134,120 |
| **170** | $62,690 | $58,350 | $67,620 |
| **180** | $48,320 | $53,200 | $51,400 |
| **190** | $68,930 | $72,780 | $67,320 |
| **200** | $298,610 | $186,140 | $232,540 |
| **Total** | **$4,522,280** | **$4,149,660** | **$4,492,460** |

Based on the current permit revenue, the base fee needs to be evaluated to forecast a potential annual revenue from a proposed new permit fee. Based on the analysis, a proposed base fee is **$35** to achieve a comparable income (see **Figure 8-2**).

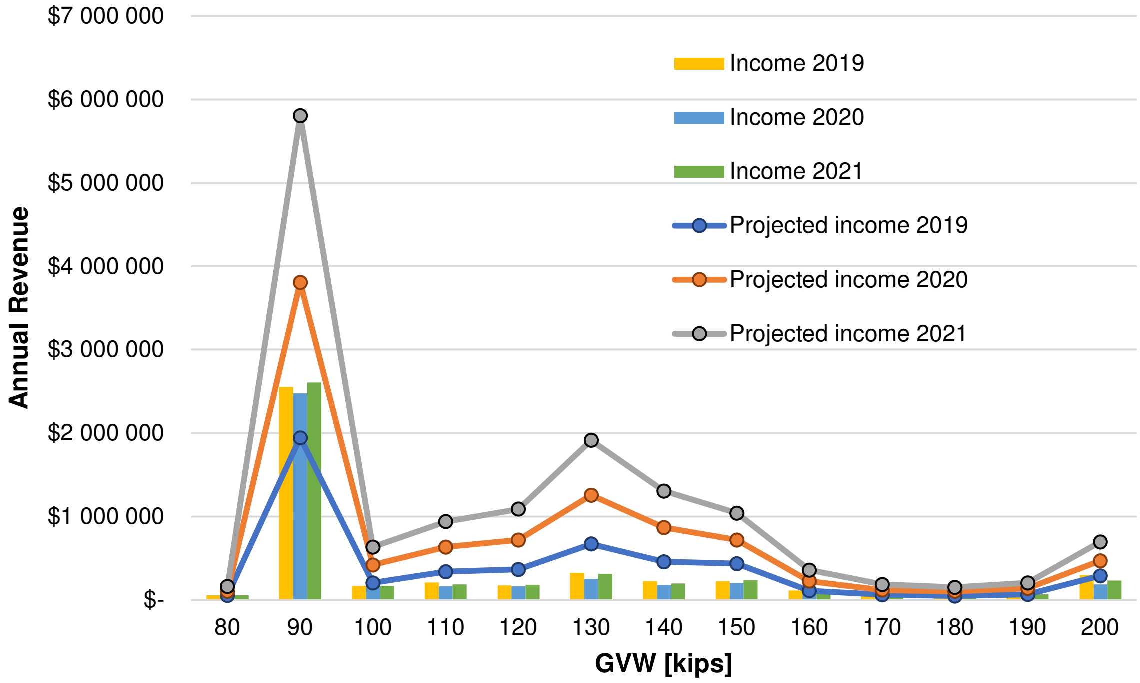
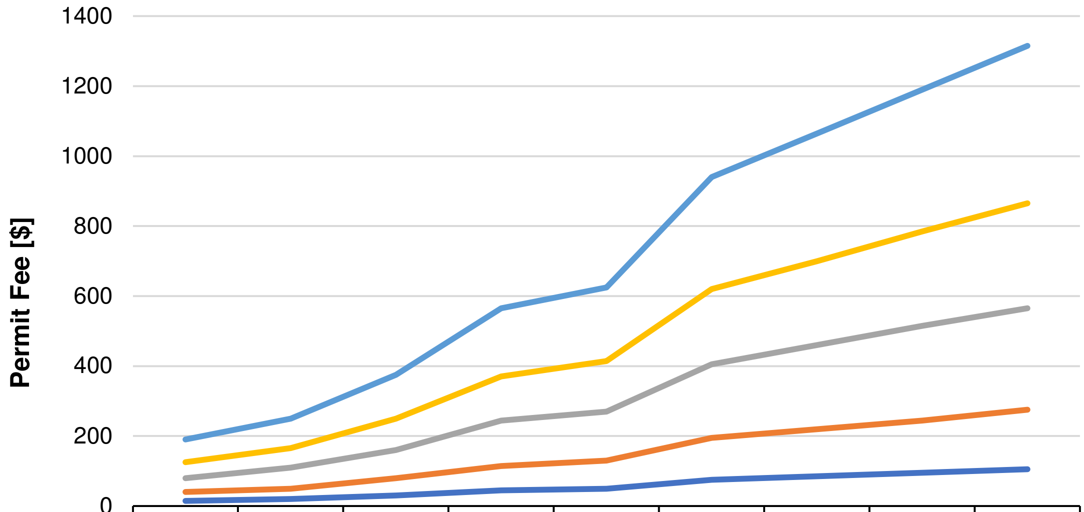



**Figure 8-2: Projected and collected annual permit income.**

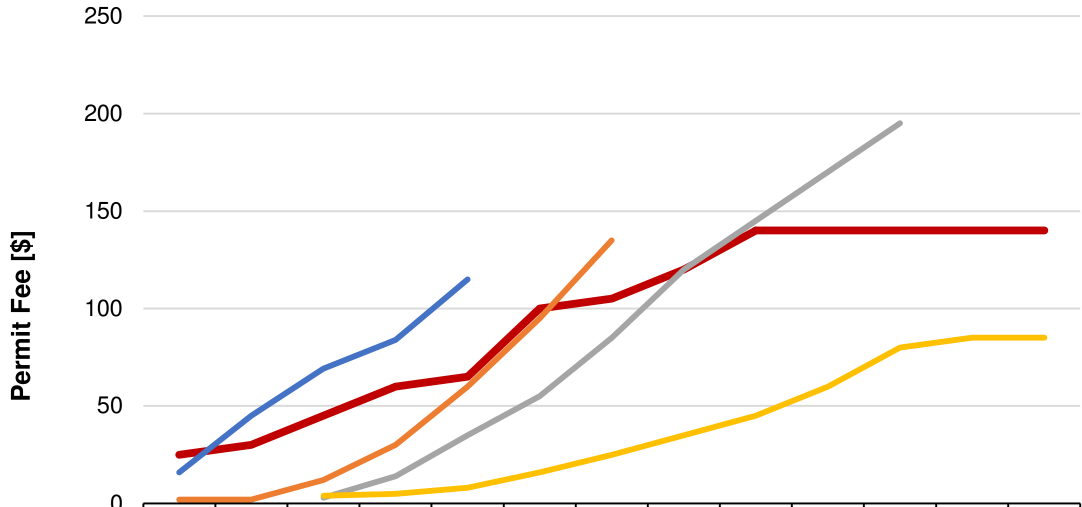
#### 8.2.3.1 Flat Fee

Based on the developed total damage for a GVW and the combination of GVW and the number of axles (see **Table 8-1**) a new permit fee schedule was developed. The base fee was taken as $35. The summary plots with the proposed flat fees are presented in **Figure 8-3** to **Figure 8-8.**



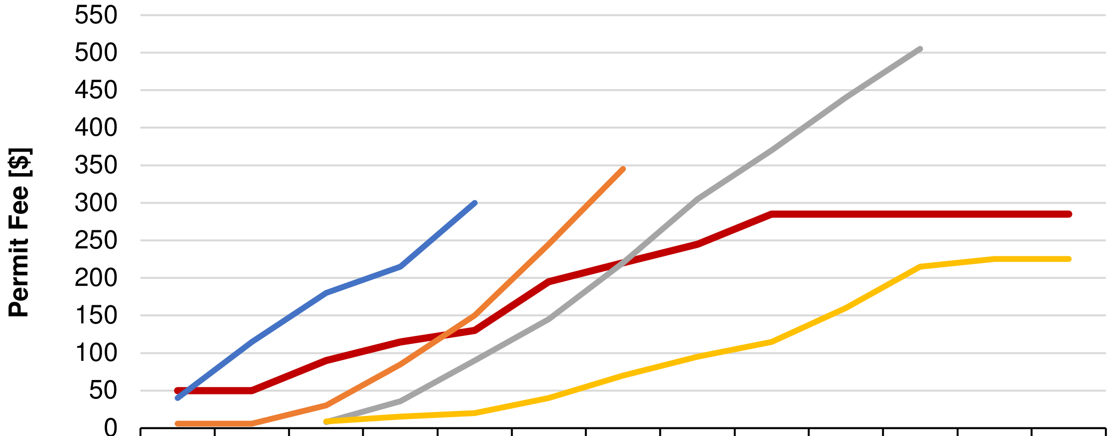

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 |
|---|---|---|---|---|---|---|---|---|---|
| Single Trip | 15 | 20 | 30 | 45 | 50 | 75 | 85 | 95 | 105 |
| 1 month | 40 | 50 | 80 | 115 | 130 | 195 | 220 | 245 | 275 |
| 3 months | 80 | 110 | 160 | 245 | 270 | 405 | 460 | 515 | 565 |
| 6 months | 125 | 165 | 250 | 370 | 415 | 620 | 700 | 785 | 865 |
| 12 months | 190 | 250 | 375 | 565 | 625 | 940 | 1065 | 1190 | 1315 |

**Figure 8-3: Permit Flat Fee based on GVW.**



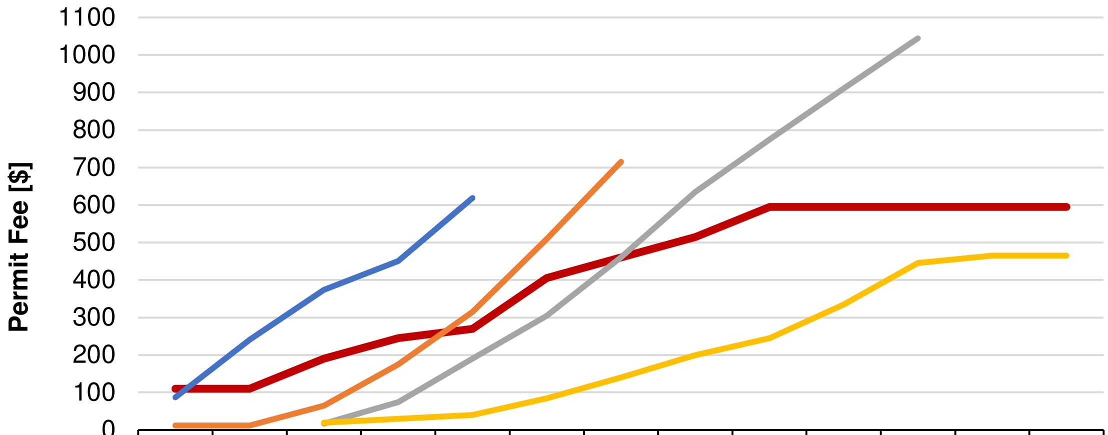

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 25 | 30 | 45 | 60 | 65 | 100 | 105 | 120 | 140 | 140 | 140 | 140 | 140 |
| <6 axles | 16 | 45 | 69 | 84 | 115 | | | | | | | | |
| 6 axles | 2 | 2 | 12 | 30 | 60 | 95 | 135 | | | | | | |
| 7 axles | | | 3 | 14 | 35 | 55 | 85 | 120 | 145 | 170 | 195 | | |
| >7 axles | | | 4 | 5 | 8 | 16 | 25 | 35 | 45 | 60 | 80 | 85 | 85 |

**Figure 8-4: Single trip permit flat fee based on GVW, and GVW and the number of axles.**



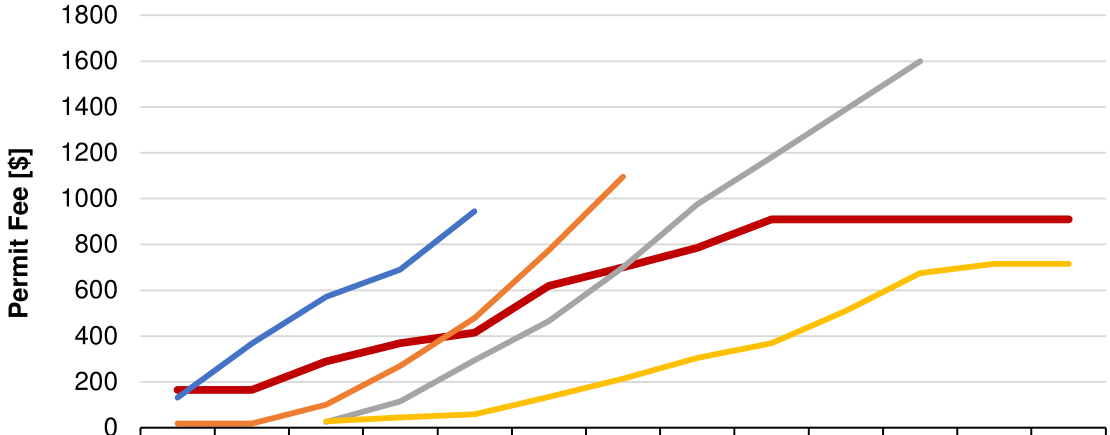

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 50 | 50 | 90 | 115 | 130 | 195 | 220 | 245 | 285 | 285 | 285 | 285 | 285 |
| <6 axles | 40 | 115 | 180 | 215 | 300 | | | | | | | | |
| 6 axles | 6 | 6 | 30 | 85 | 150 | 245 | 345 | | | | | | |
| 7 axles | | | 8 | 36 | 90 | 145 | 220 | 305 | 370 | 440 | 505 | | |
| >7 axles | | | 9 | 15 | 20 | 40 | 70 | 95 | 115 | 160 | 215 | 225 | 225 |

**Figure 8-5: Multi trip (1 month) permit flat fee based on GVW, and GVW and the number of axles.**



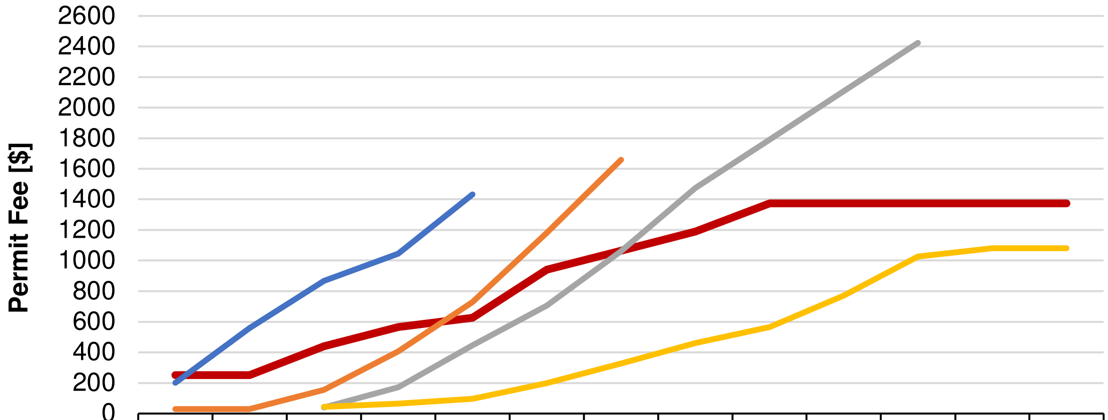

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 110 | 110 | 190 | 245 | 270 | 405 | 460 | 515 | 595 | 595 | 595 | 595 | 595 |
| <6 axles | 87 | 241 | 374 | 451 | 619 | | | | | | | | |
| 6 axles | 12 | 12 | 65 | 175 | 315 | 510 | 715 | | | | | | |
| 7 axles | | | 17 | 75 | 190 | 305 | 460 | 635 | 775 | 910 | 1045 | | |
| >7 axles | | | 20 | 30 | 40 | 85 | 140 | 200 | 245 | 335 | 445 | 465 | 465 |

**Figure 8-6: Multi trip (3 months) permit flat fee based on GVW, and GVW and the number of axles.**




| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 165 | 165 | 290 | 370 | 415 | 620 | 700 | 785 | 910 | 910 | 910 | 910 | 910 |
| <6 axles | 132 | 369 | 572 | 690 | 945 | | | | | | | | |
| 6 axles | 19 | 19 | 100 | 270 | 480 | 775 | 1095 | | | | | | |
| 7 axles | | | 26 | 115 | 295 | 465 | 700 | 975 | 1180 | 1390 | 1600 | | |
| >7 axles | | | 29 | 45 | 60 | 135 | 215 | 305 | 370 | 510 | 675 | 715 | 715 |

**Figure 8-7: Multi trip (6 months) permit flat fee based on GVW, and GVW and the number of axles.**

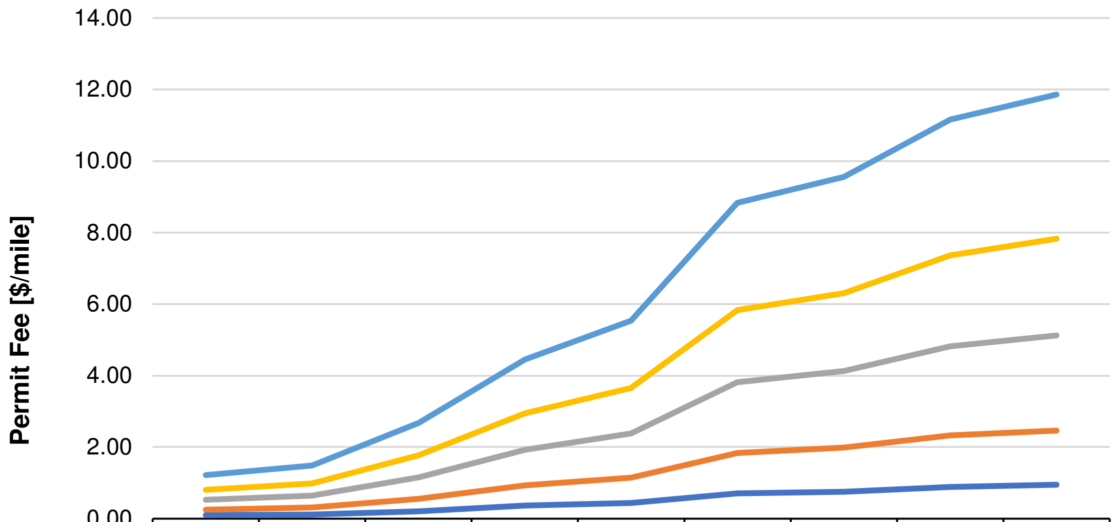



| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 250 | 250 | 440 | 565 | 625 | 940 | 1065 | 1190 | 1375 | 1375 | 1375 | 1375 | 1375 |
| <6 axles | 201 | 558 | 866 | 1045 | 1432 | | | | | | | | |
| 6 axles | 29 | 29 | 155 | 405 | 730 | 1180 | 1660 | | | | | | |
| 7 axles | | | 39 | 170 | 445 | 705 | 1060 | 1475 | 1790 | 2110 | 2425 | | |
| >7 axles | | | 44 | 65 | 95 | 200 | 325 | 460 | 565 | 770 | 1025 | 1080 | 1080 |

**Figure 8-8: Multi trip (12 months) permit flat fee based on GVW, and GVW and the number of axles.**

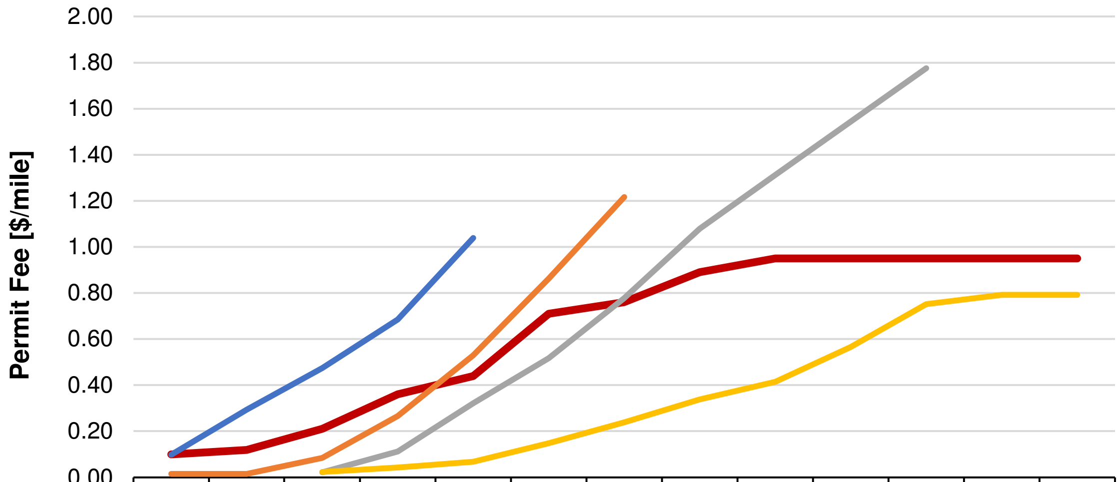
#### 8.2.3.2 Dollar per mile Fee

Similarly, a $/mile fee schedule was developed based on the total damage for a GVW and a combination of GVW and the number of axles (see **Table 8-1**). The base fee was taken as $35. The number of trips for 1 month, 3 months, 6 months, and 12 months multi-trip permits were assumed as 4, 9, 15, and 25, respectively. The multi-trip discount is proposed as 35%, 40%, 45%, and 50% for the 1 month, 3 months, 6 months as well as 12 months permits, accordingly. The summary plots with the proposed $/mile fees are presented in **Figure 8-9** to **Figure 8-14**.



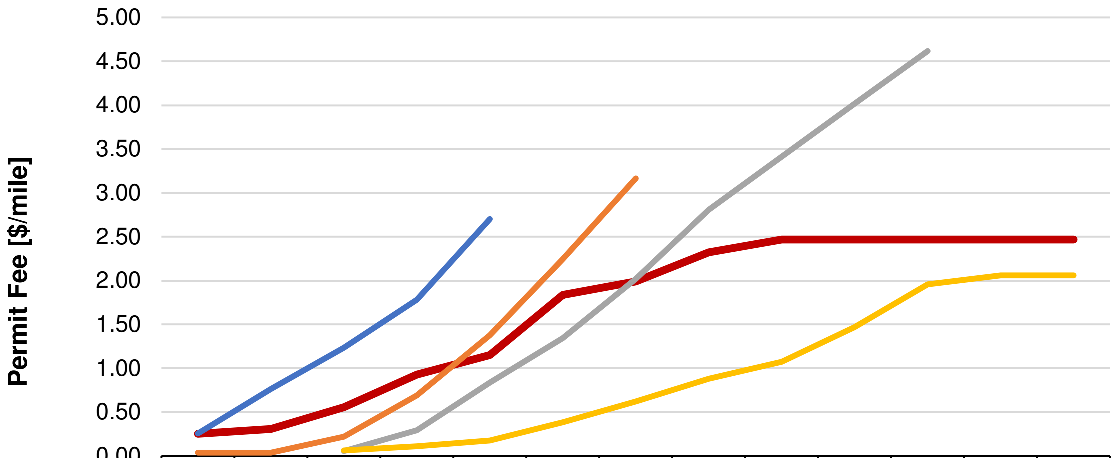

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 |
|---|---|---|---|---|---|---|---|---|---|
| Single Trip | 0.10 | 0.12 | 0.21 | 0.36 | 0.44 | 0.71 | 0.76 | 0.89 | 0.95 |
| 1 month | 0.25 | 0.31 | 0.56 | 0.93 | 1.15 | 1.84 | 1.99 | 2.32 | 2.47 |
| 3 months | 0.53 | 0.64 | 1.16 | 1.92 | 2.39 | 3.81 | 4.13 | 4.82 | 5.12 |
| 6 months | 0.81 | 0.98 | 1.77 | 2.94 | 3.65 | 5.83 | 6.31 | 7.37 | 7.83 |
| 12 months | 1.22 | 1.49 | 2.68 | 4.45 | 5.53 | 8.83 | 9.56 | 11.16 | 11.86 |

**Figure 8-9: Permit $/mile Fee based on GVW.**



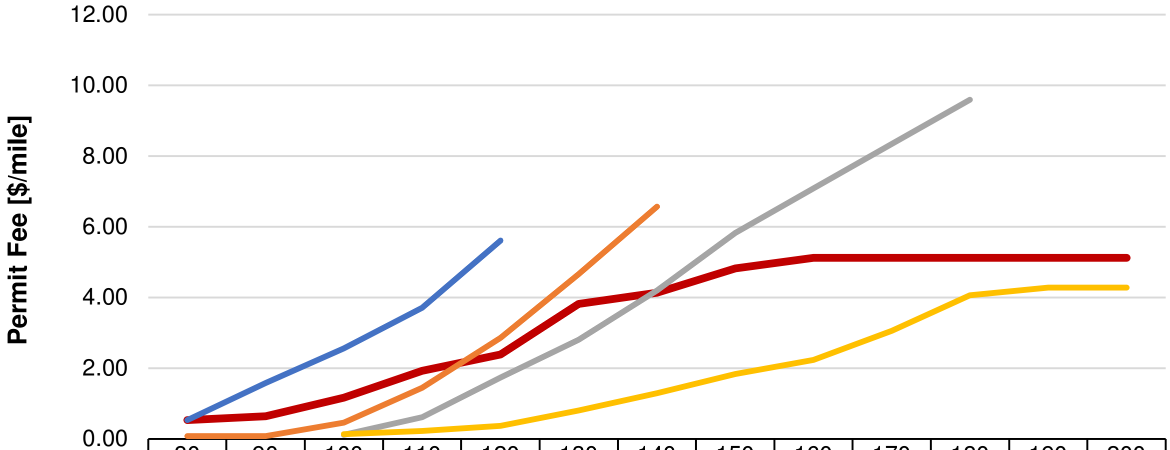

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 0.10 | 0.12 | 0.21 | 0.36 | 0.44 | 0.71 | 0.76 | 0.89 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| <6 axles | 0.10 | 0.29 | 0.47 | 0.69 | 1.04 | | | | | | | | |
| 6 axles | 0.02 | 0.02 | 0.08 | 0.27 | 0.53 | 0.86 | 1.22 | | | | | | |
| 7 axles | | | 0.02 | 0.11 | 0.32 | 0.52 | 0.78 | 1.08 | 1.31 | 1.54 | 1.78 | | |
| >7 axles | | | 0.02 | 0.04 | 0.07 | 0.15 | 0.24 | 0.34 | 0.41 | 0.57 | 0.75 | 0.79 | 0.79 |

**Figure 8-10: Single trip permit $/mile fee based on GVW, and GVW and the number of axles.**



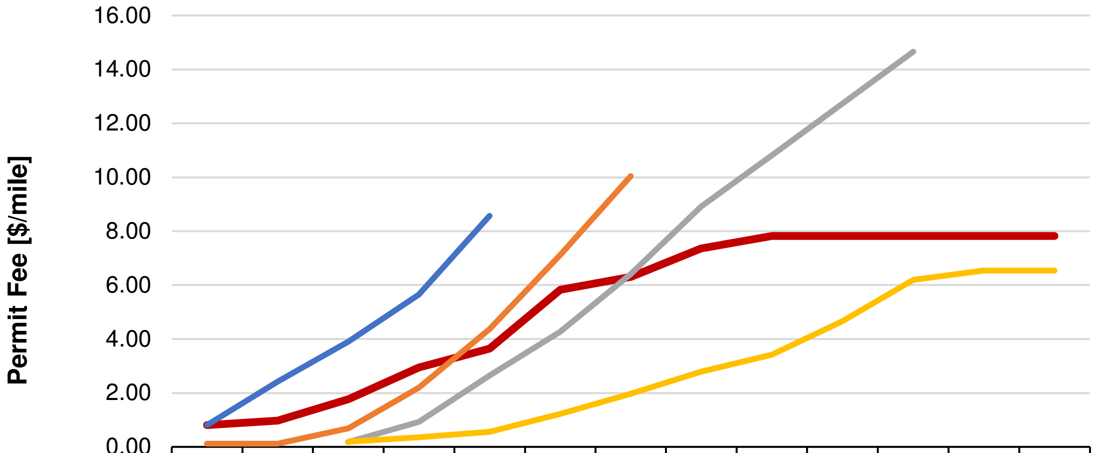

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 0.25 | 0.31 | 0.56 | 0.93 | 1.15 | 1.84 | 1.99 | 2.32 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| <6 axles | 0.26 | 0.76 | 1.23 | 1.78 | 2.70 | | | | | | | | |
| 6 axles | 0.04 | 0.04 | 0.22 | 0.69 | 1.38 | 2.24 | 3.16 | | | | | | |
| 7 axles | | | 0.06 | 0.29 | 0.84 | 1.35 | 2.02 | 2.81 | 3.41 | 4.01 | 4.62 | | |
| >7 axles | | | 0.06 | 0.11 | 0.18 | 0.38 | 0.62 | 0.88 | 1.07 | 1.47 | 1.95 | 2.06 | 2.06 |

**Figure 8-11: Multi trip (1 month) permit $/mile fee based on GVW, and GVW and the number of axles.**



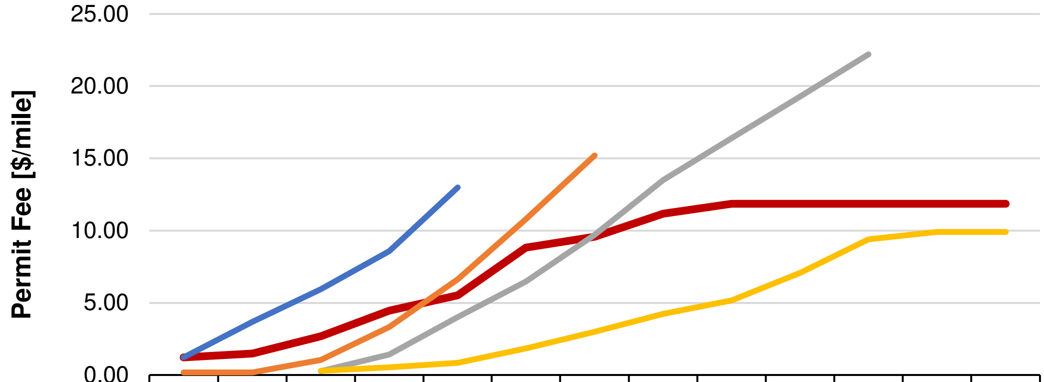

| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 0.53 | 0.64 | 1.16 | 1.92 | 2.39 | 3.81 | 4.13 | 4.82 | 5.12 | 5.12 | 5.12 | 5.12 | 5.12 |
| <6 axles | 0.53 | 1.59 | 2.56 | 3.70 | 5.61 | | | | | | | | |
| 6 axles | 0.08 | 0.08 | 0.45 | 1.44 | 2.86 | 4.66 | 6.57 | | | | | | |
| 7 axles | | | 0.12 | 0.61 | 1.74 | 2.80 | 4.20 | 5.83 | 7.08 | 8.34 | 9.59 | | |
| >7 axles | | | 0.13 | 0.23 | 0.37 | 0.80 | 1.29 | 1.83 | 2.23 | 3.05 | 4.06 | 4.28 | 4.28 |

**Figure 8-12: Multi trip (3 months) permit $/mile fee based on GVW, and GVW and the number of axles.**




| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 0.81 | 0.98 | 1.77 | 2.94 | 3.65 | 5.83 | 6.31 | 7.37 | 7.83 | 7.83 | 7.83 | 7.83 | 7.83 |
| <6 axles | 0.81 | 2.42 | 3.92 | 5.66 | 8.57 | | | | | | | | |
| 6 axles | 0.12 | 0.12 | 0.69 | 2.20 | 4.37 | 7.12 | 10.04 | | | | | | |
| 7 axles | | | 0.18 | 0.93 | 2.65 | 4.27 | 6.41 | 8.91 | 10.82 | 12.74 | 14.65 | | |
| >7 axles | | | 0.20 | 0.35 | 0.56 | 1.22 | 1.97 | 2.79 | 3.41 | 4.67 | 6.20 | 6.54 | 6.54 |

**Figure 8-13: Multi trip (6 months) permit $/mile fee based on GVW, and GVW and the number of axles.**




| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GVW | 1.22 | 1.49 | 2.68 | 4.45 | 5.53 | 8.83 | 9.56 | 11.16 | 11.86 | 11.86 | 11.86 | 11.86 | 11.86 |
| <6 axles | 1.23 | 3.67 | 5.93 | 8.57 | 12.98 | | | | | | | | |
| 6 axles | 0.19 | 0.19 | 1.05 | 3.33 | 6.62 | 10.79 | 15.21 | | | | | | |
| 7 axles | | | 0.27 | 1.41 | 4.02 | 6.47 | 9.71 | 13.50 | 16.40 | 19.30 | 22.20 | | |
| >7 axles | | | 0.30 | 0.53 | 0.85 | 1.84 | 2.99 | 4.23 | 5.17 | 7.07 | 9.40 | 9.91 | 9.91 |

**Figure 8-14: Multi trip (12 months) permit $/mile fee based on GVW, and GVW and the number of axles.**

## 8.3 PERMIT FEES IN THE U.S.

The permit fees for oversize and/or overweight vehicles generally vary across the U.S. for single and multi-trip permits. These permit fees are either consistent or based on the weight, distance, weight, and distance and/or axles. For single trip permits, the state of Alabama presently has minimum and maximum permit fees of $10 and $100, respectively, and a constant permit fee of $100 for multi-trip permits. To determine a new permit fee structure for the state of Alabama, it is necessary to understand the permit fee structure for the U.S. and Alabama's neighboring states. This chapter describes the procedure involved in the development of the new permit fee structure for the state of Alabama for single and multi-trip permits, based on a national review of the permit fee schedules.

The permit fee structure for available states was extracted using state DOTs information and available technical reports. Permit fees adopted by certain states are substantially more expensive than others. Examples of costly permit fees include Mississippi and Oklahoma. Mississippi has a minimum and maximum fee of $450 and $1,000, respectively, for a single permit, and a flat fee of $4,500 for a multi-trip permit. Oklahoma has a minimum and maximum fee of $940 and $2,040, respectively, for single permit fees and a constant fee of $4,480 for multi-trip permits. In comparison with Alabama, states such as Arkansas, North Carolina, North Dakota, Rhode

Island, and South Carolina have a flat fee of $100 for multi-trip permits. A comparison of single and multi-trip permit fees for several states is presented in **Table 8-7** and **Table 8-8**, respectively. **Figure 8-15** and **Figure 8-16** also present the distribution of single and multi-trip permit fees for the state of Alabama compared with other states. These figures show that Alabama has one of the lowest permit fee structures nationwide.

**Table 8-7: Single trip permit fees comparison.**

| GVW [kip] | Alabama | Arkansas | Mississippi | Missouri | North Carolina |
|---|---|---|---|---|---|
| 90 | $10 | $25 | $450 | $195 | $12 |
| 100 | $10 | $25 | $500 | $215 | $12 |
| 110 | $30 | $25 | $550 | $235 | $12 |
| 120 | $30 | $25 | $600 | $255 | $12 |
| 130 | $60 | $25 | $650 | $275 | $12 |
| 140 | $60 | $25 | $700 | $295 | $432 |
| 150 | $60 | $25 | $750 | $315 | $462 |
| 160 | $100 | $25 | $800 | $335 | $492 |
| 170 | $100 | $25 | $850 | $980 | $522 |
| 180 | $100 | $25 | $900 | $1,000 | $552 |
| 190 | $100 | $25 | $950 | $1,020 | $582 |
| 200 | $100 | $25 | $1,000 | $1,040 | $612 |

| GVW [kip] | North Dakota | Ohio | Oklahoma | Tennessee | Texas |
|---|---|---|---|---|---|
| 90 | $20 | $145 | $940 | $560 | $210 |
| 100 | $20 | $145 | $1,040 | $620 | $210 |
| 110 | $20 | $145 | $1,140 | $680 | $210 |
| 120 | $20 | $145 | $1,240 | $740 | $210 |
| 130 | $20 | $145 | $1,340 | $800 | $285 |
| 140 | $20 | $145 | $1,440 | $860 | $285 |
| 150 | $20 | $145 | $1,540 | $920 | $285 |
| 160 | $30 | $145 | $1,640 | $980 | $285 |
| 170 | $40 | $145 | $1,740 | $1,040 | $360 |
| 180 | $50 | $145 | $1,840 | $1,100 | $360 |
| 190 | $60 | $145 | $1,940 | $1,160 | $360 |
| 200 | $70 | $145 | $2,040 | $1,220 | $360 |

**Table 8-8: Multi-trip permit fees comparison.**

| GVW [kip] | Alabama | Arkansas | Mississippi | Missouri | North Carolina |
|---|---|---|---|---|---|
| 90 | $100 | $100 | $4,500 | $624 | $100 |
| 100 | $100 | $100 | $4,500 | $624 | $100 |
| 110 | $100 | $100 | $4,500 | $624 | $100 |
| 120 | $100 | $100 | $4,500 | $624 | $100 |
| 130 | $100 | $100 | $4,500 | $624 | $100 |
| 140 | $100 | $100 | $4,500 | $624 | $100 |
| 150 | $100 | $100 | $4,500 | $624 | $100 |
| 160 | $100 | $100 | $4,500 | $624 | $100 |
| 170 | $100 | $100 | $4,500 | $624 | $100 |
| 180 | $100 | $100 | $4,500 | $624 | $100 |
| 190 | $100 | $100 | $4,500 | $624 | $100 |
| 200 | $100 | $100 | $4,500 | $624 | $100 |

| GVW up to | North Dakota | Ohio | Oklahoma | Tennessee | Texas |
|---|---|---|---|---|---|
| 90 | $100 | $1,980 | $4,480 | $750 | $4,000 |
| 100 | $100 | $1,980 | $4,480 | $750 | $4,000 |
| 110 | $100 | $1,980 | $4,480 | $1,500 | $4,000 |
| 120 | $100 | $1,980 | $4,480 | $1,500 | $4,000 |
| 130 | $100 | $1,980 | $4,480 | $2,250 | $4,000 |
| 140 | $100 | $1,980 | $4,480 | $2,250 | $4,000 |
| 150 | $100 | $1,980 | $4,480 | $3,000 | $4,000 |
| 160 | $100 | $1,980 | $4,480 | $3,500 | $4,000 |
| 170 | $100 | $1,980 | $4,480 | - | $4,000 |
| 180 | $100 | $1,980 | $4,480 | - | $4,000 |
| 190 | $100 | $1,980 | $4,480 | - | $4,000 |
| 200 | $100 | $1,980 | $4,480 | - | $4,000 |

To determine a minimum/base permit fee for Alabama, it is necessary to compare the permit fees for the entire U.S. nation with those of Alabama's neighboring states. For single and multi-trip permits, ten Alabama neighboring states were selected for analysis. These include Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. In the analysis, the average permit fee for single and multi-trip permits were calculated for each GVW. **Figure 8-17** and **Figure 8-18** show that the average single and multi-trip permit fees for Alabama's neighboring states are higher than those for the U.S. The average minimum and maximum values are displayed in **Table 8-9**.

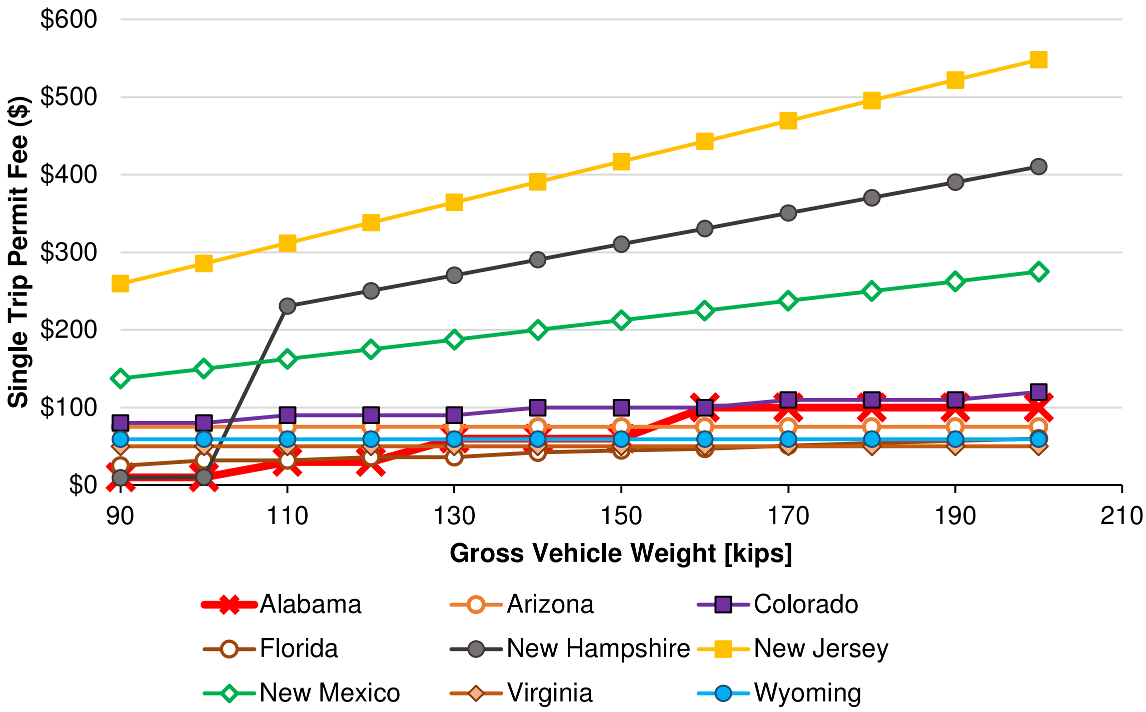



**Figure 8-15: Permit fee comparison for single trip permits.**

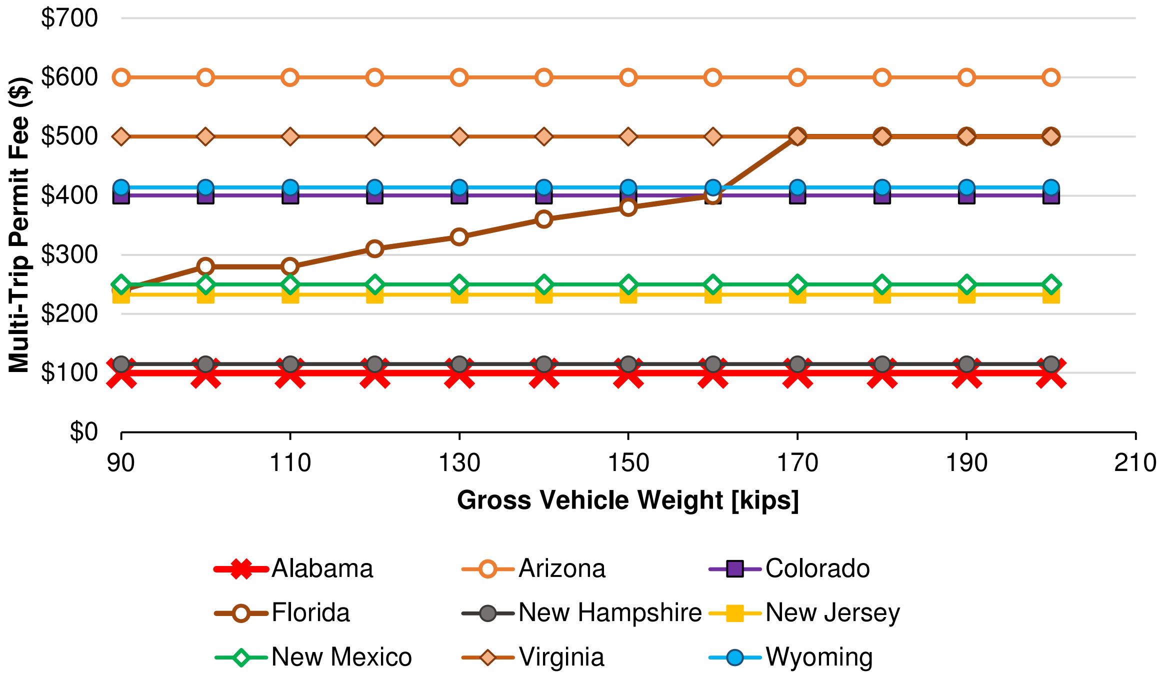



**Figure 8-16: Permit fee comparison for multi-trip permits.**

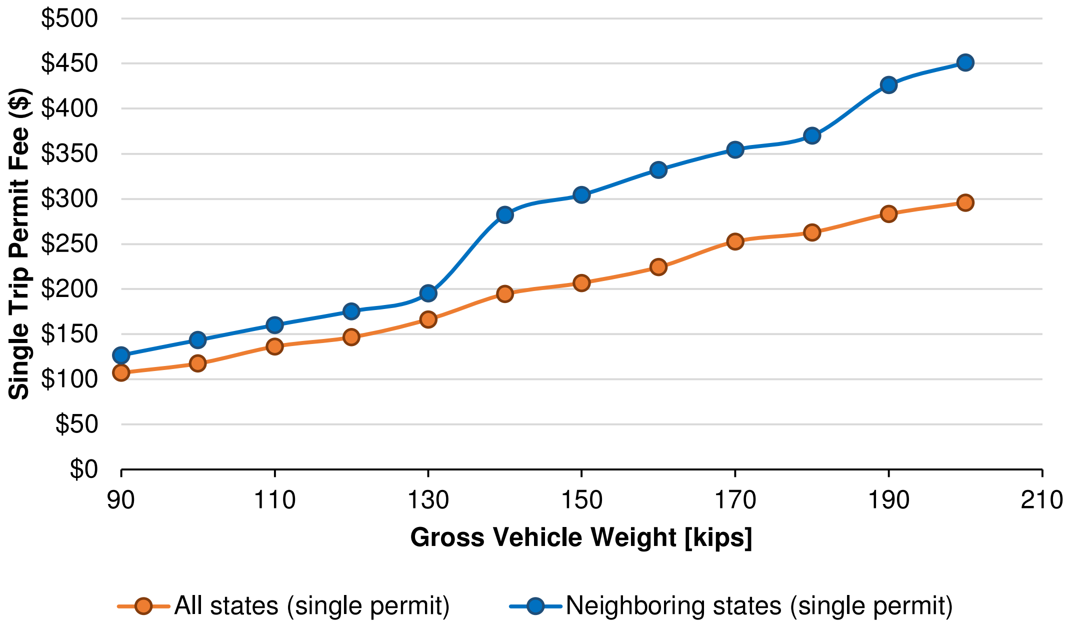



**Figure 8-17: Average single trip permit fee by GVW for the U.S and Alabama neighboring states.**

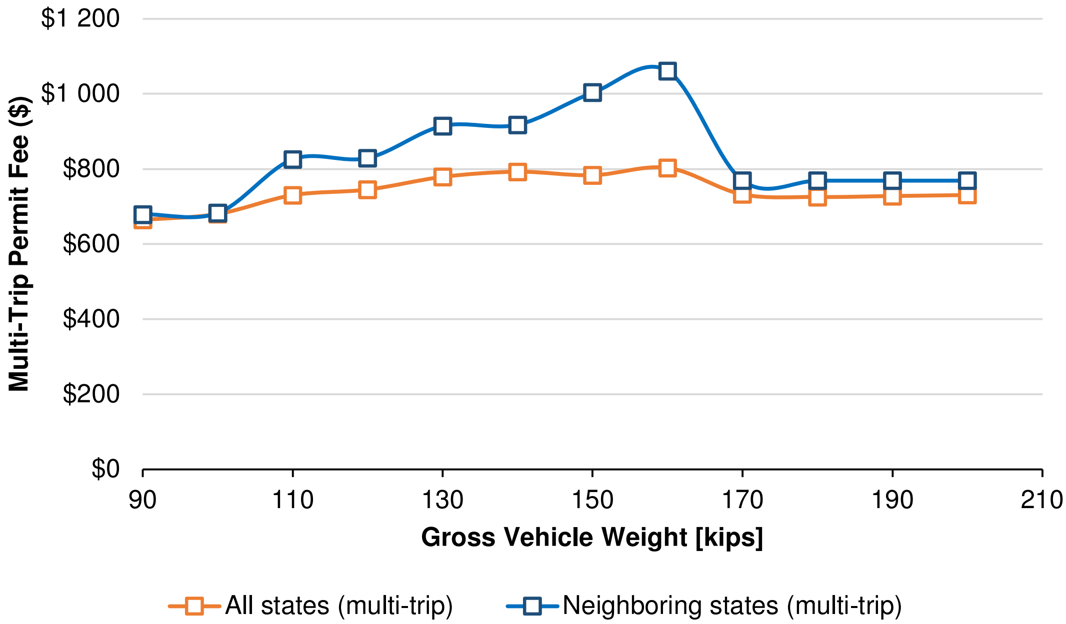



**Figure 8-18: Average multi-trip permit fee by GVW for the U.S. and Alabama neighboring states.**

**Table 8-9: Average minimum and maximum permit fees for single and multi-trip permits.**

| | Single Trip | | Multi-Trip | |
|---|---|---|---|---|
| | **All states** | **Neighboring states** | **All states** | **Neighboring states** |
| **Average minimum** | $107 | $127 | $664 | $679 |
| **Average maximum** | $296 | $451 | $731 | $769 |

# Chapter 9

# SUMMARY AND CONCLUSIONS

The impact of a growing number of overloaded vehicles on bridges and pavements has not been quantified, hence it has been a relevant issue during recent decades. The number of issued permits is growing every year, and there is a need to assess their impact on infrastructure. Weigh-in-motion data analysis shows that annual truck traffic growth is over 3%, and an increase in the number of issued permits is about 5%. The operation of heavy trucks is justified from the transportation efficiency point of view, but excessive weight and the number of permit vehicles can result in accelerated infrastructure wear and tear.

The permit fee schedule in the U.S. varies significantly from state to state. The permit fees and permit criteria are very different and can be based on axle weight, gross vehicle weight, distance, weight and distance, and flat fee. State agencies seek to establish a rational and fair permit fee structure based on damage assessment analysis. The permit fee schedule is developed to control heavy traffic and maintain good condition of bridges and roads. Therefore, it is necessary to provide a method to assess the monetary damage caused by overloaded traffic.

Alabama permit fee schedule has not been changed for decades, so there is a need to evaluate permit traffic-induced load effects. The objectives of this project were to assess the damage to bridges and pavements caused by permitted overweight vehicles in Alabama, calculate the damage for various types of vehicles and permits, and to provide a background for selection of a rational and equitable permit fee schedule.

This project utilized ALDOT permit data for the years 2013-2021 to determine the damage caused by permit vehicles to roads and bridges. The Research Team developed Alabama Transport Demand Model to identify heavy permit corridors and determine the types of bridges and roads used by the overloaded permit traffic. Over 160,000 permit trucks were considered. These trucks were run over 750,000 road links, and 195,000 bridges to determine the bridge and pavement damage. The developed methodology involves calculation of a bridge and pavement damage ratio, which is a relative increase of damage caused by the permit truck in comparison to the damage caused by a standard legal truck.

The major insights from the performed analysis are as follows:

- Automated permitting system ALPASS is a good source of information to determine the damage caused by overloaded permit trucks to infrastructure, and to find heavy permit corridors.
- Alabama Transport Demand Model (TDM) was developed to determine heavy permit corridors based on available permit trip origin and destinations. TDM is an excellent tool to support traffic, road, and bridge management.

- The developed methodology allow for calculation of a relative increase in load effects caused by permit trucks in comparison to standard legal trucks. Bridge damage uses the influence line analysis to determine maximum bending moment ratio, and pavement ESAL ratio.
- Total damage is used as a criterion to develop a new permit fee schedule. Thus, the larger the total damage ratio the higher the permit fee.
- A permit fee schedule for single trip permits and multi trip permits for 1, 3, 6, and 12 months provides more flexibility for the permittees with the seasonal work.
- Calculated total damage is used as a basis to determine a permit fee schedule and can be easily adjusted based on ALDOT preferences.

For each permit vehicle, the damage and corresponding permit fee is assessed as a function of:

1. Gross Vehicle Weight (GVW)
2. Number of trips
    - Single
    - Multiple - 1, 3, 6 or 12 months
3. Number of axles
    - < 6
    - 6
    - 7
    - >7
4. Travel distance in miles

The following options for permit fees were analyzed and are presented for consideration, with A being the simplest and D the most comprehensive and complex:

A. (1) and (2)
B. (1) and (2) and (3)
C. (1) and (2) and (4)
D. (1) and (2) and (3) and (4)

To calculate the actual permit fee, a Permit Fee Calculator is developed, and it is available in form of an interactive spreadsheet (Excel) file that is attached to this report.

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