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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

Agreement # BE695

Final Report

Prepared by

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METRIC CONVERSION TABLE

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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In this study, a damage assessment approach was developed to calculate the monetary consumption caused by overweight permitted vehicles on bridges and pavements in Florida. The damage assessment analysis for the bridges was conducted based on the fatigue damage measured by the equivalent bending moment on a representative bridge in Florida. Results of the bridge consumption analysis are given in $/miles. To calculate pavement damage cost, life cycle cost and damage analysis were rendered for 37 different representative road segments in Florida. The pavement damage was presented based on the equivalent single axle loads (ESALs). Then, a model was developed to estimate the average pavement damage for a given number of ESALs. The pavement and bridge damage costs were combined and presented in the same format as the existing overweight permit fee structure. Comparing the proposed permit fee to the current Florida fees showed that the proposed fees will increase the revenues of single-trip permits by a factor of 1.6, multi-trip 12-month months permits by a factor of 1.5, and multi-trip 3-month permits by a factor of 2.7. This is based on a 90% discount for multi-trip permits. The department can choose an appropriate discount rate for multi-trip permits based on economic considerations. The proposed change brings Florida’s overweight permit fees more in line with those of other states.</td></tr>
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EXECUTIVE SUMMARY

To adequately maintain the infrastructure and allocate the necessary funds for reconstruction, an effective damage assessment is required. Stakeholders such as state departments of transportation (DOTs) are interested in assessing the degree of damage caused by overweight vehicle operation. In this study, a damage assessment approach was developed to calculate the monetary consumption caused by overweight permitted vehicles on bridges and pavements in Florida.

The representative bridge parameters were established based on the sample bridge database, the Florida Department of Transportation (FDOT) new bridge construction cost data, the National Bridge Inventory database, and weigh-in-motion datasets. An extensive study was conducted to find parameters such as bridge cost, average daily truck traffic (ADTT), span length, and material and structural type. The cost per mile of road was estimated at $1M/mile and was used as the representative cost of a bridge in Florida for permit vehicle operation. The damage assessment analysis is based on the fatigue damage measured by the equivalent bending moment on a representative bridge in Florida. The consumption analysis was conducted separately for each gross vehicle weight (GVW) group, and the results of the bridge consumption analysis are given in $/miles.

To compute the pavement damage cost, roads were categorized into Interstates (IS), principal arterials (PA) (expressways, Other), and minor roads (MR) (minor arterial, major collector). This classification was based on different road structures and traffic levels. Thirty-seven different road segments (different road categories, traffic levels, construction costs, and milling and resurfacing (M&R) practices) were used to estimate pavement damage cost (PDC). Life cycle cost and damage analysis were rendered for each of the road segments. The damage was presented as equivalent single axle loads, using the “fourth-power law,” a popular approach based on the American Association of State Highway and Transportation Officials (AASHTO) Pavement Design Guide. A model was then developed to estimate the average pavement damage for a given number of ESALs. Using the average ESALs at each road category, the average pavement damage was estimated at $0.018 for IS, $0.049 for PA, and $0.147 for MR per mile ESALs. The type of the road (IS, PA, MR) that a truck will use during a trip and its number of axles were the determining factors used in computing the permit fees associated with each truck.

To match the current permit fee structure used in Florida, the damage cost was averaged across all road categories, vehicle types, and number of axles. Averaging was weighted based on road length and frequency of each vehicle type and number of axles in Florida. This matched the current permit fee structure and enabled determining the fees based only on the Gross Vehicle Weight and total miles traveled. While this

approach simplifies the computational and enforcement effort, it reduces the equitability of the charged fees because damage cost can increase ten-fold depending on the number of axles and road category, given the same Gross Vehicle Weight.

The pavement and bridge damage costs were combined and presented in the same format as the existing overweight permit structure. Hence, multi-trip permits are used as a fixed price; the $/mile is multiplied by the average length of the trip (180 miles) and the estimated number of trips (25 trips for 3-month and 100 trips for 12-month permits). With respect to multi-trip permits, the damage cost was significantly higher than current imposed fees. Thus, various percentage discount rates (90%, 80%, 70%, 60%, and 50%) were applied to multi-trip permits.

The proposed permit fees were then compared to Florida's current fees. The comparison showed that assuming the same traffic as at present, the proposed fees will increase the revenues of single-trip permits by a factor of 1.6, multi-trip 12-month permits by a factor of 1.5, and multi-trip 3-month permits by a factor of 2.7. This is based on a 90% discount for multi-trip permits. The department can choose an appropriate discount rate based on economic considerations. The proposed change brings Florida's overweight permit fees more in line with those of other states.

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PART A: INTRODUCTION AND BACKGROUND INFORMATION

1. Introduction

The collection of fees is intended to help pay for additional wear and tear to highways caused by overloaded permit vehicles. To adequately maintain the infrastructure and allocate the necessary funds for maintenance, an equivalent damage assessment and cost analysis is required. Therefore, there is a need to check the adequacy of the current permit fee structure. Stakeholders such as state DOTs are interested in assessing the degree of damage caused by overweight vehicle operation. Almost all state DOTs have sponsored studies to determine the impact of overweight traffic on infrastructure. This report seeks to find the damage costs of bridges and pavements as two principle road structures impacted by overweight vehicles in Florida. The report is organized in four major parts (Parts A, B, C, and D).

Part A. Background information: Part A contains chapter 2-4. The primary objective of chapter two is to conduct a literature review of the available published documentation, similar research work, and manuals as pertaining to the impact of overweight vehicles on highway structures. Then, in chapter three, the major sources of information related to the fees associated with heavy trucks and overweight loads are reviewed. The vehicular traffic on highways can be categorized into legal loads, oversize and/or overweight (OS/OW) permitted loads and illegal loads. Each vehicle consumes a small portion of the service life of bridges and pavement. Assessment of life consumption due to live load requires thorough consideration of these groups of vehicles. Historic fees related to heavy trucks such as permit fees, registration fees and fuel tax for the state of Florida are reviewed in chapter four.

Parts B and C. Bridge and pavement damage cost assessment: This report assesses the damage on bridges and pavement caused by permitted overweight vehicles in Florida. The objective of the damage assessment analysis is to assign fair costs to the various vehicles and permit types. This may be achieved by using the issued permit database to determine the total monetary consumption of bridges caused by permit loads. The real traffic data of permit vehicles operating on the roads and bridges in Florida is utilized to determine the total damage. Then, the current permit fee schedule is used as a reference to compute monetary damage.

Part D. Compilation of bridge and pavement damage costs. The consumption of bridges and pavements are combined. Then, the results for single and multi-trip permits are compared with other states. Finally, the revenue generated by the proposed and current permit fees is presented and compared.

2. Literature Review

2.1. Federal and States Legislations on Overload Traffic

2.1.1. Weight Limits and Permitting

There are many factors contributing to the service life of asphalt pavements, such as traffic, environment, type of material and design. Research shows that the actual load applied on pavement is heavier than what is estimated during the design phase. These types of overloads accelerate pavement deterioration and shorten the service life of pavement [1]. Since the structural design of pavement depends on the characteristics of road traffic, the pavement on low functional routes incurs more damage compared to a road with more demands like interstate highways [2]. A study about the effect of overloaded trucks showed that trucks with 6,000 pounds above the legal limit of 20,000 pounds could reduce the pavement service life to half [3]. In addition to load magnitude, the number of axles and the axle grouping (e.g., single axle: the distance between axles is large; tandem axle: two axles close to each other and far from other axles; tridem axle: three axles close to each other and far from other axles) affects the performance of pavement. Generally, trucks with a single axle or tandem axles cause cracking distresses in the pavement due to the concentration of load in a limited contact surface area. On the other hand, trucks with multiple axles that spread the load over a larger contact surface area cause more rutting distresses [4]. However, in addition to the configuration of axles, there are other factors like intertwined traffic or environmental factors that result in different types of distresses [5].

According to the U.S. DOT's Federal Highway Administration (FHWA) report in 1990, the number of trucks traveling along U.S. highways over a 10-year period has increased by about 44%. This increase, which is more than double the number of heavy trucks on the road, could result in an exponential reduction in the performance of the infrastructural system [1], [6], [7]. This indicates less traffic safety and an increase in infrastructure maintenance costs because the existing structural capacity of roads is not increasing at the same pace as the growth of heavy traffic [8]. It is estimated that in the 1990s, the yearly cost caused by illegal overweight trucks ranged between $167 and $670 million. Also, a more recent estimation for these costs shows that an average impact per truck mile traveled equals to $0.08, which adds up to $1.1 billion per year [9].

To minimize pavement deterioration, states have enforced axle weight limits and gross weight limits; however, trucks can carry more weight than the limit when they obtain permits from state DOTs. Thus, the cost of the fee can significantly affect the number of overweight trucks on the road and consequently, the rate of deterioration of the pavement and other infrastructure.

Taking into account the adverse effects of heavy truckloads, the federal government issued the first national standard with the Federal-Aid Highway Act of 1956. This was based on research by the American Association of State Highway and Transportation Officials (AASHTO). The limitations set forth by this act are on axle and gross weight. Since it is not easy to accurately weigh each axle, the weight per axle is usually used as an estimation. Currently, the interstate federal weight limits for a single axle is 20,000 pounds per axle, tandem axles are 34,000 pounds per axle pair and the gross vehicle weight is 80,000 pounds (Federal Bridge Formula (FBF)). However, some states have higher weight limits than the federal 80,000-pound limit. Examples include Oregon, with a maximum gross vehicle weight of 105,500 lbs., Washington with a maximum gross vehicle weight of 105,500 lbs., and Wyoming with a maximum gross vehicle weight of 117,000 lbs. Also, most state weight limits on interstate highways exceeds federal limits. As shown in Figure 2-1, for five-axle semi-trailers, the most common permitted weight ranges from 100,001 to 110,000 pounds. For single axle trucks under routine single-trips, the maximum allowable load ranges from 22,000 to 45,000 pounds. This range is between 34,000 to 65,000 pounds for tandem axles, which is not applied in twelve states [10]. As shown in Figure 2-2, for a single axle, the most common permitted weight ranges from 20,001 to 25,000 pounds, and for the tandem axle, it is between 45,001 to 50,000 pounds.

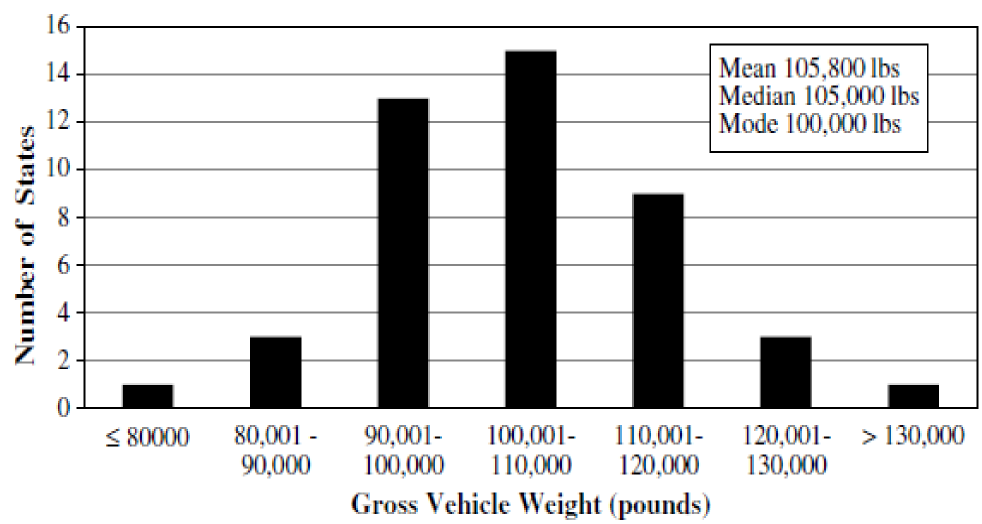
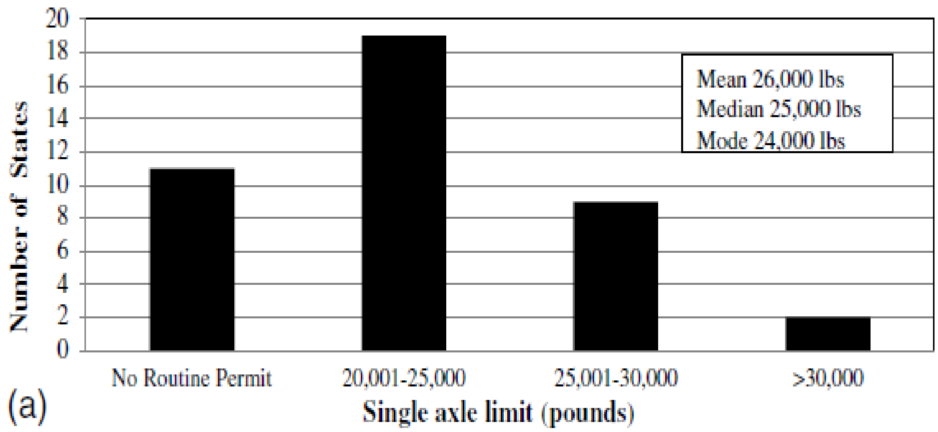


Figure 2-1. Gross weight for five-axle semi-trailers versus the number of states [10].



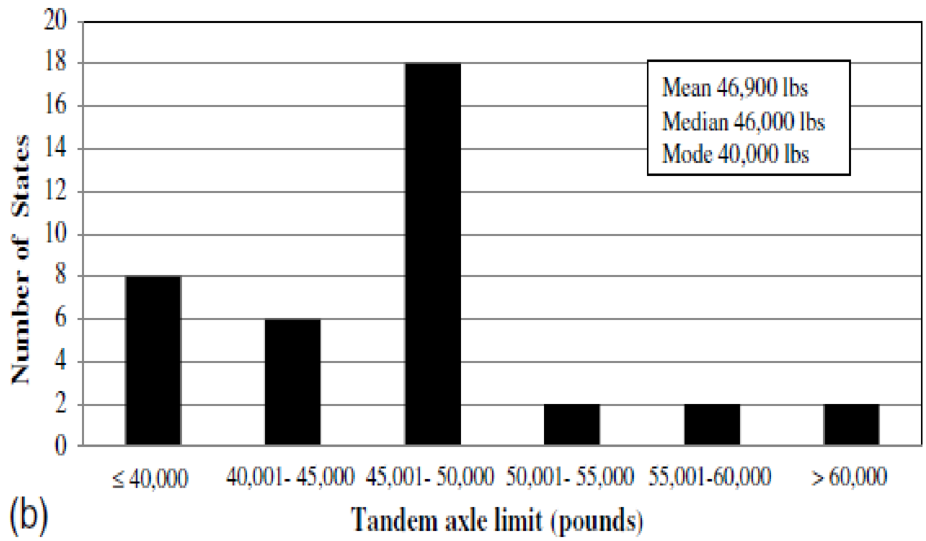


Figure 2-2. Axle weight limits versus number of states: (a) single axle; (b) tandem axle [10].

If a truck exceeds the typical overweight load limits, it is called a *superload*. This type of load demands states to ensure a sufficient capacity of the infrastructures on the route and follow specific safety operations. A superload truck must have detailed information about axle configuration and load applied by each axle. The most common way to deal with superloads is on a case-by-case basis. However, some states prohibit superloads, while others simply issue permits. According to a Dunning et al. article, the most common maximum superload permit ranges between 140,001 to 150,000 pounds (Figure 2-3).

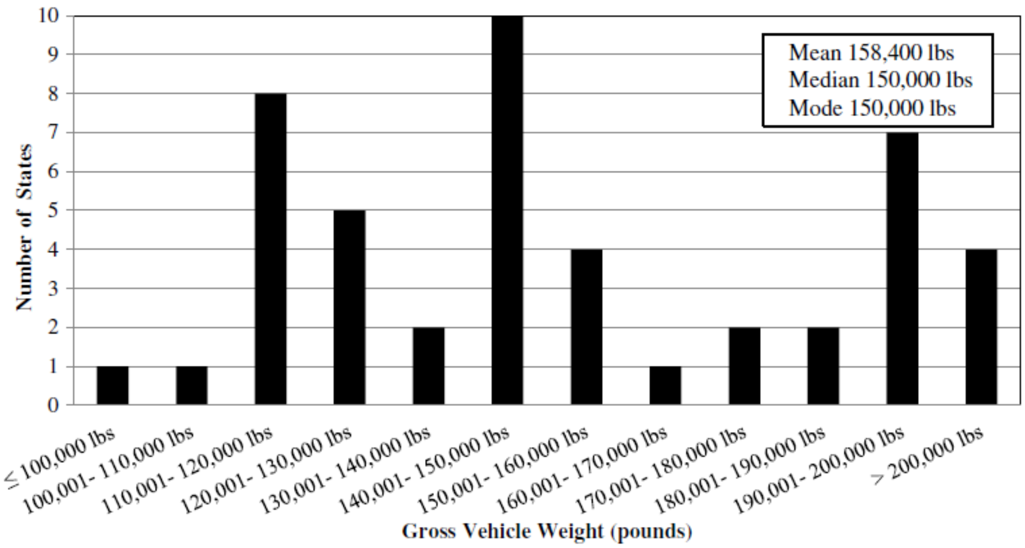


Figure 2-3. Maximum superloads permitted [10].

2.1.2. Issues Related to User Fees for Overweight Freight Trucks

The user fees, which are used to provide funding for rehabilitation and maintenance of infrastructure on roads, should be proportional to the damage that each load induces. Efficient user fees can reduce infrastructure life-cycle costs. Implementation of user fees or any adjustment and change in existing fees should be carefully studied because it has many direct and indirect effects. For example, depending on the changes in the user fee, it could encourage truck drivers to take a route from another state or to break down the load and use smaller trucks or not ship at all [11]. However, it must be taken into account that any change in the freight shipment industry could affect the market, price of goods, and consequently, the consumer’s decision. Although the increase in user fees could benefit the road infrastructure by decreasing the number of overloaded trucks, their effects on the overall economy should be carefully investigated. Political issues should also be considered in the decision-making process. For example, providing specific facilities such as truck-only toll (TOT) lanes for truck facilities has been in discussion at the national level. The advantage of using TOT lanes is that there is no need to upgrade all lanes on the road. Also, the traffic will be separated into small vehicle traffic and truck traffic, which are usually slower, thus promoting road safety. However, the willingness of the trucking industry to pay for something they were using for free is not determined, and the feasibility of financing such a facility depends on their decision [12].

In addition to economic and political considerations, determining the appropriate user fee demand requires the modeling of various traffic loads in their specific geographical location. A study conducted in Iran used a deterioration model that considered pavement material properties (asphalt layer thickness, pavement temperature, subgrade condition, and traffic speed). Results showed a significant increase in damage when the load passed the weight limits [13].

However, based on a survey, not all DOTs have the same intent in determining the permit fees for overweight trucks, and their objectives vary from one state to another. The most common intents are [10]:

1. Discouraging overweight freight shipments, or deterring the overweight vehicles.
2. Providing enough funding for infrastructure maintenance.
3. Covering administrative costs associated with oversized and overweight trucks.
4. Adjusting fees proportional to neighbor states.

Different policies for each state regarding user permit fees make it difficult to estimate the user fees of multistate freight operations. An online survey of state DOTs showed that lobbyists and legislators play the main role in the determination of permit fees for overweight trucks.

2.1.3. Permit Fees Categories in the U.S.

There are five main categories concerning overweight single trip truck permit fees in the U.S.: flat-based, axle-based, weight-based, distance-based, and weight- and distance-based. Figure 2-4 shows the number of states that use each type of permit fees. On the other hand, the majority of the annual permits are flat-based, and they usually do not consider limited distance or the level of weight above legal limits.

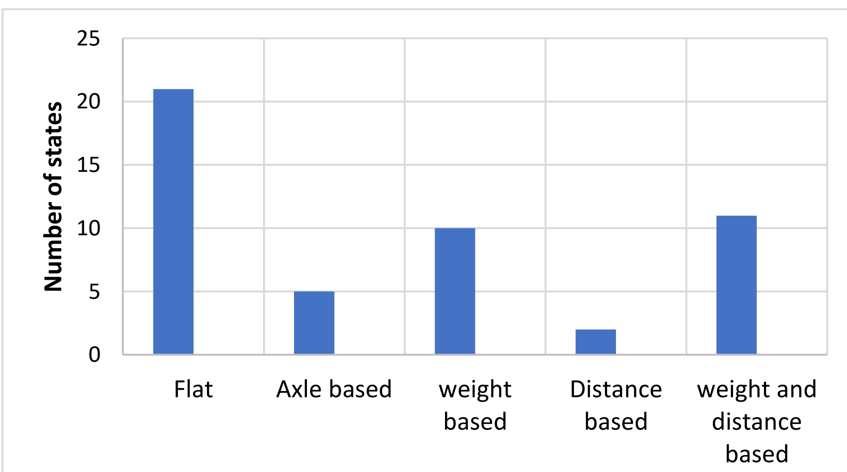


Figure 2-4. The number of states using five different categories in 2011.

The flat user fee is the simplest type of user fee for both state permit offices and trucking companies. There are two types of flat fee: one is the flat-fee single-use permits, and the other is for annual permits. Providing a logical relation between single-use and annual permits is important. In 2011, in one state, the annual permit was $10 and the single-use was $5. Based on the record, the trucker used the annual fee travel more than twice per year. Therefore, a survey should be conducted to have an estimation of the number of annual trips of the truck. Although the flat user fee is simplest to administrate, heavier loading is encouraged since the damage was amortized unfairly across all carriers' fee.

Weight-based fees: This type of fee charged for tons of loads in excess of the legal weight limit. Although this type of permit considers how much stress is induced on the infrastructure, it does not take into account the length of time that the load is moving on the road. Thus, two trucks with the same weight might pay equally, whereas one traveling hundreds of miles will pay more than the other.

Distance-based: Indiana and Virginia are the only two states that consider travel distance without taking into account the amount of excess weight shipped. There are many issues with this type of fee. One is that determining and tracking the distance traveled by the truck is hard to administrate and enforce. Thus, this difficulty for law enforcement might make it easier for truckers to abuse it. To solve the problem of a distance-based fee, some European countries use the global positioning system (GPS) technology to track the miles traveled by trucks [14], [15]. However, there are some political challenges when it comes to using this type of technology in the United States [16].

Axle-based fee: This type of fee is commonly used for individual facilities such as toll bridges.

2.2. Truck Overloads and Enforcement

In order to discourage the illegal overweight operation of trucks in the future, it is important that DOTs put enough effort into recognizing excess weight trucks and charge them enough to compensate for the damage they cause to the infrastructure. In recent years, weight monitoring is going through rapid changes. A few years ago, all trucks carrying heavy loads had to wait in a line to get on a scale, but now, thanks to intelligent transportation systems and minicomputers, it is easier and faster to weigh the truck and avoid the waste of time and money. According to an online survey, the most common techniques used for enforcement are weight-in-motion (WIM), mobile enforcement team, and fixed weigh stations. The electronic bypasses help to reduce the processing time and traffic operation at checkpoints by using multiple and regional statewide systems such as PrePass, BestPass, NCPAss, I-Pass, etc. [10]. The use of WIM technology has significantly increased between 1989 and 1995 by almost 60 million units. However, based on recent weight enforcement statistics (data collected between 2006-2012) on the number of violations of overweight trucks, data show a similar trend as at the time that the WIM system was not implemented as widely as it is now [17].

Although weigh stations help to control and recognize the illegally overweight trucks, there are still trucks that find ways to avoid these stations by taking a bypass road or traveling after hours of operation. Researchers have found a sudden decrease in the number of overweight truck violations after deploying the stationary weigh stations. However, this decrease is the result of heavy trucks switching to alternative routes [18]. A more recent study in Minnesota in 2005 revealed that 90% of the total number of violations were recognized by mobile units carrying portable scales [19]. Based on an FHWA report (Table 2-1), the stationary scales caught only 0.7% of violations. On the other hand, the average percentage of all violations caught by inspections performed with portable and semiportable scales were about 55%. This indicates that violators avoid scales. However, increasing the number of trained inspectors to adequately control the increasing number of illegal overweight trucks depends on the budget allocated to transportation agencies, which is usually not enough for effective weight enforcement measures [20]. Fiorillo et al. developed a model to optimize the number of inspections in each country based on the "broken window principle". This principle is used by criminologists and also widely implemented in many U.S. cities to reduce crime. They concluded that their methodology is capable of improving the efficiency of the enforcement by redistributing the number of inspections to areas that have more frequent illegal trucks [21].

2.3. Studies on Overload Effects on Bridges

The study of truck weight and its effect on roads and bridges has been performed in many states and dates back to the 1970s. Many states have sponsored studies to develop methodologies to quantify damage and develop a cost analysis based on assumed cost models. A cost impact study for the Indiana DOT was conducted in 1979 by [22] to determine the impacts of a gross vehicle weight (GVW) increase (from 73280 lb (73.28 kip) to 80 kip) on bridges and pavements. A study for the New York State DOT was conducted in 1987 by the BTML [38] on the effects of permit truck weights on bridges. In 1991, the Minnesota DOT [23] conducted a study in response to a TRB Special Report 225 [24] to investigate bridge-related impacts. A study for the Illinois DOT [25] was conducted to determine the impact of weight limit change on bridges. Another study was conducted in 1992 [26] for the Washington State DOT to estimate the impact of Turner trucks on the state’s bridges. A study for the Ohio DOT by Moses, 1992 was conducted to develop a permit fee system based on bridge damage costs.

Table 2-1. U.S. commercial vehicle weight-enforcement activities 2006–2012 [17].

	2006	2007	2008	2009	2010	2011	2012
All-Weighs (10^3)	**229,450**	**217,444**	**200,419**	**182,256**	**198,564**	**185,498**	**189,743**
WIM(10^3)	142,598	132,257	119,826	116,176	118,025	119,718	116,640
Static Weighs[1](10^3)	86,851	85,186	80,593	66,080	80,538	65,780	73,102
Semiportable Scales	422,860	425,731	357,502	373,073	285,484	323,936	278,308
Fixed Scales(10^3)	85,900	84,213	79,644	65,182	79,703	64,922	72,258
Portable Scales	529,053	547,261	590,873	525,350	549,844	533,931	565,669
Violations[2]	**621,391**	**530,350**	**555,168**	**489,975**	**478,576**	**415,545**	**408,492**
Axle Weight Violations	269,758	233,563	248,813	220,631	216,735	178,209	179,774
Gross Weight Violations	149,561	126,761	120,384	116,291	114,171	84,490	91,006
Bridge Weight Violations	202,072	170,026	185,971	153,053	147,670	152,846	137,712
Permits[3] (10^3)	**4,598**	**4,827**	**5,215**	**4,528**	**4,838**	**4,944**	**4,918**
Non-Divisible Trip Permits (10^3)	3,399	3,743	3,693	3,285	3,510	3,762	3,878
Non-Divisible Annual Permits	250,505	332,148	322,288	298,805	303,230	320,767	296,870
Divisible Trip Permits	426,381	398,003	489,712	369,906	341,737	334,650	201,633
Divisible Annual Permits	521,906	354,194	710,476	574,142	683,395	526,364	541,584

1 Static weight includes the total number of vehicles weighed from semiportable, portable, and fixed scales.
2 Violations include those from the axle, gross, and bridge formula weight limits.
3 Permits issued are for divisible and non-divisible loads on a trip or on an annual basis, as well as for the over-width movement of a divisible load.

At the beginning of the 21st century, many states sponsored a study on overweight loads. In 2004 conducted a study [28] on the behavior of steel bridges under specific permit trucks for the state of Connecticut. The study was conducted [31] on the fatigue of older steel bridges to overweight and oversized loads in Indiana in 2005. Another study in 2005 for the state of Louisiana state was conducted by [30] on the effects of specific commodities transporting vehicles on Louisiana infrastructure. Later in 2012, a multiphase study in Wisconsin was done by [31], [32] of the impact of overweight vehicles. A laboratory test and numerical simulation were performed for deck deterioration as part of the study.

The increase in the average gross weight, axle load of the vehicles and density of truck traffic (ADTT) was frequently reported in this study, and the theoretical consequences to the infrastructure were evaluated. In 1979, nationwide survey results [33] were presented to the U.S. Congress, which showed that 86% percent of respondents evaluated the impact of the OW trucks on the transportation infrastructure as “at least to the moderate extent." At the same, there has been a substantial increase in the weight and the population of overweight vehicles over the past several decades [34]. The summary of the possible forms of damage due to heavy traffic operation is to be completed based on the extensive literature review. Potential sources of information include:

- National Cooperative Highway Research Program (NCHRP) Synthesis reports,
- Technical and scientific reports published or sponsored by State DOTs, FHWA [35],
- Others.

Some of the early efforts sponsored by national and state DOTs in order to evaluate the impact of increased truck loads on roads and bridges in terms of accumulated damage and corresponding costs were summarized in [36], [76]. Thus, the impact of the increase of the legal limit for GVW by 11% was studied by [37] for the Indiana DOT. Based on considered cases (overstress, the fatigue of the steel components and deck deterioration), the increase of the legal weight limit will result in a $2-3 million increase annually. One year before the study performed by BTML Division of Wilbur Smith Associates, (1987) predicted a $23,500 annual cost of fatigue damage (as the cost of repairs at the end of fatigue service life) to the steel bridges in New York due to heavy truck traffic. The cost of damages was proposed to be distributed to the annual overweight permits. Professor Moses (TRB, 1990) considered the effects of different truck-weight limits on the duration of the fatigue service life. The resultant estimated annual cost varied substantially, up to $50 million, depending on the load scenario. However, the cost of the bridge failure due to overstress was recognized as having dominated over the fatigue life reduction. Later, the Minnesota DOT, (1991) sponsored a study that adopted the recommendations of TRB Special Report 225 [39] to assess the cost impact of weight-limit increases. The model considered the impact of the overstresses of bridge components as weak as service life reduction due to fatigue. The consequences in terms of dollars included the cost of bridge maintenance and replacement, as well as weight enforcement, posting, and safety means. The moment increase factor (the maximum bending moment due to a truck divided by the moment produced by the rating truck) was determined for each loading scenario in the study. At minimum, the MIF was determined to be 1.20.

A similar study sponsored by the Illinois Department of Transportation [40], [59] was conducted after the increase in the state’s weight limit from 73.3 to 80 kip.The cost model was based on the replacement of the selected bridge (one of 15) at the end of its service life. The estimated costs of damage at the end of the 6^{th} year after the weight limit increase varied from $12.3 to $30 million annually. At the same time, authors recommended relying on the alternative cost-estimate model since the exhaustion of the fatigue capacity of a fatigue-prone detail rarely leads to bridge failure and replacement.

The study sponsored by the Washington State DOT and performed by [41] focused on the evaluation of the impact of Turner trucks on the bridges in the state. As a result, 65% of the state's roadway system was recognized as structurally deficient. The cost analysis was based on the load rating procedure and one-time bridge replacement cost through the remaining life factor. In Ohio, Professor Moses proposed a permit fee system that would reflect the corresponding fees for truck overweight. Later on, the a study to evaluate the impact of the [27] permitted OW trucks on the state's transportation infrastructure. The impact of heavy trucks on bridge structures was determined using the incremental methods earlier proposed by [36]. The total resultant annual cost of bridge damage was reported to equal $22 million.

Comprehensive research [20] to develop the bridge's cost-responsibility portion for different types of vehicles. Thirty-nine bridges (with a 30 to 240-foot span) were selected nationally and evaluated in terms of the fatigue resistance of the steel components and concrete decks. The cost allocation model included the cost of construction, replacement, and minor and major bridge rehabilitation of the new bridges.

Another study titled "Effect of Truck Weight on Bridge Network Costs" focused on the evaluation of the truck weight effects on infrastructure. This study was sponsored by AASHTO and FHWA in 2003 with an objective to develop a methodology to estimate bridge network costs due to a change in truck weight limits [36]. Based on the state-of-the-practice literature review, the four cost-impact categories were recommended. Bridge damage was categorized into the fatigue of existing steel bridges, decks, and deficiency due to overstressing. Also, deficiency due to the overstress of new bridges was considered. A level one- and level two-type analysis was proposed based on the extent of data availability, and a group of bridge Archetype bridges was developed.

In 2013, the South Carolina DOT sponsored a study to analyze the impact of heavy vehicle traffic on infrastructure and develop policy recommendations. Several alternative fee structures were proposed, such as an axle-based system and flat fee. Stakeholder interviews were conducted as part of the study [42].

The effect of OW trucks on New York infrastructure was investigated by [43]. The study, which was sponsored by the New York State Department of Transportation (NYSDOT), focused on the development of a methodology for estimating the effects caused by heavy trucks on New York State's infrastructure.. In modeling the effects of overweight trucks on bridges, the overweight WIM traffic data was categorized to probable divisible permits, special hauling permits, and illegals. The response of overweight traffic data was considered using the overstress of main bridge members and cyclic fatigue accumulation. To assess the effects on pavement, an incremental cost approach was considered using an increase in the design thickness of pavement layers and a possible increase in the maintenance schedule. The cost effect was calculated based on the response of bridge material and construction. The cost effect was studied on a representative sample of 22 bridges along the I-88 corridor in New York State. Based on the cost allocation study, it was found that the total cost for the entire New York State infrastructure is $240 million per year, $95 million per year for bridge network, and $145 million per year for pavement. The study initiated by the FHWA within the Moving Ahead for Progress in the 21st Century Act (MAP-21) [44] was partially focused on the analysis of the effects of the overweight and oversize vehicle operations on the New York State infrastructure. The potential benefits and costs in this study were evaluated, along with the enforcement policy. Six different scenarios of the legally allowable truck configurations were considered (Figure 2-5). The 5-axle tractor-trailer truck with GVW 80,000 lbs. was used as a reference truck for comparison. The fatigue analysis was performed for the various fatigue-prone details of the simply supported and continuous steel bridges.

The cost analysis is based on the reduction of the fatigue service life of the bridge component and corresponding one-time cost to repair the damaged component. The negative effect of the increased axle (or group of axles) weight on bridge fatigue life, while the number of overweight vehicles is called the most impacting factor or parameter. In terms of the cost, the fatigue-induced repairs create a non-significant portion of the total bridge cost.

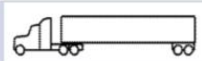
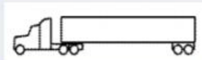
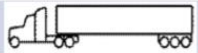
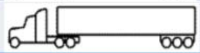
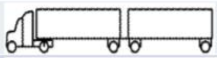
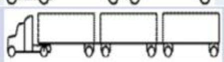
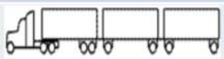
Scenario	Configuration	Depiction of Vehicle	# Trailers or Semi-trailers	# Axles	Gross Vehicle Weight (pounds)	Roadway Networks
Control Single	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	80,000	STAA[1] vehicle; has broad mobility rights on entire Interstate System and National Network including a significant portion of the NHS
1	5-axle vehicle tractor, 53 foot semitrailer (3-S2)		1	5	88,000	Same as Above
2	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	91,000	Same as Above
3	6-axle vehicle tractor, 53 foot semitrailer (3-S3)		1	6	97,000	Same as Above
Control Double	Tractor plus two 28 or 28 ½ foot trailers (2-S1-2)		2	5	80,000 maximum allowable weight 71,700 actual weight used for analysis[2]	Same as Above
4	Tractor plus twin 33 foot trailers (2-S1-2)		2	5	80,000	Same as Above
5	Tractor plus three 28 or 28 ½ foot trailers (2-S1-2-2)		3	7	105,500	74,500 mile roadway system made up of the Interstate System, approved routes in 17 western states allowing triples under ISTEA Freeze and certain four-lane PAS roads on east coast[3]
6	Tractor plus three 28 or 28 ½ foot trailers (3-S2-2-2)		3	9	129,000	Same as Scenario 5[3]

Figure 2-5. Truck configuration and weight scenarios analyzed in the 2014 CTSW study [44].

The national representative bridges (500 bridges of the 12 most common types) were selected based on the National Bridge Inventory (NBI) database, including the Interstate System (IS) and National Highway System (NHS). The structural parameters and the geometry of the structural components were used based on selected bridges. The LRDF and LFR rating procedures were applied to the selected bridges and load trucks in order to investigate the impact of increasing the legal limit on the bridge rating. It was concluded that the 17% increase in the legal truck GVW will result in a 4.6% and 9.5% increase in the number of IS and NHS bridges being rated below 1.0. The corresponding cost of a one-time repair for the 17% GVW increase is $2.2 billion.

The study that investigated the impact of the OW/OS permit fee structure on the infrastructure was conducted for the State of Texas and was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration. The objective was to conduct a study of infrastructure damage caused by oversized and overweight vehicles (OS/OW) and to provide recommendations for permit fee adjustments if required.

The methodology to quantify the pavement and bridge consumption rate per mile was developed as part of the project. Also, the new fee schedule was developed to account for the costs associated with OS/OW vehicles. Also, the revenue analysis was conducted to compare the revenue generated from permit sales and the revenue estimates from the new permit fee structure. It was concluded from the permit sales of financial year 2011 that the revenue collected was $111.4 million, compared to the estimated revenue of $671.4 million, resulting from the revenue estimates based on the new permit fee structure.

The bridge consumption portion of the report is discussed herein. The study proposes a bridge consumption cost per mile to support the revision of Oversize/ Overweight (OS/OW) fees. The following steps were used to calculate bridge consumption:

1. Overlay bridges on the permit routes traveled using Geo-reference software.
2. Characterize the routed and non-routed permit loads.
3. Summarize the bridge information such as span lengths to calculate bending moment.
4. Calculate the bending moment for each OS/OW vehicle.
5. Calculate the bridge consumption using the following formula:

$$Consumption_{OSOW} = \left[(Area)(190)(0.11) \left[\frac{M_{OSOW}}{M_{Inventory}} \right]^{m} \right] \div (2{,}000{,}000) \qquad \text{Eq. 1}$$

where:
$M_{inventory}$ – Live load bending moment for the Inventory Rating Load for each bridge in the permit dataset;
M_{OSOW} – Live load bending moment for the Oversize Overweight Load for each bridge in the permit dataset;
m – Constant: material dependent;
190 – Asset value for a bridge in dollars per bridge deck square foot;
0.11 – The bridge asset value responsibility for heavy trucks;
2,000,000 – Number of allowable load cycles that define bridge design life according to AASHTO.

6. Calculate cost per bridge on each segment.
7. Estimate cost-per-mile for each permit GVW weight category.

A broad study to assess the damaging effects of truck traffic in New Jersey was conducted in 2015 by [45], which was sponsored by the New Jersey Department of Transportation (NJDOT). A model was proposed based on a literature review of the effects of overweight vehicles from other states and deterioration models.

A software tool, ASSISTME-WIM, was developed to estimate the actual damage costs on New Jersey highways due to overweight trucks. The Life Cycle Cost (LCCA) was conducted, and it was estimated that the average cost of moving one ton of load by an overweight truck per mile in New Jersey is about $0.33, and 40% of the damage is attributed to bridges and 60% to pavement.

The evaluation of concrete decks under loading was part of the main objectives. In that study, a flowchart was developed in order to obtain a complete life cycle of a deck rating curve without the interruption of repair events or cycles. A regression analysis was performed for the filtered condition rating data on each highway, and the method of least squares was used to estimate the parameters. The deterioration curves for interstate highways are shown in Figure 2-6.

In the following study, [46] have shown that the average expected service life of bridge decks on interstate highways, U.S. numbered, and New Jersey State highways are 40.4, 48.0, and 64.6 years, respectively, assuming that service life ends when the deck rating downgrades to four. However, a high variation among different highways is observed within the same type of highway, which could be attributed to the variations of loading level and frequency. It was found that both axles per day and wheel load played roles in determining the service life of decks. The capacity of bridge decks was defined as the lifetime axle count, NA, which represents the total number of axles passing the bridge over the predicted service life span, as shown in Equation 2.

$$N_A = \sum_{i=0}^{y} APD_i \times 365 \qquad \text{Eq. 2}$$

The lifetime axle count was plotted versus the equivalent wheel load, as shown in Figures 2-7, and linear regressions were performed for three highway types using the method of least squares. With the obtained correlation, the service life of a concrete deck can be estimated based on a given wheel load and axles per day, as shown in Figures 2-8. This information is illustrated in Figures 2-8, which would be obtained based on bridge inventory, as well as WIM-based truck load data, and can be very useful in calibrating and validating prediction models for the service life of concrete decks. Table 2-2 presents a summary of relevant studies on the estimated cost of damage due to overweight traffic.

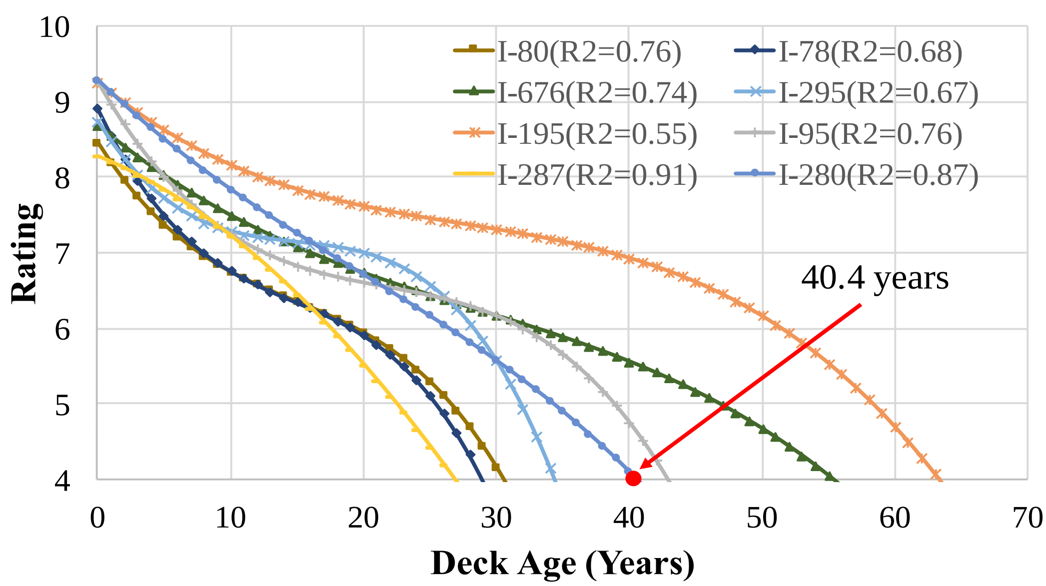


Figure 2-6. Deterioration curves for decks on interstate highways in New Jersey.

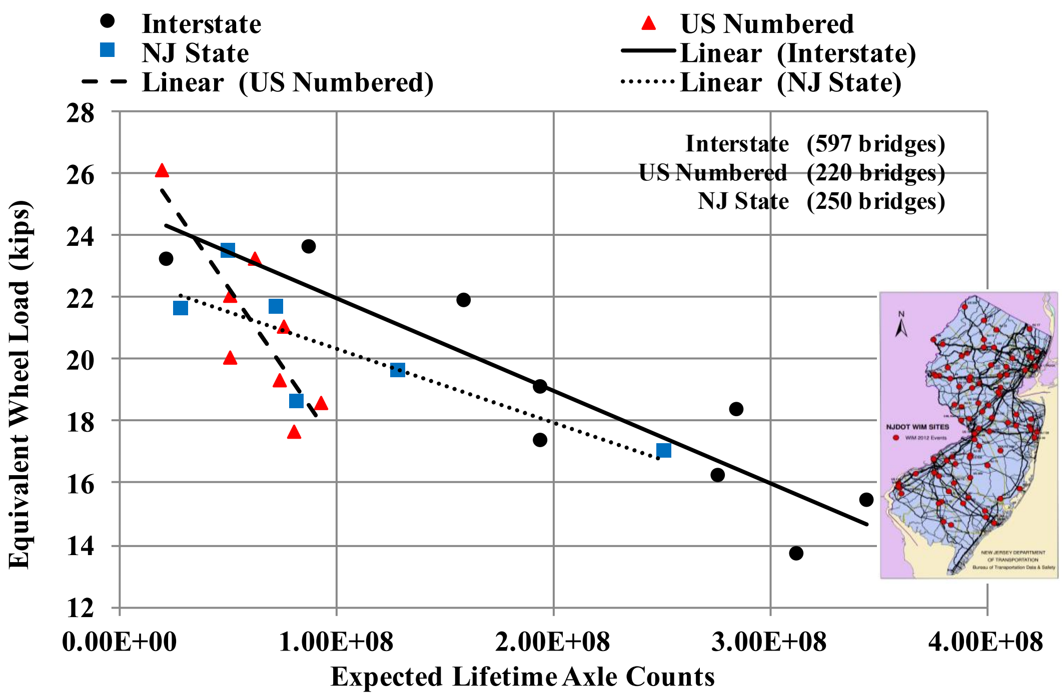


Figure 2-7. Correlation between wheel load and expected lifetime axle counts.

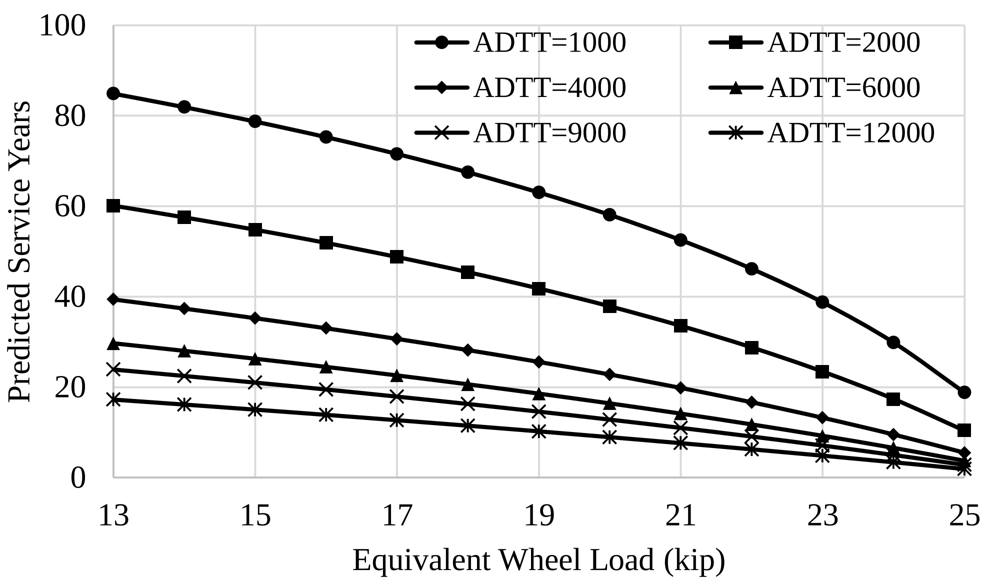


Figure 2-8. The predicted service life of deck under given wheel load and ADTT.

Table 2-2 Summary of relevant studies on the estimated cost of damage due to overweight traffic

Source	State	Transportation infrastructure	Mechanisms considered	Dataset – Load side	Dataset – resistance side	Dataset – Cost analysis
Oversize/Overweight Vehicle Permit Fee Study	Texas	Pavement	Rutting, fatigue cracking, and roughness	OS/OW issued permits		1. TxDOT's average low-bid price portal (unit cost of materials)
Oversize/Overweight Vehicle Permit Fee Study	Texas	Bridge	Fatigue and different fatigue curves depending upon the type of material	1.OS/OW issued permits 2. Non-routed permits	FHWA's National Bridge Inventory (NBI)	The current asset value of bridges - Texas 2030 Committee 2. Permit fees collected for FY 2011
Effects of Overweight Vehicles on NYSDOT Infrastructure	New York State	Bridge	Overstress of main members 2. Cyclic fatigue accumulation in main members and decks	WIM data	FHWA's National Bridge Inventory (NBI) "WINBOLTS" – database assembled by NYSDOT 3. Detailed bridge plans	RSMeans - "Heavy Construction Cost Data"
Effects of Overweight Vehicles on NYSDOT Infrastructure	New York State	Pavement	Incremental cost approach	WIM data	NYS pavement database	RSMeans - "Heavy Construction Cost Data"
Impact of Freight on Highway Infrastructure in New Jersey	New Jersey	Bridges	Fatigue in steel bridge girders, pre-stressed bridge girder tendons, and RC decks	WIM data	FHWA's National Bridge Inventory (NBI)	Unit cost of bridge construction from FHWA
Comprehensive Truck Size and Weight Limits Study	Washington D.C.	Bridges	Fatigue damage to bridges and bridge decks, girder overstress.	Different Legal Truck Weight Scenarios	FHWA's National Bridge Inventory (NBI)	One-time repair/replacement cost

2.3.1. Evaluation of Load Effects Due to Heavy Vehicle Operation

A variety of technical approaches and models were proposed, discussed and published by researchers and transportation agencies in order to evaluate the response of the infrastructure to the increase of the truck traffic volume (ADTT) and GVW [44]. The objective remains challenging and requires a commonly accepted methodology.

However, there are a few criteria to be considered in order to evaluate the impacts of overweight vehicles, including structural impact (overstress) and fatigue wear (accumulated damage) of the bridge girders or decks (Figure 2-9). The latter is not widely studied or reported in the literature due to the unavailability of a reliable durability model for concrete bridge decks [44].

The assessment of the actual impact of any changes in truck traffic is not a trivial task. In addition, inspection and maintenance reports have not been analyzed with regard to OW truck traffic. The National Bridge Maintenance Database (NBMD) [47] can be used once completed in order to keep track of bridge performance through inspection and maintenance during a bridge's service period. Development of the NBMD mainly includes the structure and format of how the information about bridge parameters, inventory condition, and inspection and repair history are collected from state transportation agencies. The database will contain the cost of construction and maintenance of the bridge structure and could be applied to the development cost analysis of the damage accumulation process.

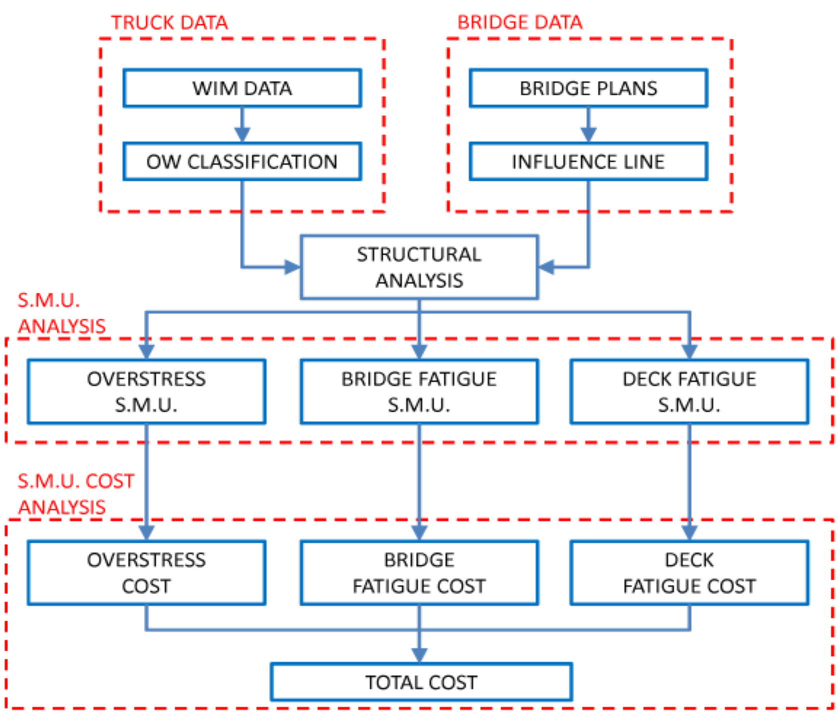


Figure 2-9 Bridge overweight effect quantification procedure flowchart [43]

In order to evaluate the cost effect of the girder overstress due to heavy truck operation, different load scenarios can be considered. The load effect caused by the oversize/overweight vehicles can be compared to the reference load scenario that corresponds to the federal weight limit or design load. The cost effect can be determined as a fraction of the one-time replacement or repair cost needed prior to the end of the design service life.

For the damage accumulation analysis of the fatigue-prone details [48] of girder bridges, a basic fatigue life analysis can be performed. The resultant fraction of time consumed by the truck traffic flow (based on the WIM records) can be then compared with the duration of the design fatigue life. However, this analysis will evaluate the impact of each truck in the fleet independently and ignore the accumulated damage due to the previous load cycles. A study by [44] proposes an alternative approach of comparing the load effects of individual trucks (incremental load effects) by considering different load scenarios.

The study by [44] also summarizes the main approaches to evaluate the effect and cost of bridge damage due to overweight traffic. The incremental damage cost analysis is based on the comparison of the fatigue damage caused by the considered OW truck and control vehicle. The simplified structural analysis of the idealized bridges (more applicable for the overstress criteria) can be based on load effect evaluation and the AASHTO [49] bridge rating procedure. The use of the “allocation” factor to evaluate the fraction of the bridge damage cost is associated with the responsibility of the bridge component. While different studies adopted different approaches to quantify the damage and damage costs to the transportation infrastructure, there is no commonly or nationally accepted method. The purpose of this review is to select the most common conservative technique to evaluate the relevance of the existing permit structure in Florida.

2.3.2. Fatigue Damage to the Bridge Deck

Although there are several studies that focus on the development of the reliable deterioration model for bridge decks, there is still no nationally acceptable procedure to evaluate the structural and cost effect of OW vehicles. AASHTO [50] defines the durability service limit state for bridge decks. While the strength limit states determine the required ultimate carrying capacity of the deck, the durability limit state regulates the required duration of its service life. The magnitude of the service load cycle corresponding to the axle weight of the design truck is below the ultimate carrying capacity of the deck [36].

A series of studies recommended by the National Academy of Sciences was performed by FHWA [44] to evaluate the effects of changes in the Federal Truck Size and Weight on bridge structures. Among a variety of existing techniques, the most straightforward approach was selected. It is based on the comparison of the load effects and structural behavior of the deck due to the different load scenarios. The cost analysis included possible posting issues. The rating procedure was based on the heaviest axle of the considered truck scenario.

2.3.3. Fatigue Damage to the Bridge Girders

The evaluation of the fatigue resistance of the steel girders, as well as the procedure to quantify the amount of accumulated damage, is widely studied. The fatigue analysis of the steel bridge can be reduced to the evaluation of fatigue-prone details, such as web stiffeners or cover plate ends. The fatigue limit states consider the loss of the carrying capacity due to the cyclic load-induced accumulated damage. In this case, fatigue crack formation occurs under the cyclic stress magnitudes lower than the ultimate capacity. Therefore, the magnitude, especially the frequency of the stress range, is critical in the fatigue analysis. The procedure of estimation of the fatigue service life is presented as the nominal-stress life approach in the AASHTO LRFD Bridge design specifications [48].

The performance of fatigue prone details can be represented with a commonly known S-N curve, as shown in Figure 2-10. The fatigue resistance of the bridge component can be expressed in terms of the magnitude of the constant amplitude stress range (S) and number of cycles (N).
The stress range and fatigue life relationship are:

$$N = AS^{-m} \qquad \text{Eq. 3}$$

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

The evaluation of the damage accumulated by bridges due to heavy vehicles is always associated with the fatigue analysis. One important question that must be addressed in the discussion of fatigue damage accumulation is: Do all traffic-induced stress cycles contribute to the accumulation of damage and potential formation of a fatigue crack? The current U.S. practice is that all stress cycles are considered, even if only a small percentage [51] of the traffic-induced stress ranges are above the constant amplitude fatigue limit.

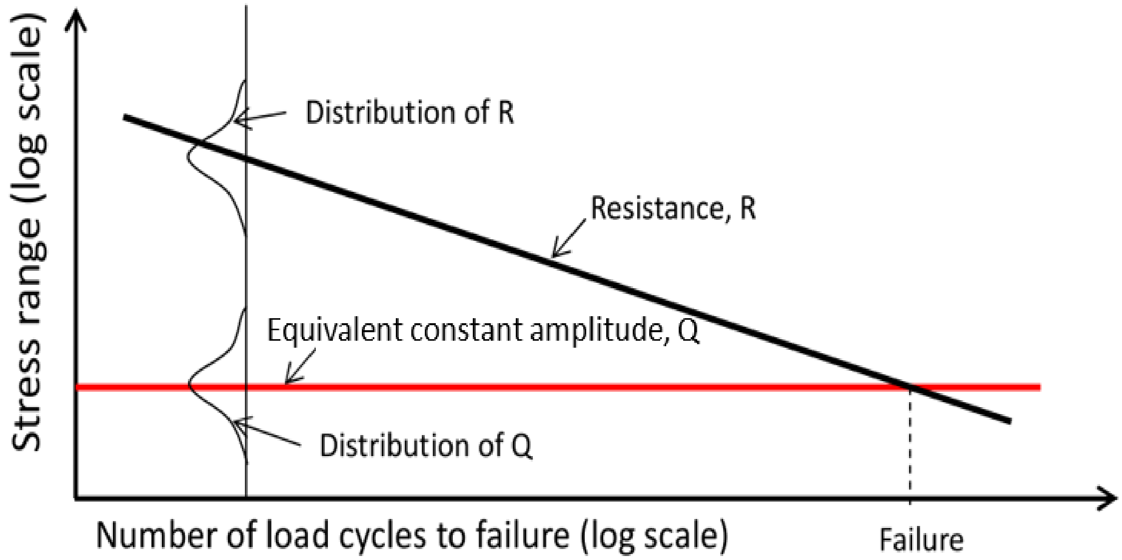


Figure 2-10 Fatigue failure on S-N curve [52]

Another question that should be asked is: What truck configuration should be selected as the representative for the current truck traffic and be used as a reference truck in the analysis? The first proposed fatigue truck dates back to 1978 [53] and was proposed based on FHWA's loadometer survey [51] in 1970. It was a 3-axle truck with a 14-ft. and 30-ft. axle spacing and a GVW of 50 kip distributed at 0.122, 0.444 and 0.444 of GVW for axles 1, 2 and 3, respectively. In the NCHRP 299 [54], which was based on 27,000 WIM measurements from 30 sites nationwide (California, Oregon, Michigan & New York), the GVW was modified to 54 kip without any modification to axle configurations. Hence, the current fatigue truck was developed in 1978, but it was validated in 2012 by WIM data from seven states (California, Florida, Idaho, New York, Michigan, Texas and Vermont) [55]. The truck traffic, excluding panel, pickup, and other 2-axle/4-wheel trucks, are considered for effective GVW. Truck traffic from Class 6-13 is considered for calculating effective truck weight.

With the constant increase of truck traffic size and weight, it is reasonable to project the future increase of the federal limit for OW vehicles. A number of studies were focused on the evaluation of the possible consequences of the weight limit change [35], [36], [44], [56]–[60]. The impact of truck traffic weight increase can be evaluated as a fraction of the effective stress magnitude due to controlled and proposed truck configurations [44]. This approach is based on the cumulative damage theory used to calculate the magnitude of the effective stress range. Based on the Palmgren-Miner [61] rule, the fatigue life depends on the magnitude of the stress ranges to a certain power (Table 2-3). This makes the fatigue damage very sensitive to even very small changes in the magnitude of a stress range. The baseline fatigue damage [44] due to the reference truck can be presented as:

$$BL_{ref} = \frac{1}{\Delta S_{eff}^{m}} \qquad \text{Eq. 4}$$

where: ΔS_{eff}^{m}- calculated the effective stress range for the control vehicle;

The same fraction of damage can be determined for an alternative/proposed load scenario:

$$BL_{alt} = \frac{1}{\Delta S_{eff}^{m}} \qquad \text{Eq. 5}$$

where: ΔS_{alt}^{m}- calculated effective stress range for an alternative load scenario;

The comparison of these fractions will result in the percentile of fatigue life change due to the change of the weight limit:

$$Change = \left(\frac{BL_{alt}}{BL_{ref}}\right) - 1 \qquad \text{Eq. 6}$$

The general procedure of the fatigue life evaluation [48] includes the following steps:

1. Selection of the fatigue critical details of the considered bridge.
2. Determination of the magnitude of the effective stress range of the selected fatigue-prone detail due to the live load spectra.
3. Infinite fatigue life check: Is the calculated stress range below the threshold for the selected detail?
4. In the case of finite fatigue life, the formula for Fatigue II limit state will be rearranged and applied.
5. Comparison of the computed duration of the fatigue life with the alternative load scenario.

2.3.4. Overstress of Bridge Superstructure Components

The overstress criteria are often used to evaluate the impact of OW vehicles on the key components of bridges regardless of the bridge type or material of the superstructure [36], [43], [44]. The level of overstress can be determined through the comparison of the load effect (bending moment and shear force) due to the considered load spectra with the reference load scenario. The reference load scenario can be represented by the design truck (HS-20) or AASHTO rating truck, the vehicle representing federal weight limit. [43] proposed the direct comparison of the load effects determined based on the WIM data with the HS-20 truck as a moment ratio. Therefore, the vehicles producing the moment ratio above 1.0 were considered damaging trucks. The HS-20 was picked up as a design truck load for most of the bridges in New York State. The damaging vehicles were further divided by the following categories: legal trucks (LG), divisible vehicles (DV), special hauling vehicles (SH) and likely illegal (IL). The highest percentage of vehicles producing overstress were the DV and SH vehicles, while the highest impact in ($), the cost allocation model, is produced by IL vehicles.

An alternative method used to evaluate the overstress of the bridge girders is the use of the evaluation procedure [44], [49]. The corresponding cost effect was evaluated through a one-time bridge improvement cost, taking the rating factor (RF) equal to 1.0 as a baseline criterion. Each of the six load cases were considered and the cost effect was evaluated. The exceedance of the baseline rating factor indicated the need for the load carrying capacity of the superstructure (the most economical option).

2.3.5 Estimation of Cost of Bridge Damage Due to Impact of Heavy Trucks

The methodology adopted by [62] focused on 22 bridges along the I-88 corridor in New York and then estimated a whole bridge network in New York.

The procedure was divided into three phases:

1. Estimate the percentage of Legal and Overloaded vehicles.
2. The maximum moment response of each bridge is found by running each overloaded truck through the influence line. The following two types of bridge response effects are considered:
   - Overstress of main bridge members.
   - Cyclic fatigue accumulation for main members and decks.
3. Using the truck response to estimate the cost effect caused by each truck.

The general overview of the procedure is shown in Figure 2-9. The procedures were developed by using a concept of safety margin utilization (S.M.U.). In the first phase, two primary databases, traffic data and bridge data, were used. The traffic database is from WIM-collected records. The traffic data is sorted to extract only overloaded vehicles that cause damage to bridge superstructures. The bridge data is from sources such as the National Bridge Inventory (NBI) and “WINBOLTS,” which is a bridge database created by the NYSDOT. It is used to obtain information about bridge influence line information. Information about span lengths, or the number of spans to obtain influence lines for bridge critical sections, was collected in the second phase.

In the third phase, the overstress effects and fatigue effects were calculated for the longitudinal members of the structure and compared with the HS-20 loading. In the calculation of overstressing effects, the response created by the WIM truck is normalized with the HS-20 load. The HS-20 load was considered since many bridges in

New York were designed for HS-20. The number of overloaded vehicles in terms of HS categories are categorized.

2.3.6 Girder Fatigue Damage

For the fatigue damage model [43], the procedure used in the LRFD fatigue analysis is used [48]. The reduction of life of the bridge by truck "" is calculated using:

$$L_i = AFB \times L_n \qquad \text{Eq. 7}$$

Where:

L_n = life reduced by design truck

α = parameter is shown in Table 2-3

AFB – Amplification of girder fatigue damage which can be determined, as shown below:

$$AFB = \frac{D_i}{D_n} = \frac{(\Delta F_i^{\propto} n_i)}{(\Delta F_n^{\propto} n)} \qquad \text{Eq. 8}$$

The cost of bridge damage in dollars ($) can be determined using Eq. 9:

$$CT_{FB} = \frac{Cost_{HS-J}}{ADTT\ 365\ DL} AFB \qquad \text{Eq. 9}$$

where:
CT_{FB} – Cost of fatigue damage per crossing ($)
HS-J – Design envelope of level below the effect of truck "i" (HS-20 to HS-60)
$Cost_{HS-J}$ – Cost of the bridge ($)
AFB – Amplification of damage (Eq. 8)
ADTT – Average daily truck traffic
DL – Design life in years assumed 75 [48]

Table 2-3 α for different bridge components

Bridge Type	Alpha parameter (α)
Concrete Slab	4.1
Concrete T Beam	4.1
Concrete Box Beam	4.1
Concrete Continuous Slab	4.1
Concrete Continuous T Beam	4.1
Steel Girder	3.0
Steel Continuous Girders	3.0
Prestressed Concrete	3.5
Prestressed Concrete Box Beam	3.5
Concrete bridge decks	17.95

2.3.7 Deck Fatigue Damage

The proposed fatigue analysis for a bridge deck is similar to the one adopted for the bridge girders. It was also followed by the model proposed by Perdikaris [63]. In the fatigue design truck, instead of the 24 kip second and third axles, it is split into two 12 kip tandem axles. The reduction of life of a bridge deck by truck, i is calculated using Equation 10. The amplification factor in the case of a deck analysis is based on the effect of the WIM truck axle load versus the proposed design fatigue truck (Figure 2-11).

$$AFD = \frac{D_i}{D_n} = \left(\frac{\sum_{axles}(P_j)_i^{17.95}}{\sum_5 (P_j)_n^{17.95}}\right) \qquad \text{Eq. 10}$$

Where:
AFD – Amplification factor of deck fatigue damage due to a crossing of truck *i*
P_i – Weight of axle *j* of the truck (Figure 2-11)
The cost of bridge damage in dollars ($) for a single truck crossing can be determined using Eq.11:

$$CT_{FD} = \frac{Cost_{Deck}}{ADTT\ 365\ DL} AFD \qquad \text{Eq. 11}$$

Where:
CT_{FD} – Cost per crossing per truck for deck fatigue ($)
HS-J – Design envelope of the level below the effect truck "i" (HS-20 to HS-60)
$Cost_{Deck}$ – Cost of the deck ($)
ADF – Amplification of damage from the analysis according to Eq. 10
ADTT – Average daily truck traffic
DL – Deck design life in year assumed equal to 40 years.

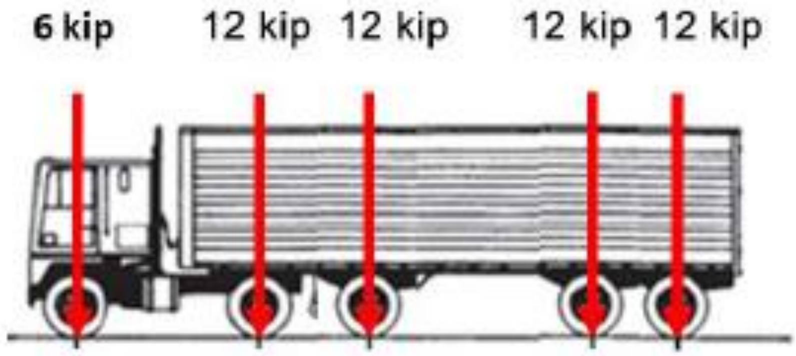


Figure 2-11 Proposed fatigue truck to evaluate deck durability.

The fourth and final phase was the "Safety Margin Utilization" (SMU) cost analysis. The concrete deck cost model was obtained from the RSMeans database. Moreover, the superstructure model for different types of superstructures such as concrete slab, pre-stressed girder bridge, and steel bridge were considered.

2.3.8 Overstress Safety Margin Utilization

FHWA cost allocation method was proposed to evaluate the effect of the truck traffic stream that exceeds the load effect due to the design truck. The cost ($) of the bridge design for truck *J* is:

$$CT_{HS-I} = \frac{Cost_{HS-J} - Cost_{HS-20}}{DL\ NT_{HS-I}} \quad \text{Eq. 12}$$

Where:

HS-I – HS design class from 20 to 55,

HS-J – The next design class above I from 25 through 60,

CT_{HS-I} – Cost per crossing per truck that exceeds the design class I ($),

$Cost_{HS-20}$ – Cost of the bridge for the design truck HS-20 ($),

NT_{HS-J} – Number of vehicles that exceed the effect of the design load HS-I per year,

DL – Deck design life in years is assumed to be equal to 40 years.

2.4. Studies on Overload Effects on Pavement

2.4.1. Equivalent Single Axle Approach

This method was a result of the AASHTO Road Test conducted from 1958-1960 in Illinois. This method considers an equivalent single axle load equation that was derived to convert axles of various configurations and load magnitudes into an equivalent number of passes of a standard axle, which is an 18,000lb. single axle with dual tires. Load equivalency factors are obtained based on the loss of present serviceability index (PSI) and do not directly address the individual distresses such as fatigue cracking and rutting. The equation for Flexible pavement is:

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \qquad \text{Eq. 13}$$

And for Rigid pavement is:

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1 + \frac{1.624 \times 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32\,p_t) \times \log_{10}\left[\frac{(S_c')(C_d)(D^{0.75}) - 1.132}{215.63(J)\left(D^{0.75} - \frac{18.42}{\left(E_c/k\right)^{0.25}}\right)}\right] \qquad \text{Eq. 14}$$

where:

W18 – predicted number of ESALs over the pavement's life,

SN – structural number, abstract number expressing structural strength requirement,

ΔPSI – change in serviceability index over the useful pavement life, typically from 1.5 to 3.0,

M_R – subgrade resilient modulus, typically from 3,000 to 30,000 psi (10,000 psi is pretty good),

D – slab depth,

S'c– PCC modulus of rupture, a measure of PCC flexural strength, usually between 600 and 850 psi,

Cd – drainage coefficient, relative loss of strength due to drainage characteristics and the total time it is exposed to near-saturated conditions, usually designated as 1.0,

J – load transfer coefficient, accounts for load transfer efficiency, lower J-factors = better load transfer, between 3.8 (undoweled JPCP) and 2.3 (CRCP with tied shoulders),

E_c – PCC elastic modulus, 4,000,000 psi is a good estimate,

K – modulus of subgrade reaction, estimates the support of the PCC slab by the underlying layers, usually between 50 and 1000 psi/inch,

ZR – the probability that serviceability will be maintained at adequate levels from a user's point of view throughout the design life of the facility. Accounts for the inherent uncertainty in design,
S_0 – standard deviation in traffic, variability in materials and construction practices.

This method is also called the “fourth-power law.” For example, a single axle loaded to 60,000 pounds is three times more than the interstate legal limit, and causes 81 times more damage compared to a single axle loaded to 20,000 pounds [10]. This approach is used by many researchers. Meyburg calculated ESALs/truck and then multiplied by the miles driven and a cost coefficient ($/mile) to get an infrastructure cost. They tested ESALs from both per vehicle and per axle basis and concluded that per axle better represents the actual pavement damage [64].

In another study conducted by Barros et al. [65], the ESAL method is used to quantify the damage effects of overloaded vehicles and developed a model based on violation data. First, he assumed that a limited number of trucks are carrying a larger amount of freight. Barros estimated 38146 ESALs of pavement damage per year based on 9,060 overweight violations per year, which corresponds to a 7.63% loss in pavement life caused by overload and considering 500,000 ESALs per year. In the second analysis, he increased the number of trucks for the given weight of cargo to remove any overweight trucks. He observed that the increase in the volume of traffic resulted in a 6.17% loss in pavement life, which is slightly less than the first assumption. Thus, he concluded that given a total weight of cargo, using a heavy load truck or more load trucks but a lesser load could result in almost the same reduction in pavement life [65].

2.4.2. Mechanistic-Empirical Approach

This approach uses mechanistic pavement models to model pavement responses under applied loads, and the responses are correlated to pavement performance.

Chen et. al used the same method and took into account the repeated load rather than the damage due to a single pass. The finding shows that even for super heavy trucks, the induced strain is not necessarily the critical strain. Thus, it is important to consider the repetition of the load through the Asphalt Institute’s fatigue and rutting transfer function [66].

$$N_f = 0.0796\left(\frac{1}{\varepsilon_i}\right)^{3.291}\left(\frac{1}{E_{ac}}\right)^{0.854} \quad \text{Eq. 15}$$

$$N_c = 1.365 \times 10^{-9}\left(\frac{1}{\varepsilon_c}\right)^{4.477} \quad \text{Eq. 16}$$

where:
N_f – allowable number of load repetitions to control fatigue cracking,
N_c – allowable number of load repetitions to control rutting,

ε_t– tensile strain at the bottom of the asphalt layer,
Eac – asphalt modulus, psi,
ε_c– vertical compressive strain on top of the subgrade.

If the load configuration, load magnitude and final serviceability are known, this equation can be used to find the relative damage in effect of any axle type and convert it to the standard 18,000-lb equivalent.

According to Chen's observations, the rutting is the predominant distress for super heavy traffic loads.

Jooste and Fernando provide a method to assess pavement damage on super heavy routes [67]:

1. Estimate pavement layer thicknesses along the route using ground penetration radar (GPR).
2. Use non-destructive testing along with a falling weight deflectometer (FWD) to assess the structure of the pavement.
3. Use an automated road analyzer to measure pavement roughness.
4. Use Texas Triaxial Class data to evaluate potential subgrade pavement failure under super heavy loads.

Finally, in order to determine the spots that are vulnerable to failure, the Mohr-Coulomb stress analysis, Texas Triaxial data and computed stress will be used.

Sadeghi et al. conducted research to evaluate the deterioration pattern of flexible pavement under overloaded traffic. They tried to develop a practical method to calculate fines for overweight vehicles. First, they developed a theoretical method to make a sensitivity analysis to determine the most influential parameter in the deterioration of the pavement. The parameters in the study were layer thickness, pavement temperature, subgrade conditions, and vehicle speed. Then, these parameters where formulated based on their effects on the pavement at different loading conditions. Rutting and fatigue damage were two main distresses that were considered in the modeling. The procedure included the following steps [13]:

1. Modeling the pavement (model geometry and mechanical feature, loading pattern, failure criteria, and analysis method).
2. Recognizing the effective parameters on pavement damage.
3. Mathematical modeling of the load-operational life.
4. Modeling the deterioration under two, three, and five-axle trucks.
5. Determining the ticketing amount based on the life reduction factors and total cost of pavement.

To use their model in practice at road checkpoints, the following information should be known:

- the amount of overweight load,
- the length of the vehicle's trip,
- average cost of pavement per meter,
- thickness and temperature of the pavement,
- California bearing ratio (CBR) of subgrade, and
- vehicle speed and type.

Sadeghi et al. suggested developing a software that can perform the calculation and link it to a digital truck scale to obtain the appropriate amount of fines for each overload.

Two researchers worked on the fatigue cracking performance of the asphalt mixture 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. Then, a 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 [68]. Salma conducted a similar laboratory test evaluating the rutting of asphalt mix and concluded that the rutting damage is proportional to axle configuration and vehicle weight [4].

The Ohio Department of Transportation [105] studied the effects of Michigan heavy vehicles on pavement performance by observing trucks traveling from Michigan to northern Ohio. The following equation was obtained by the use of traffic, rutting, cracking, roughness and deflection data, and regression analysis: :

$$RUTF = 0.035 + 0.984(C13) + 0.03(B + C) + 0.0007(months) \qquad \text{Eq. 17}$$

where:
RUTF is the rutting in flexible pavement (inch),
C13 is the number of FHWA class 13 vehicles in the lane per day in thousands,
B= Total number of trucks in FHWA classes 8-12 in thousands,
C= total number of trucks in FHWA classes 4-7 in thousands; and the month is the number of months of testing.

However, the study did not compare the damage caused by different axle loads and configurations, and a limited number of four roads were studied. In another research study at Michigan State, the effect of various axle and truck configurations on major pavement distresses were investigated. Pavement surface damage data that was used for the study was obtained from the Michigan Department of Transportation (MDOT) database. This study used the distress index (DI) to measure cracking, and the ride quality index (RQI) to measure rutting and roughness. The results showed that in terms of cracking, trucks with single and tandem axles appear 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. However, the roughness of the pavement did not show a strong correlation with the type of axle configuration [4].

In a research study conducted by Jorge C. Pais, the impact of overloaded vehicles is evaluated by calculating the truck factors for each vehicle category using three different models [69]: the traditional four power model, the model developed by Pais and Pereira and the French model. Although the models produced different results, the trend was almost identical. They also used the Shell fatigue equation [70] to calculate the pavement thickness based on the traffic level. The results showed that pavement thickness required 10 cm for some vehicles, and the proportional cost can be as much as 30%.

Dawid et al. used data obtained from WIM stations on seven state roads to find a correlation between the fatigue damage of pavement and the number of overloaded trucks. Their analysis showed that an increase in the percentage of overloaded vehicles from 0% to 20% can reduce the fatigue life of asphalt pavement by about 50%. Also, their research results indicate that a 10% decrease of overloaded trucks may increase the service life of the pavement from 4 to 6 years [71].

J.C. Pas et al. conducted an investigation to evaluate the effects of overloaded trucks with different types of axle configurations on five different asphalt layers of thickness and five different subgrade stiffness modules. The study showed that the effects of vehicle loads decreases by increasing the asphalt layer thickness. Also, the subgrade showed the least effect on pavement fatigue distress. The implication of their study was that if the maximum legal weights are taken into account for pavement design, the adverse effects of overloaded trucks on pavement will be reduced. However, considering the overweight loads for design purposes can increase the costs by more than 100% compared to the design based on the weight of legally loaded trucks.

In a research study conducted by Muhammad Raheel et al., the effects of axle configuration on pavement were measured [72]. They used data collected from a WIM station in a period of three months to quantify axle loads. The methodology used in their study is summarized in Figure 2-12.

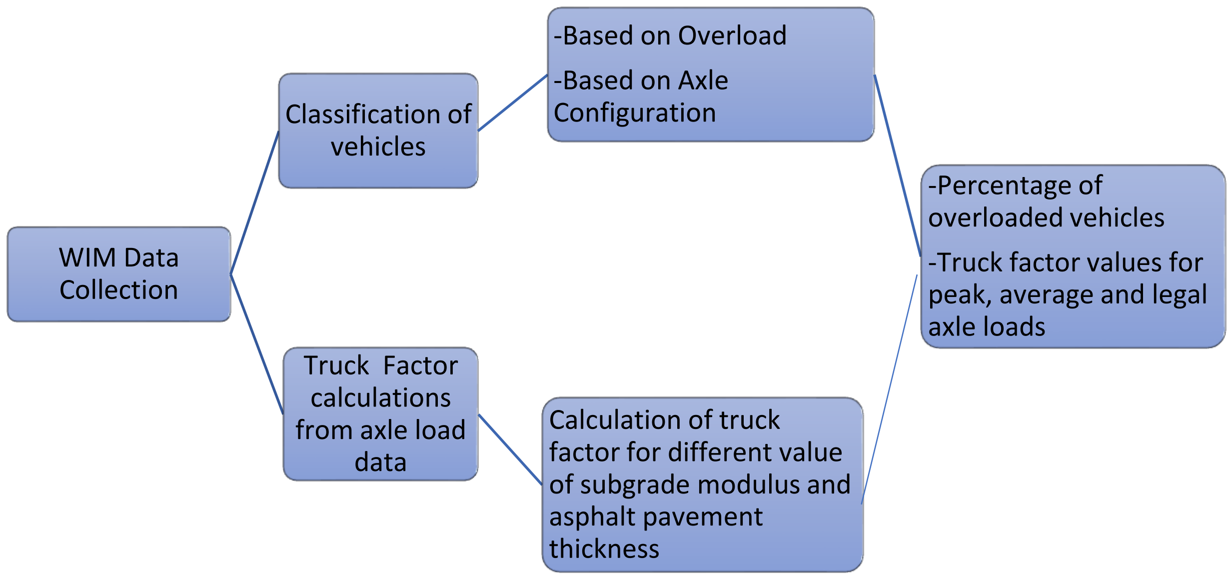


Figure 2-12 The methodology used to find truck factors and overloaded vehicles [72].

The following equation was used to convert the traffic stream into ESAL:

$$ESAL = k\left(\frac{P_x}{P_{80}}\right)^{\alpha} \qquad \text{Eq. 18}$$

where:

k – the coefficient represents the type of axle (truck factor)

α – represents the mode of distress

The truck factor for each vehicle is calculated using the equation provided by Pais et al. [69]. As stated by Pais et al., *k* includes the effects of asphalt layer thickness, modulus of subgrade and axle configuration and axle load (Eq. 19).

$$k = 254.03 * (E_{sub})^{0.033393} * (h)^{-1.0416} * (e)^{-1.2928*AP} \qquad \text{Eq. 19}$$

where:
$\boldsymbol{E_{sub}}$ – subgrade modulus (Mpa),
h – the thickness of asphalt layer (cm),
AP – axle parameter.

Muhammad et al. found that for a 2-axle vehicle, the impact is 3.33 times the 3-axle vehicles and 5.45 times the 6-axle semi-trailers [72]. They also found that by a twofold increase in the thickness of the asphalt layer, the truck factor decreases by 47%.

2.4.3. Estimation of Cost of Pavement Damage Due to Impact of Heavy Trucks

There are several factors that affect the economic incentive to load trucks that carry a heavier weight than the legal limit. In a study conducted by Jessup, the following factors were considered as incentives to use overload the truck [73]: type of responses to citations, decrease in the number of fines for contested cases, the amount of fines collected by the state, and allocation of fines collected by the state. In a study on Washington's fine system, the trucker's incentive to overload is modeled to find the relationship between the economic incentive to load trucks and the effectiveness of the judicial system. 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 fee or fines for overloading 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 will decrease the incentive to overload.

According to the 1990 Truck Limit Report, increasing truck weights significantly reduces the cost of freight shipment. However, it should be taken into account that the deterioration of infrastructure is significant enough to consider a funding mechanism to provide enough funding for maintenance and rehabilitation.

In a study by Meyburg et al. [64], the costs and benefits of increasing the GVW are estimated. In this study, the GVW was increased to 125%, 135% and 145% of the legal limit. Then, the fourth-power rule was used to estimate the ESALs for each load level and were assigned to the cost rates of the interstate, state and local highways.

The potential benefit was calculated by assuming that freight makes fewer but heavier trips to deliver the same total weight. It could be understood from Meyburg et al.'s analysis that by decreasing the number of trucks (heavier loads), trucking companies benefit more from lower labor costs and fewer trips.

In another study, Barros performed an economic analysis by applying the classic life cycle cost to determine the effects of overweight trucks [65]. There are two scenarios in this research. In one scenario, the cost of maintenance and rehabilitation is calculated while considering overweight trucks, and in another scenario, without the effects of overweight trucks. Barros indicated the following factors to be considered in his analysis:

1- Inflation rates to consider future costs of construction.
2- The average trip length of each overloaded truck.
3- Traffic control, enforcement costs, and engineering costs are examples of other related expenses.

Barros used the following equation to calculate the net present value for a number of conditions in New Jersey.

$$NPV = I.C. + \sum_{k=1}^{N} R.C. \left[\frac{1}{(1+i)^{n_k}}\right] \qquad \text{Eq. 20}$$

where:
NPV– Net present value,
I.C. – initial construction cost,
R.C. – recurring rehabilitation/maintenance costs,
K – rehabilitation/maintenance activity,
I – interest rate,
N – year in which rehabilitation/maintenance occurs.

In terms of all aforementioned assumptions and based on the economic condition in 1983, Barros estimated increased pavement costs ranging from $7 million to $43 million per year.

In a study conducted by the Transportation Association of Canada (TAC), the effects of reducing the number of overweight trucks on the highways were studied. 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 (HWD) data. Results showed that considering 30,000 trucks per day, of which 15% were assumed to be overloaded trucks, results in an overall road damage cost of $621 per kilometer per day and an overall cost of 226,677 per km per year [74].

Agency and user costs are two major expenses that should be considered by conducting a life-cycle cost analysis (LCCA). Agency expenses include all of the costs related to owning the organization over the life of the project segment, which are mainly initial construction and maintenance costs. On the other hand, user costs are vehicle operation, accidents and environmental. In a research study conducted by Hao et al., only agency costs were considered in the calculation of LCCA for the purpose of permit fee determination. The NPV of agency costs is calculated using the discounted monetary value of future costs and uses the discounted monetary value of future costs by transforming costs at the different time periods, which are then restored at the end of the analysis period to a similar unit of measurement (Eq. 21).

$$NPV = C + \sum_{i=1}^{k} Mi(\frac{1}{1+r})^{ni} - S.(\frac{1}{1+r})^{N}$$ Eq. 21

$$S = \left(1 - \frac{La}{Le}\right).Cs$$ Eq. 22

where:
C – Present cost of initial rehabilitation activity,
r – Discount rate,
Mi – Cost of the i-th maintenance and rehabilitation activity in terms of constant dollars,
ni – number of years from the present to the i-th maintenance and rehabilitation activity,
S – Residual value at the end of the analysis period,
La – Difference between the year of the last maintenance activity and the year of end of life cycle analysis,
Le – Expected life of the maintenance activity,
Cs – Cost of the maintenance activity having salvage value,
N – Length of the analysis period in years.

$$\mathrm{EUAC} = \mathrm{NPV}.\left(\frac{r.(1+r)^{N}}{(1+r)^{N}-1}\right)$$ Eq. 23

where:
EUAC - equivalent uniform annual costs,
r – discount rate,
N – is analysis period.

Two most important factors in the LCCA estimation are analysis period and discount rate. The analysis period should be long enough to include pavement rehabilitation treatments. The analysis period of 40 years for new construction and 30 years for rehabilitation of pavement is suggested by the NCHRP Guide for Pavement-Type Selection. The discount rate usually from 3% to 5%. The long-term discount rate values could be found in the updated edition of the Office of Management and Budget (OMB) Circular A-94. Rehabilitation and reconstruction were also considered in the analysis. In this research, it was assumed that the service life of reconstruction and each overlay is equal to half of the service life of the initial construction. Maintenance costs were calculated using the cost formula proposed by the NJDOT (Eq. 24 and 25).

Mill+overlay: $3.98.M+7.0.T_{ac}$ Eq. 24

Full reconstruction: $65.71+7.0T_{ac}$ Eq. 25

where:.
M – thickness of milling in inches
T_{ac} – thickness of asphalt concrete overlay in inches [75].

2.5. Interim Conclusions

- The analysis that focused on the bridge and pavement damage assessment has been noteworthy during recent decades and widely sponsored by the FHWA and state DOTs.
- The most common criteria used to evaluate the impact of overweight vehicles on bridges are structural impact (overstress) and fatigue wear of the bridge girders or decks.
- The Incremental/Federal Method described in the NCHRP Report 495 (Fu et al., 2003) was recognized [44] as the most conservative for cost assessment of the fatigue-induced bridge damage.
- Multiple studies reported that the overstress criterion was predominant over the deck and girder fatigue criteria for the cost estimation of the bridge damage due to heavy traffic operation.
- Two common ways to evaluate pavement damage are with the utilization of axle equivalency factors (based on the 1993 Pavement Design Guide) and the Mechanistic-Empirical method using fatigue and rutting life.

3. The Practice of Overweight Truck Data Collection

Generally, trucks may be oversized, overweight, or both oversized and overweight. The oversized load may be overlength, overwidth, overheight, or any combination of the three. Legal limits for trucks are established to provide safety for the infrastructure and gather finances to maintain a good condition of the infrastructure. In this chapter, types of trucks, loads and federal and state limits are discussed [77].

The definition of "Heavy Vehicle" in the context of this project is a vehicle exceeding the size and weight regulation (TS&W) in the State of Florida. "Superload Vehicle" is defined as a vehicle exceeding 199 kip of GVW, and each superload vehicle is analyzed individually.

3.1. Vehicles Categories

Traffic flow is a composition of vehicles that can be divided into groups depending on axle loads and axle spacing. The vehicles can be considered as legal, permit, or illegal. Overloaded vehicles can belong to the permit group if the owners applied for and received a legal permit from the Maintenance Bureau. Otherwise, the vehicles are illegally overloaded, in violation of the law and subject to a penalty.

Legal loads contain vehicles that do not exceed weight and size limits. Federal law prevents state law from imposing vehicle weight limits on interstate highways that deviate from established federal weight limits and specific exceptions. This means that states are subject either to the standard federal weight limits for interstate highways or to state-specific grandfathered limits or exceptions.

Grandfather provisions define the size and weight allowances that exceed federal standards on state highways in the United States. These provisions are exempt from previously existing rules. Grandfather provisions have exceptions to the limits of axle weights and gross vehicle weight. The first grandfather provisions were established in 1956 and in the 1975 bridge formula, and axle spacing tables were also introduced. These provisions are particular for each state [79].

Permit vehicles are legally operating vehicles that are oversized, overweight, or both. Permit vehicles need to follow the limitations of gross weight, single axle, tandem axle, and tridem axle loads. Nationally, every state must follow federal rules, but each state also has its own policy of issuing permits. There are permits that are issued by states that allow vehicles of specific configurations and sizes to exceed the size and weight limitations. Permits can be issued as single trip permits or multiple trip permits. The permit establishes time limitations, designated routes, number of trips, or other limitations. The movement of permitted oversized or overweight vehicles must also comply with the requirements and safety considerations specified in the agency's Administrative Permit Manual.

According to AASHTO LRFD [80], the normal vehicular live load for bridges (Strength I Limit State) includes all legal trucks, "grandfathered" exceptions and vehicles permitted by routine permits. Illegally overloaded vehicles without permits belong to an unanalyzed portion of the bridge live load that is more likely to create an extreme lifetime stress condition. Vehicle categories are presented in Figure 3-1.

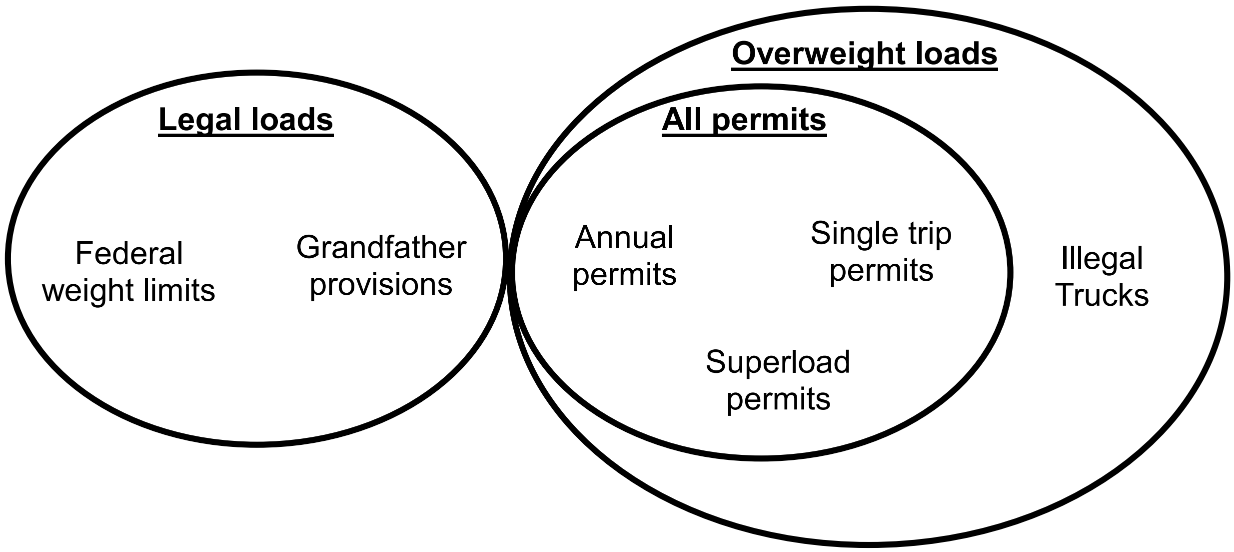


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Figure 3-1 Vehicle categories

3.2. Types of Loads

Loads can be categorized as divisible, non-divisible and superload. Divisible loads are the vast majority of loads on the road (Figure 3-2). These are any load that takes less than eight hours to disassemble. Permitting a divisible load varies under each state law. Divisible load permits may be issued by the state based on historic state "grandfather" rights or Congressional authorization for a state-specific commodity or route movement at a greater size or weight [81], [82].

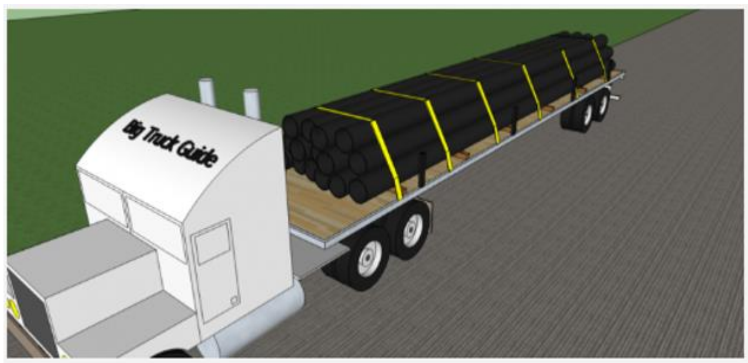


Figure 3-2 Divisible vehicle (Jakubicek 2019)

Another load category is an indivisible load, which is very different in terms of the type of weight regulations. Generally, indivisible loads are loads that cannot easily be broken apart (Figure 3-3). Common loads that cannot be broken down are construction equipment and specialized loads. “Indivisible” is defined as any load or vehicle exceeding applicable length or weight limit, and is not easily disassembled and separated into smaller loads or vehicles. It requires more than eight working hours to dismantle using appropriate equipment. The applicant for an indivisible load permit has to prove the number of work hours required to dismantle the load. The regulations controlling these loads are written in state laws. Permits can be issued regardless of the axle, gross weight, or FBF formula requirements for indivisible vehicles or loads [81].

Figure 3-3 Indivisible vehicle (Jakubicek 2019)

“Superload” is defined differently by each state, and can be based only on the dimension, weight, or a combination of both. Many states consider the superload threshold, but there is no single definition. Logistical consideration of moving a superload may cause more extensive issues, including a thorough review of the vehicle, and sometimes require a state escort due to the oversize, which might be hazardous to other traffic. In Florida, the superload threshold of gross vehicle weight is 199 kip, and this is also established for superloads, of which no tire load may exceed 550 lbs. per inch of the tire section width. This type of permit is very rare and constitutes about 1-3% of overall permits [83]. A summary of the types of loads is shown in Figure 3-4.

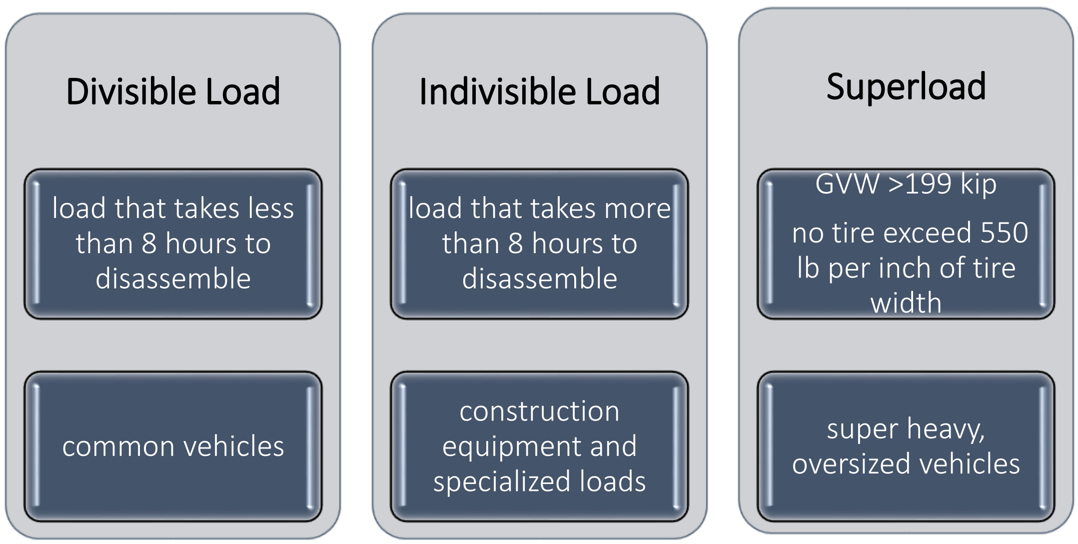


Figure 3-4 Types of loads (Jakubicek 2019)

3.3. Federal Permit Regulation for Overweight Vehicles

Laws established in 1956, 1974, 1982, and 1991 are the basis for today’s federal requirement to regulate commercial vehicle size and weight in the Interstate System and the National Highway System in the United States. The current federal vehicle size and weight balance between ensuring the preservation of the bridge road and infrastructure on the highway network, and also safety, and vehicle productivity (Federal Highway Administration and U.S. Department of Transportation 2015). The Federal-Aid Highway Act of 1975 limits the weight of single axles, tandem axles, and gross vehicle weight on the Interstate Highway System. Federal limitations of weights and axle spacing are shown in Figure 3-5.

Single Axle	• 20,000 lb
Tandem Axle	• 40,000 lb
Tridem Axle	• Per FBF
Gross Vehicle Weight	• 80,000 lb

Figure 3-5 Federal requirement for vehicles.

In the United States, vehicles are allowed to operate without a permit and are considered legal as long as they satisfy the weight recommendations of the Federal Bridge Formula Weights (Eq. 26) [84]. The primary purpose of the formula is to reduce the risk of damage to highway bridges by adequately distributing the load by limiting the axle configuration and axle load distribution.

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right] \qquad \text{Eq. 26}$$

where:
W – the overall gross weight of any group of two or more consecutive axles to the nearest 500 pounds [lbs],
L – The distance between the outer axles of any group of two or more consecutive axles [ft],
N – The number of axles in the group under consideration.

The Federal Bridge Formula sets a limit on the gross weight that maybe carried on a group of two or more consecutive axles. The exception for two consecutive tandem axles is that they may carry a gross load of 34,000 pounds each if the overall distance between the first and last axles is 36 feet or more.

For state and local highway systems, each state has its own set of weight guidelines. Many vehicles that do not obey the Federal Bridge Formula B, but do obey a state's legal weight guidelines, are commonly referred to as vehicles with "grandfather rights" [85]. Weight limits that are in use now, along with Formula B and state-specific "grandfather" exceptions, were established in the mid-1970s [79].

3.4. State Permit Regulation for Overweight Vehicles

Permit regulations and monitoring procedures were developed to provide safety to transportation structures. Nevertheless, the issue of controlling drivers who violate the law remains unresolved, as well as the question of the extent to which vehicle can be overloaded. Numerous sources have reported on the relative proportion of illegal vs. law-abiding haulers [35], [56]–[60].

The intent of the law under which the FDOT issues vehicular permits is to protect motorists from traffic hazards caused by the movement of overweight and oversized vehicles or loads on state highways and to minimize damage to infrastructure, thus protecting the investment in the State Highway System. Furthermore, it is important to mention that all of the fees should help to recover FDOT's administrative costs, as well as repair any excessive wear that permitted loads may cause to the State Highway System [78].

Each state has particular permit regulations for the transportation of certain goods. Vehicles that are oversized, overweight, or both can legally operate prior to applying for a permit. State departments of transportation are the authorities that issue permits authorizing vehicles to operate off the Interstate Highway System in excess of the vehicle's legal gross weight limit. Vehicles need to follow the limitations on gross weight, single axle, tandem axle, and tridem axle loads [86]. Legal weights for Florida are shown in Figure 3-6 [81].

Single Axle	• 22,000 lb
Tandem	• 44,000 lb
Tridem	• Per FBF/ 66,000 lb
Gross vehicle weight	• 80,000 lb

Figure 3-6 Legal weight for Florida, including 10% tolerance.

It is very important to set boundaries and define legal, permit, and illegal vehicles. Figure 3-7 distinguishes legal loads and permits available for vehicles in Florida, which will be described later in this chapter.

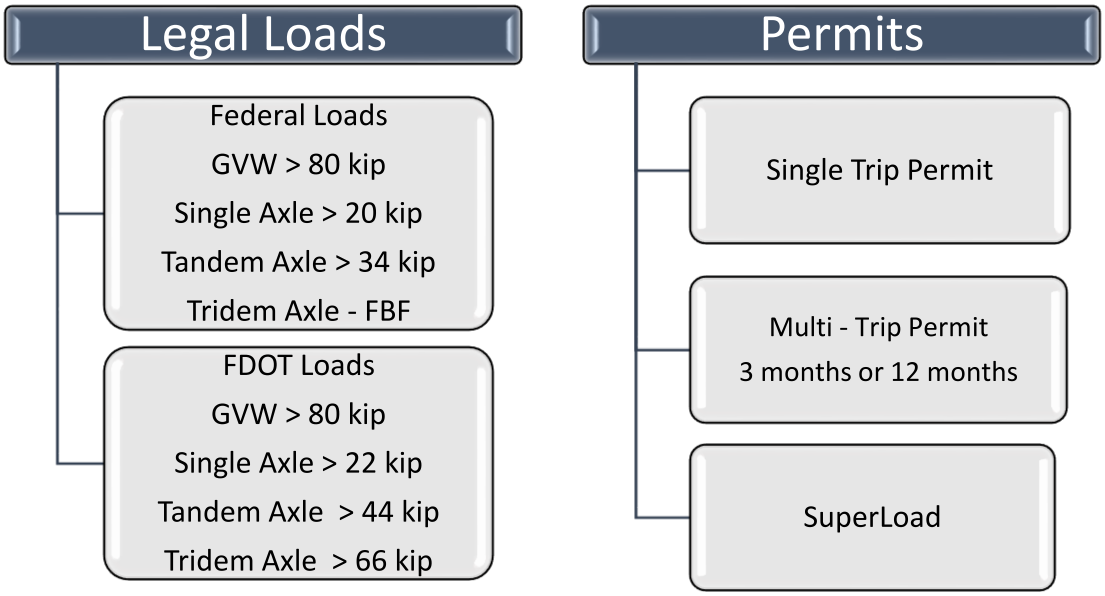


Figure 3-7. Legal loads vs. permits

FDOT issues divisible load permits that allow operating on the state network only. No interstate travel is allowed. The driver is responsible for obtaining permission to operate on the local network from the appropriate local authorities. In Florida, a permit is needed when one of the following conditions is met:

- Maximum width of a vehicle or a combination of a vehicle and load exceeds 102" or exceeds 96" on less than a 12-foot wide travel lane.
- Maximum height of a vehicle or a combination of a vehicle and load exceeds 13'6" or 14’ for automobile transporters.
- Maximum length of a single-unit vehicle exceeds 40'; a Truck Tractor with a semi-trailer exceeding 48' with a kingpin distance that goes beyond 41', measured from the center of the rear axle, or group of axles, to the center of the kingpin of the fifth wheel connection; a Straight Truck with a trailer when the combination exceeds 68'; and Truck Tractors hauling automobiles with a semi-trailer exceeding 50' as a qualifying auto transporter [87] or a front end overhang exceeding 3' 4".
- Gross weight of a vehicle or vehicle axle load combination exceeds the legal limits established in Florida Statute 316.535. There are different types of permits, which are time-dependent: single trip, multi-trip, and route-specific multi-trip. A single trip permit is valid from one point of origin to one destination, and the hauler is allowed up to ten days to complete the move. Trip permits are analyzed for weight based upon the route provided by the applicant. Multi-trip permits are valid for an unlimited number of trips for three months or one year from the date of issuance. The maximum gross weights allowed on a specific number of axles are presented in

Table 3-1. Multi-trip permits must be used in conjunction with the map identified on the face of the permit [88].

Table 3-1 Maximum gross weight allowed in Florida for 3- to 7-axle groups

Outer	MAXIMUM GROSS WEIGHT ALLOWED ON THIS NUMBER OF AXLES (IN POUNDS)					Outer
Bridge	ALL TOLERANCES ARE INCLUDED					Bridge
Distance						Distance
(Feet)	3 Axles	4 Axles	5 Axles	6 Axles	7 Axles	(Feet)
9	47,000					9
10	48,000					10
11	48,500					11
12	49,500					12
13	50,500	55,500				13
14	51,000	56,500				14
15	52,000	57,000				15
16	53,000	58,000				16
17	53,500	58,500	64,500			17
18	54,500	59,500	65,000			18
19	55,500	60,000	66,000			19
20	56,000	61,000	66,500			20
21	57,000	61,500	67,000	73,500		21
22	58,000	62,500	68,000	74,000		22
23	58,500	63,000	68,500	74,500		23
24	59,500	64,000	69,500	75,000		24
25	60,000	64,500	70,000	76,000	82,000	25
26	61,000	65,500	70,500	76,500	82,500	26
27	62,000	66,000	71,500	77,000	83,500	27
28	62,500	66,500	72,000	78,000	84,000	28
29	63,500	67,500	72,500	78,500	84,500	29
30	64,500	68,000	73,500	79,000	85,500	30
31	65,000	69,000	74,000	80,000	86,000	31
32	66,000	69,500	75,000	80,500	86,500	32
33		70,500	75,500	81,000	87,000	33
34		71,000	76,000	82,000	88,000	34

Table 3-1. Maximum gross weight allowed in Florida for 3- to 7-axle groups (continued)

Outer	MAXIMUM GROSS WEIGHT ALLOWED ON THIS NUMBER OF AXLES (IN POUNDS)					Outer
Bridge	ALL TOLERANCES ARE INCLUDED					Bridge
Distance						Distance
(Feet)	3 Axles	4 Axles	5 Axles	6 Axles	7 Axles	(Feet)
35		72,000	77,000	82,500		35
36		72,500	77,500	83,000		36
37		73,500	78,000	84,000		37
38		74,000	79,000	84,500		38
39		75,000	79,500	85,000		39
40		75,500	80,500	86,000		40
41		76,500	81,000	86,500		41
42		77,000	81,500	87,000		42
43		77,500	82,500	88,000		43
44		78,500	83,000			44
45		79,000	83,500			45
46		80,000	84,500			46
47		80,500	85,000			47
48		81,500	86,000			48
49		82,000	86,500			49
50		83,000	87,000			50
51		83,500	88,000			51
52		84,500				52
53		85,000				53
54		86,000				54
55		86,500				55
56		87,500				56
57		88,000				57

The different types of FDOT permits are presented in Figure 3-8. Permits can be requested for overloaded and oversized vehicles, and also for a specific time period or specific route. In this research, overweight vehicles are of interest, which is why the classification of permits is shown only on the basis of weight and time period.

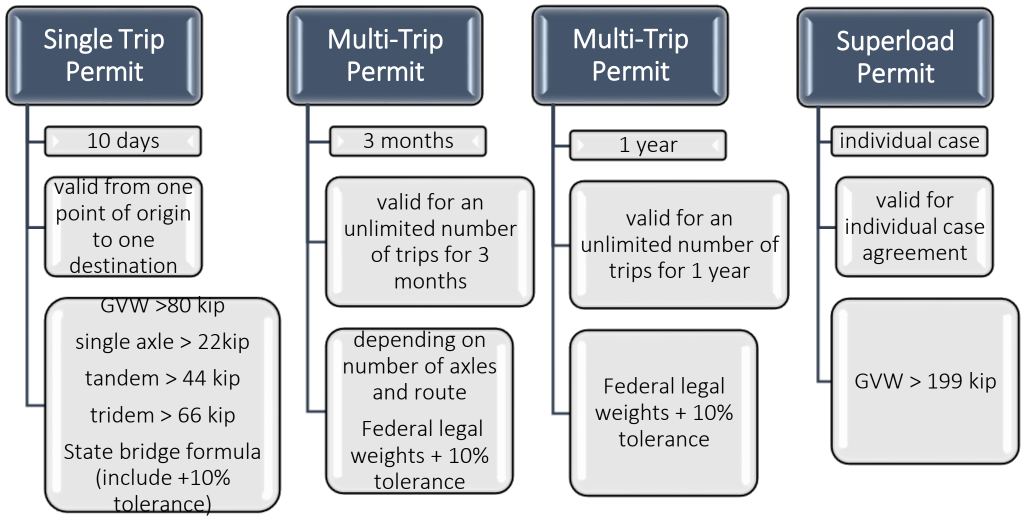


Figure 3-8. Types of FDOT permits.

3.5. State Enforcement Policies and Control of Illegally Overloaded Vehicles

Enforcement activities and permit operations greatly influence motor vehicle size and weight regulations. Individual states are responsible for the efficient enforcement of state and federal laws that refer to the size and weight of operating vehicles. Approaches to choose the combination of weighing scale operations, deployment strategy, and responsible enforcement agency differ considerably [89]. The problem of illegally overloading trucks goes far beyond the safety of roads and bridges [57], [58]. Violators create high competition in the transportation service market, while drivers that follow permit rules are at a disadvantage. Most states follow the federal weight limits to protect the roads and bridges from progressive damage. However, requests to increase axle load limits to reduce transportation costs were frequently reported. The estimated annual savings on transportation costs from a repeal of the GVW limit of 355kN (80,000lb) exceeds $2 billion [57].

The state enforcement agency is responsible for weight enforcement organization, hours of the enforcement effort, location and hours of fixed scales, operation, and ways of employing portable scales. The scale system includes three general types: portable, semi-portable, and permanent (fixed) scales. The enforcement system has to be correlated to efficiently verify overloaded and oversized vehicles. The enforcement system also defines specific routes for permit vehicles. For this purpose, route maps assign permit vehicles to the specified route(s) and may be used in connection with single or multiple-trip permits. In some states, they can provide a basis for routine permit issuance up to specified overlimits. The Citation Database also helps by checking the effectiveness of the enforcement in a particular state. In most cases, the haulers of cited vehicles are obliged to bring their vehicles within the legal limits. Commonly, part of the load has to be removed if the gross vehicle weight limit is exceeded. In general, the fine is a function of the amount by which the vehicle is overweight. Effective enforcement is necessary to ensure the safety of the entire motoring public and provide that loads do not shorten the service life of highways [89]. Fully coordinated permit issuance and weight enforcement results in better uniformity of provisions, procedures, and effects.

3.6. Revenue Sources

3.6.1. Permit Fees

Each state jurisdiction requires that vehicles exceeding the legal limits on size and/or weight must purchase oversize/overweight (OS/OW) permits to travel within that jurisdiction. The Overweight Permit Fee Structure should be adequate for the damage that heavy vehicles cause to infrastructure. Therefore, the cost of the damages caused by a certain vehicle type can be associated and compared with the total amount of fees (Permit Fee, Registration Fee, Fuel Costs). State DOTs issue permits on a daily basis to OS/OW vehicles that travel on highways that exceed the legal truck size and weight regulations. Many OS/OW vehicles may pass through more than one state from a starting point to an end point. Some states require haulers to buy separate permits for each state they travel through. The permit fee structure varies by each state. The five basic permit fee structures currently used among the states are flat fees, distance-based fees, weight-based fees, weight-distance-based fees, and axle-based fees [10]. Figure 3.-9 shows the permit fee structure adopted by different states in the entire U.S. Florida has weight-distance-based fees. Also, the methods used for cost calculation of permit fees and reasons for collecting permit fees vary from state to state. The most common goal is to recover the maintenance, repair, and construction costs of roads and bridges in the state.

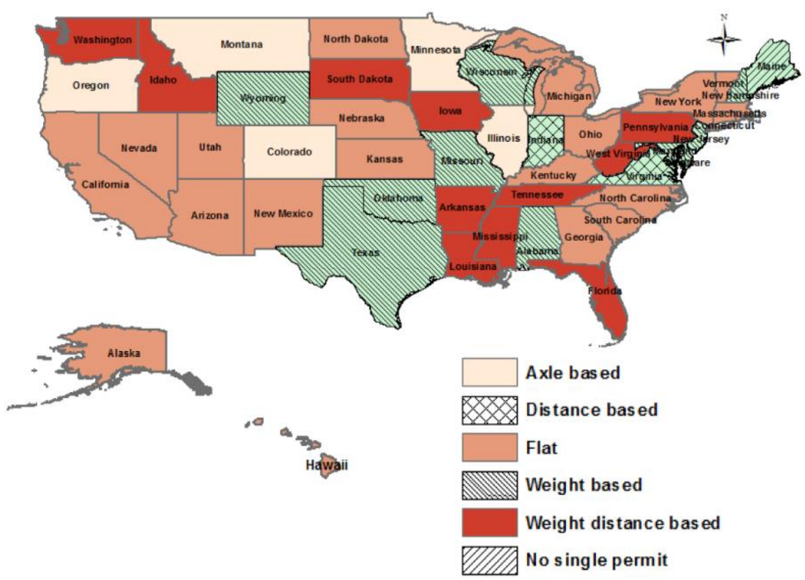


Figure 3-9 Permit fee structure of different states in the U.S [10].

The fee schedule for oversized vehicles is based on the overdimension criteria and duration time of a permit. Table 3-2 introduces the current Florida permit fee schedule and fees associate with oversized vehicle violations.

Table 3-2 Fee Schedule for overdimension permits by FDOT [90].

	TRIP PERMIT/ 10 Days	MULTI-TRIP/PERMITS/ 12 Months	ROUTE SPECIFIC/ MULTI-TRIP/ PERMIT/ 3 Months
(1) OVERDIMENSION			
(a) Straight trucks and semi-truck-tractor-trailer.			
Up to 12 feet wide, or up to 13 feet 6 inches high or up to 85 feet long.	$5.00	$20.00	$5.00
Up to 14 feet wide or up to 14 feet 6 inches high or up to 95 feet long.	$15.00	$150.00	$38.00
Up to 14 feet wide or up to 18 feet high or up to 120 feet long.	$25.00	$250.00	$63.00
Over 14 feet wide or over 18 feet high or over 120 feet long.	$25.00	NOT ISSUED	$125.00
(b) Overlength semi-trailers of legal width, height, and weight, which exceed 53 feet In Length up to 57 feet 6 inches in length or overlength semi-trailer with kingpin setting greater than 41 feet.	$10.00	$30.00	NOT ISSUED
(c) Truck crane or earth handling equipment moving under own power, up to 12 feet wide or 14 feet 6 inches high.	$15.00	$150.00	$38.00
*(d) Trailers or equipment towed with ball or pintle.			
*Up to 10 feet wide or up to 13 feet 6 inches high or up to 80 feet long.	$5.00	$20.00	$5.00
*Up to 12 feet wide or up to 13 feet 6 inches high or up to 105 feet long.	$5.00	$330.00	$83.00
*Up to 14 feet wide or up to 14 feet 6 inches high or up to 105 feet long.	$15.00	$500.00	$125.00
Over 14 feet wide or over 14 feet 6 inches high or over 105 feet long.	$25.00	NOT ISSUED	$250.00
NOTE: All permitted dimensions (length, height, width) must be within limits shown for permit fee.			

Moreover, Florida has a fee schedule for overweight vehicles, based on Gross Vehicle Weight and some other overweight special exemptions. Table 3-3 introduces the current Florida permit fee schedule and fees associate with overweight violations.

Table 3-3. Fee Schedule for overweight vehicles by FDOT [90]

.	TRIP PERMIT 10 Days	MULTI-TRIP PERMITS 12 Months	ROUTE SPECIFIC MULTI-TRIP PERMITS 3 months
(2) OVERWEIGHT			
*(a) Up to 95,000 pounds.	$0.27 Per Mile	**$240.00	$60.00
*(b) Up to 112,000 pounds.	$0.32 Per Mile	**$280.00	$70.00
*(c) Up to 122,000 pounds.	$0.36 Per Mile	**$310.00	$78.00
*(d) Up to 132,000 pounds.	$0.38 Per Mile	**$330.00	$83.00
*(e) Up to 142,000 pounds.	$0.42 Per Mile	**$360.00	$90.00
*(f) Up to 152,000 pounds.	$0.45 Per Mile	**$380.00	$95.00
*(g) Up to 162,000 pounds.	$0.47 Per Mile	**$400.00	$100.00
(h) Up to 199,000 pounds.	$0.003 Per 1,000 Pounds Per Mile	$500.00	$125.00
(i) Over 199,000 pounds.	$0.003 Per 1,000 Pounds Per Mile	NOT ISSUED	$250.00
(j) Containerized Cargo Unit.	$0.27 Per Mile	$500.00	$125.00
(k) Overall Wheel Base (Inner Bridge/External Bridge).	$10.00	$35.00	NOT ISSUED
(l) Implements of husbandry, farm equipment, agricultural trailers/products and forestry equipment (Local Moves Only).	$5.00	$17.00	NOT ISSUED
(3) SPECIAL PERMIT FEES			
Transmission Fee	$5.00	NOT APPLICABLE	NOT APPLICABLE
*Dimensions greater than 12 feet wide or 13 feet 6 inches high or 85 feet long will have an additional dimension fee with a combined fee of not to exceed $500.00.NOTE: For weights over 80,000 pounds [paragraphs (2)(a) through (h), above], add an administrative cost of $3.33 for issuance of permit, which does not include the costs charged by wire services for their services. Permit fees shall be based on 25-mile increments rounded up to the nearest dollar. Example: A 112,000 pound load traveling 67.5 miles would cost (75 miles X $0.32) plus $3.33 = $27.33 rounded up to $28.00 in addition to the $5.00 transmission fee when applicable.			

The Project team received a Permit Data Dictionary Report (FDOT) with information about attributes included in the database. The permit database contains information about issued permits in Florida. The complete data was requested, but only part of the database was received. At this stage of the project, statistical data analysis for different types of permits is presented. The first classification is based on the type of permit such as overweight, oversize or both overweight and oversize. The statistics for the years of permit data received from 2016, 2017, 2018 and 2019 are shown in percentages in Figure 3.-10. Figure 3-10 indicates the consistency of the data among the years, and of all of the issued permits, 55% are oversize permits, 5% are overweight permits, and 40% are a combination of oversize and overweight permits.

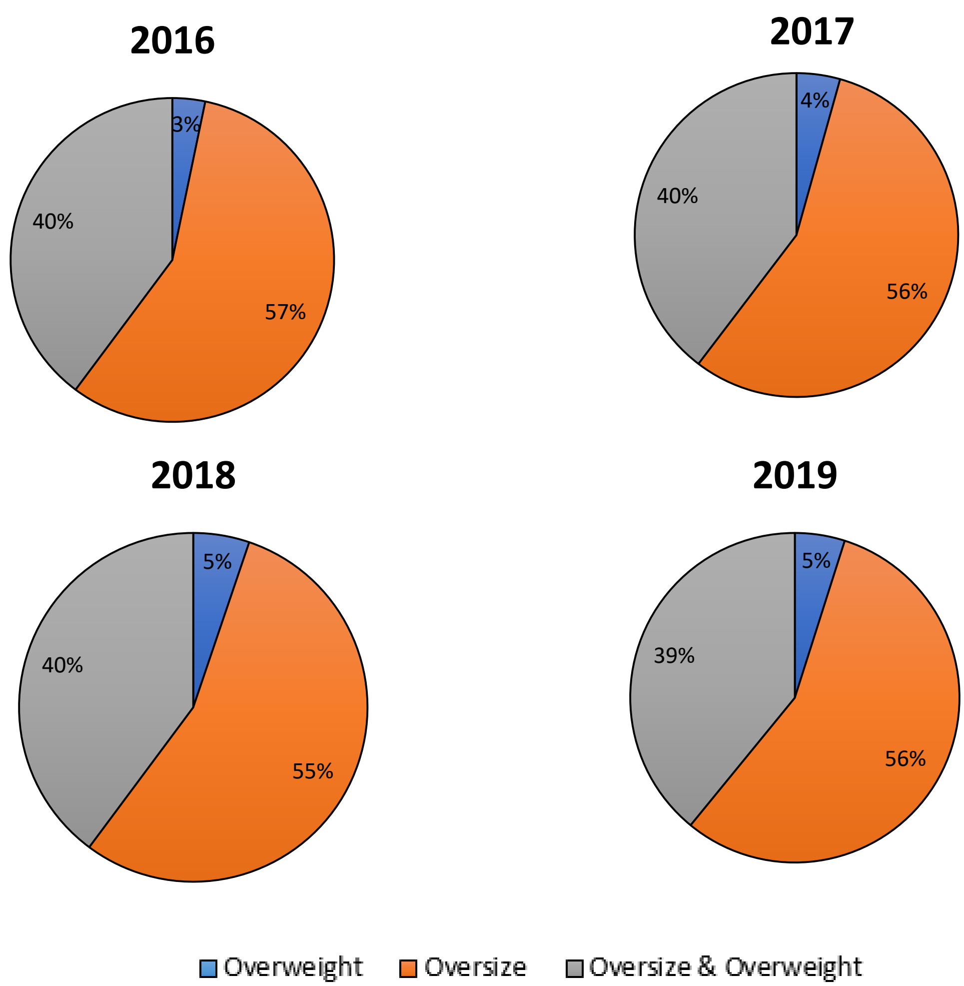


Figure 3-10 Statistical summary of oversize-overweight issued permits.

The statistical summary for the number of oversize, overweight or both oversize and overweight vehicles for each year is shown in Figure 3-11.

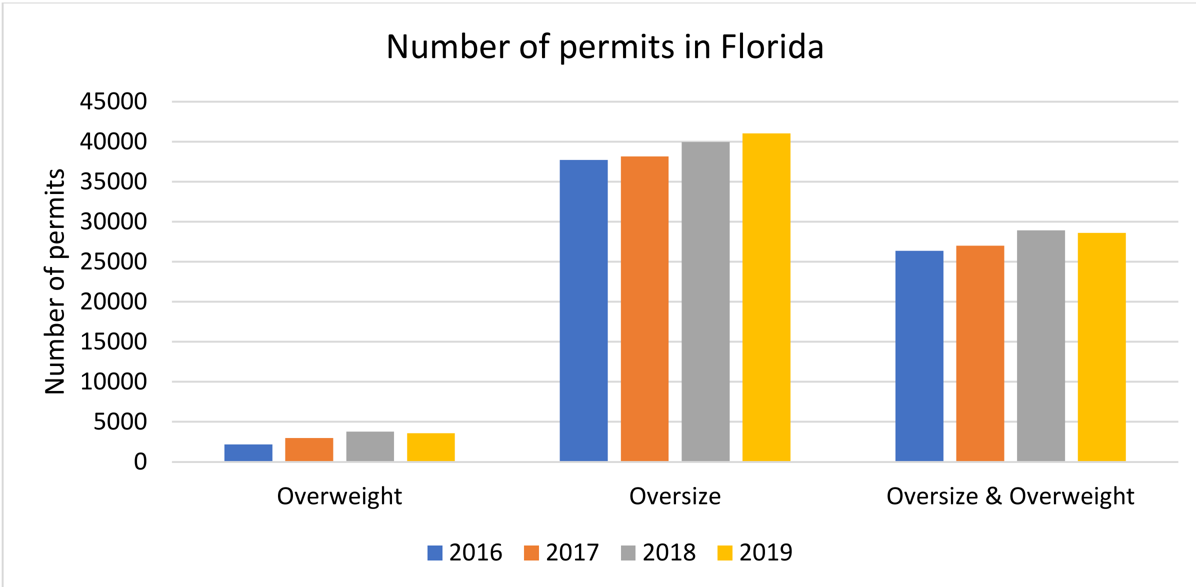


Figure 3-11 A number of issued oversize-overweight permits in years 2016–2019.

The percentage of issued permits of a given type is consistent over the years. The statistics for given years is shown in Figure 3-12. Figure 3-12 shows that about 75% of issued permits are single trip permits. Multi-trip permits for 12 months (non-specific) for a vehicle are about 20-25%. There is also an additional distinction between multi-trip permits for 12 months that are vehicle-specific. In July 2017, a new permit type was added; this new permit was collected only for half of a year and is 1% of the total number of collected permits, but in 2018, it was 4%, and in 2019, it was 6%. Hence, there is a noticeable upward trend. The multi-trip permits for 3 months are a very small amount, about 0.5% of permits.

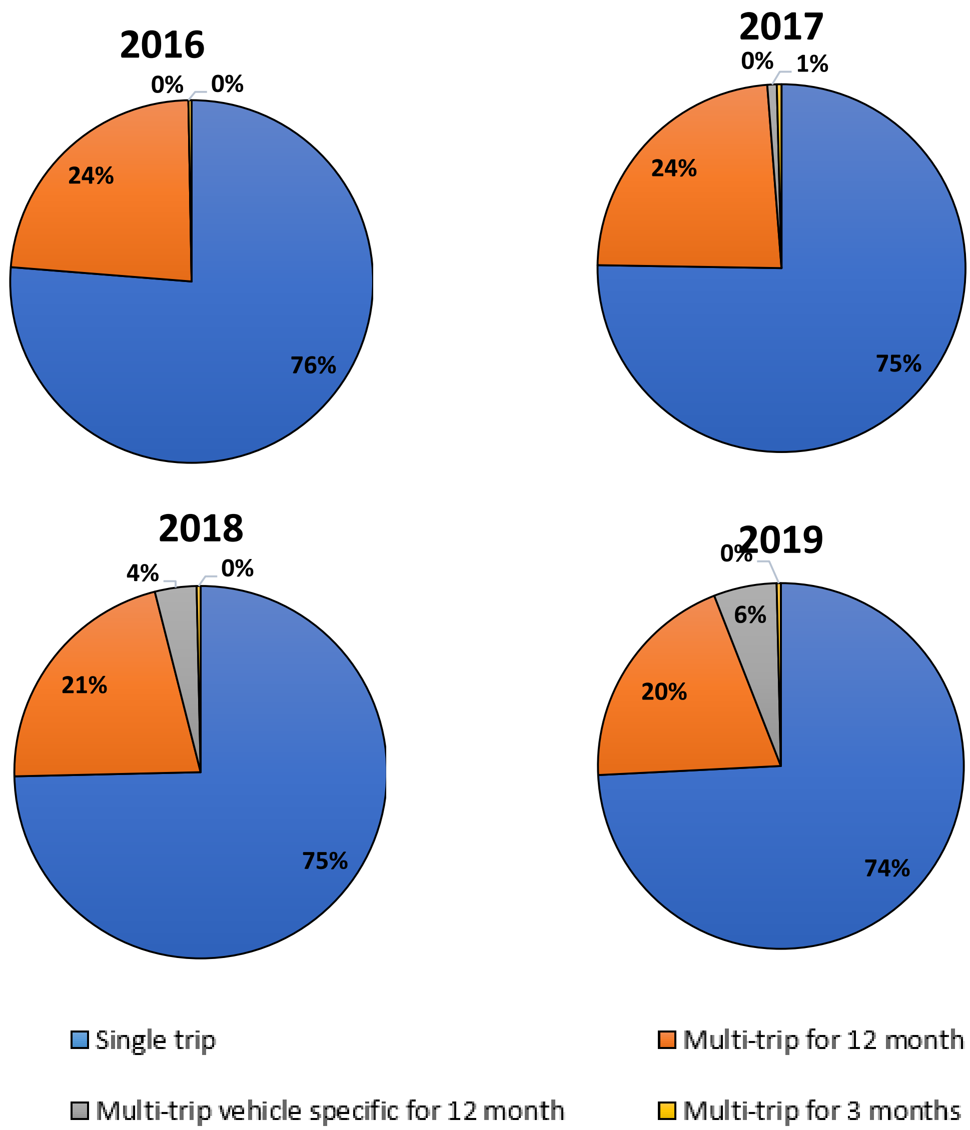


Figure 3-12. Statistical summary of single trip and multi-trip permits.

Also, a statistical summary of the number of single trips, multi-trips for 12 months or vehicle-specific and non-specific, and 3-month multi-trip permits is shown for each year in Figure 3-13.

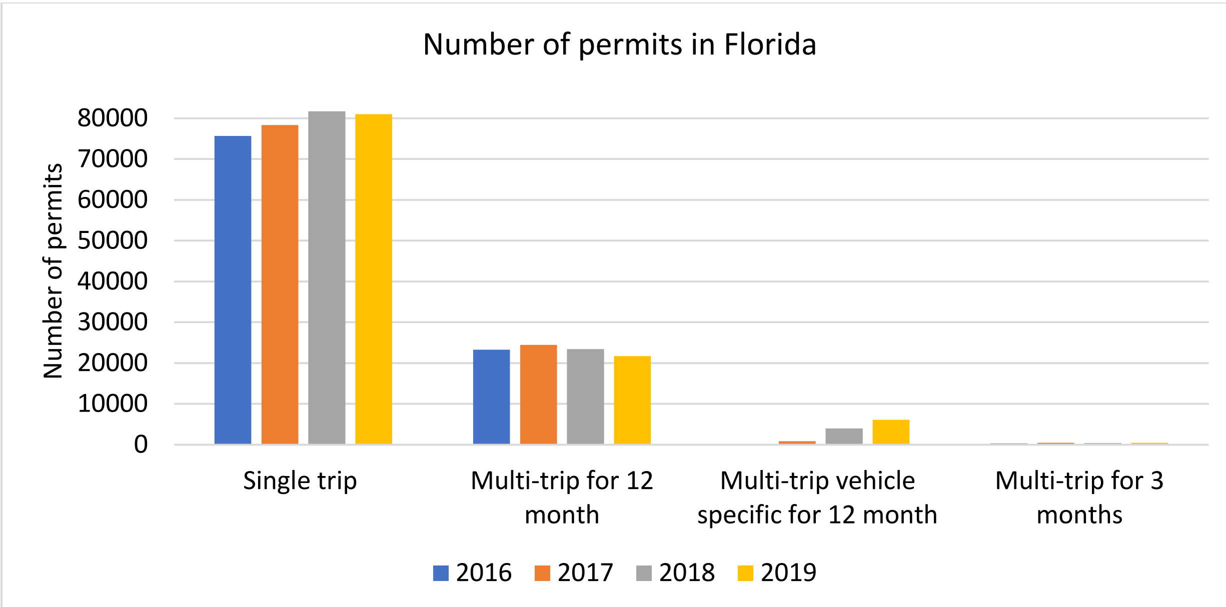


Figure 3-13. Statistical summary of single trip and multi-trip permits for years 2016–2019.

The next step is to show statistics for overweight issued permits and the combination of the overweight and oversize group of vehicles that are of interest in this project. In Figure 3-14, the number of issued permits from the overweight category is shown vs. time-dependent permits such as: single trips and multi-trips for 12 months, specific for vehicle multi-trips for 12 months, and multi-trip permits for 3 months for considered years. And in Figure 3-15, the number of issued permits from the overweight and oversize category is shown vs. time-dependent permits such as: single trip, multi-trip for 12 months, specific for vehicle multi-trips for 12 months, and multi-trip permits for 3 months for considered years.

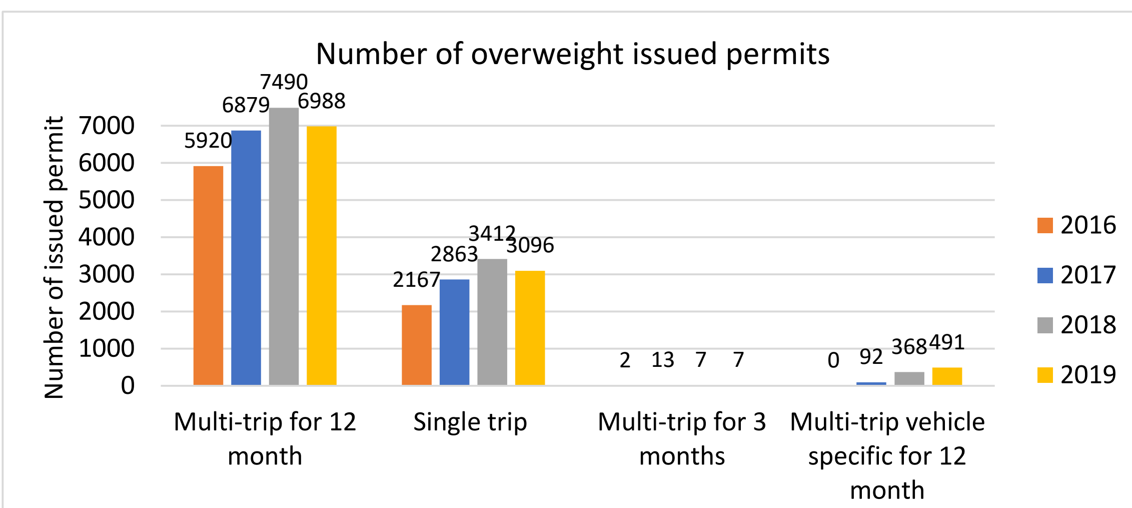


Figure 3-14. Statistical summary of an overweight permit for years 2016-2019.

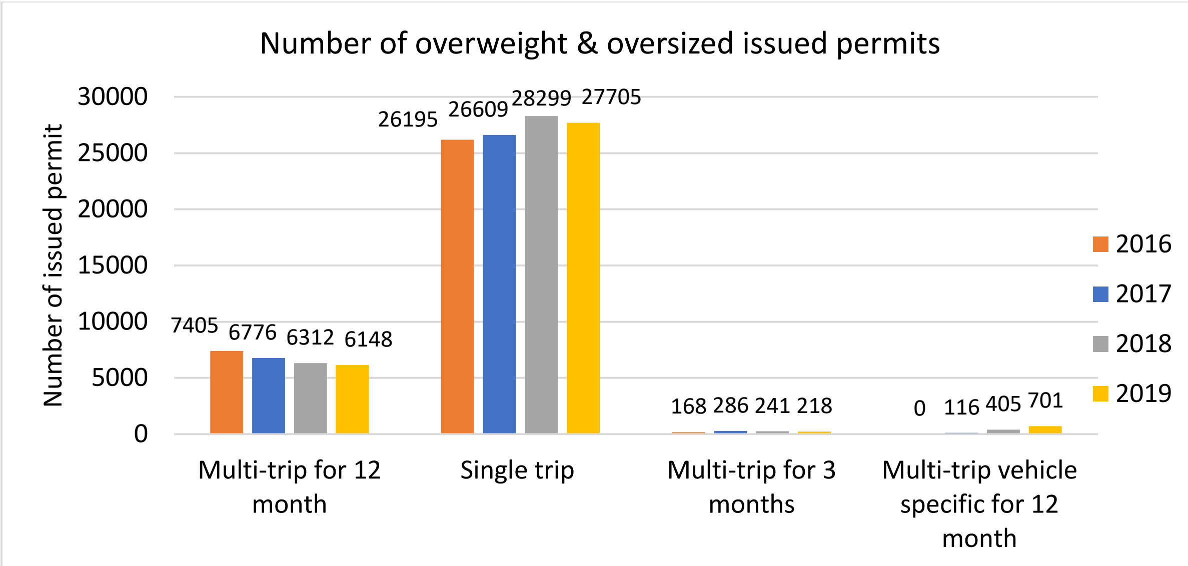


Figure 3-15. Statistical summary of overweight and oversize permit for years 2016-2019.

For the overweight permit vehicles, the amount of multi-trip 12-month permits are the largest statistic. On the other hand, for the oversize and overweight group, the amount of single trip vehicles is the largest. From the statistical analysis, the number of single trip permits is the largest, but not for the overweight vehicles. This conclusion will be considered at the next stage of the project. The FDOT issues 400-450 OS/OW permits on a daily basis. The summary for an annually issued permit in Florida with an average daily number of issued permits is shown in Table 3-4.

Table 3-4. Annual and daily issued permits in Florida for years 2016-2019.

Year	Number of issued permits	Workdays	Average daily number of issued permits
2016	99,260	252	394
2017	104,116	251	415
2018	109,497	250	438
2019*	109,218	250	437

* incomplete data

There is an upward trend in the number of issued permits in Florida. Using linear regression, the increasing trend in a number of issuing permits is predicted and shown in Figure 3-16.

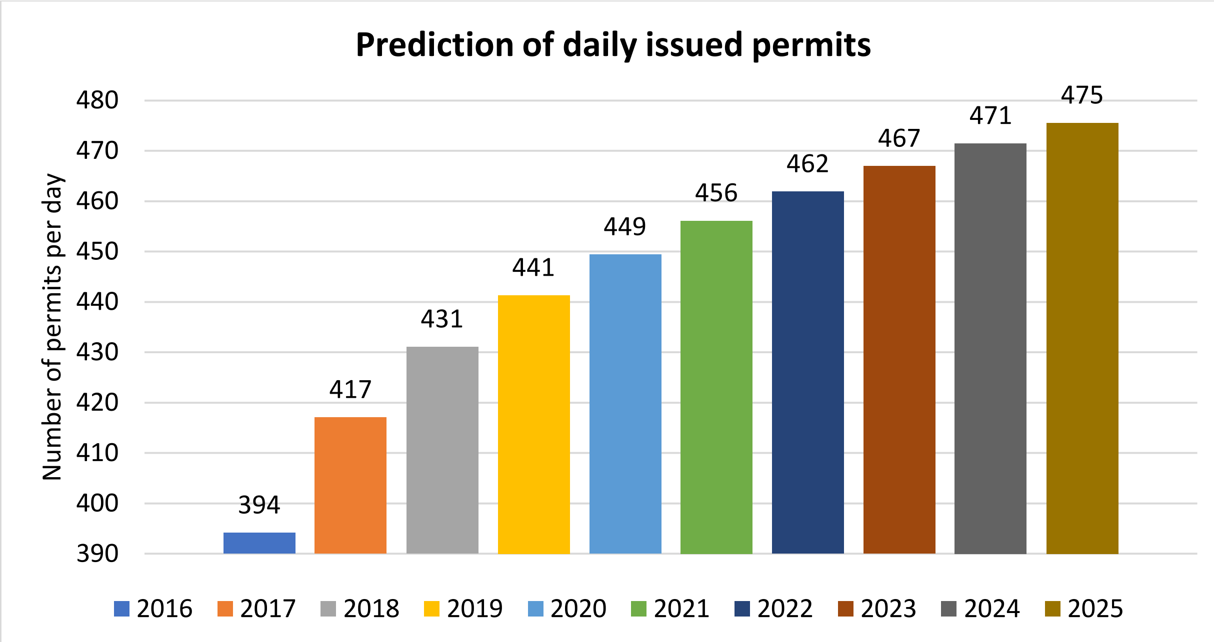


Figure 3-16. Prediction of daily issued permits in Florida for years 2016-2025.

The revenue collected from the permits in recent years will be assessed in the next task.

3.6.2. Registration and Title Fees

Registration fee is regulated by each state. Every vehicle needs to be registered and titled with the state's transportation agency or department of motor vehicles [91]. A vehicle needs an initial registration fee, annual registration fee, and the license plate fee. The vehicle title is a legal document that establishes a person as an owner of the vehicle. Motor vehicles cannot be driven legally without a registration.

The method of charging registration and title fees varies widely among states. Typically, an initial registration fee is a one-time fee assessed by each new owner.

Annual registration fees are charged to motorists for each vehicle under operation in the state. The map shown in Figure 3-17 presents various types of fees in the U.S. Several fee criteria are considered, such as: flat, weight-based, value-based, aged-based and other fees.

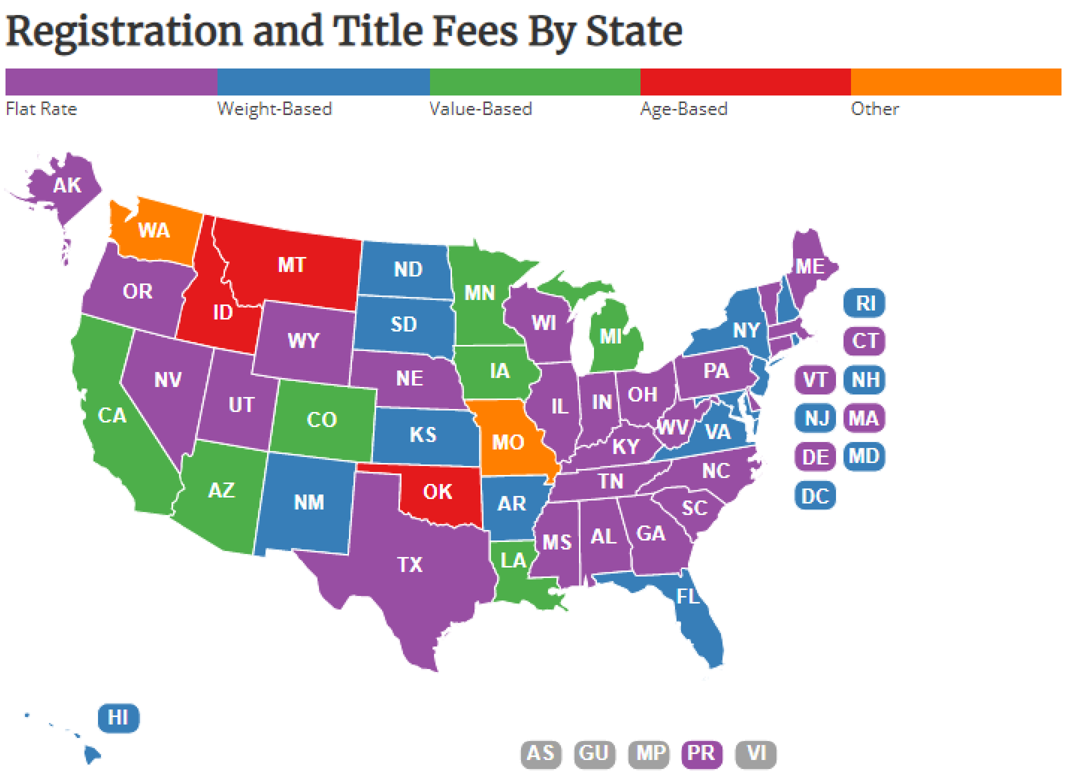


Figure 3-17. Registration and titles fee by the state in the U.S.

Florida is classified as a weight-based fee state. More detailed information about the fees in Florida are shown in Figure 3-18 [92].

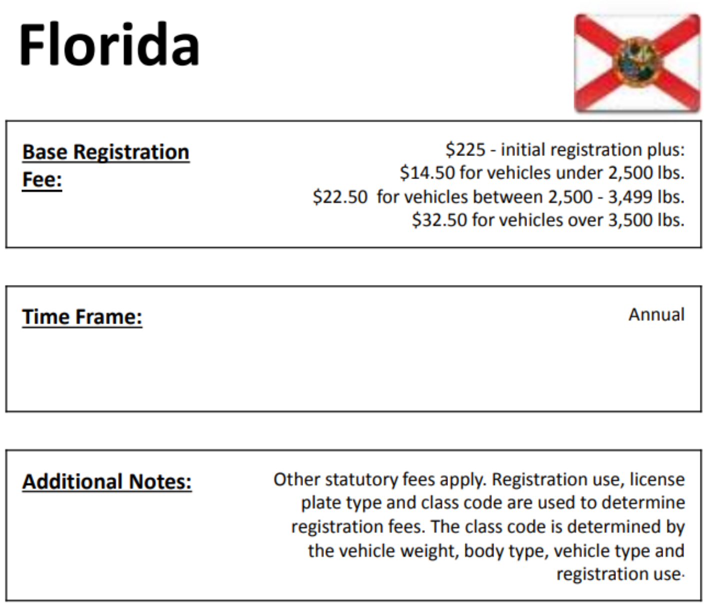


Figure 3-18. Vehicle registration fees in Florida.

The initial registration fee in Florida is equal to $225. This fee is required if the purchaser does not have a Florida license plate or has a new vehicle (also called . “new wheels on the road”).

The Initial Registration Fee in Florida includes three vehicle taxes, which the 1990 Legislature increased to finance transportation improvements. Originally, in 1989, the amount of that fee was $30. The fee applies to automobiles, light trucks, and some recreational vehicles. In 1990, the Legislature increased the fee to $100, directing the additional $70 to the Skilled Trades Training Fund (STTF).

The registration fee comparison between states in the U.S. is shown in Figure 3-19 [93].

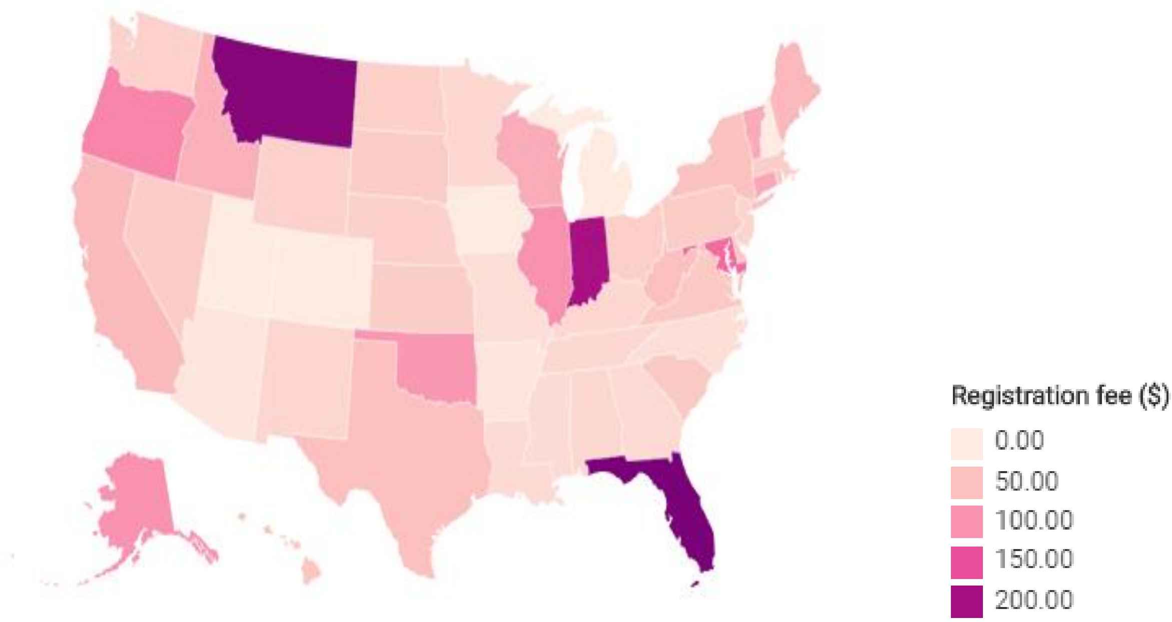


Figure 3-19. Vehicle registration fees in $ in the U.S.

The initial registration fee in Florida is in the group of the highest amount in dollars per registration. The other type of registration fee is an annual registration fee, which in Florida depends on the vehicle weight, body type, vehicle type, and registration use. Table 3-5. shows annual registration fees depending on the net weight of the truck.

Table 3-5. Annual registration fee in Florida [94].

Vehicle	Net weight	Fee
Truck	<=1999	$ 14.50
Truck	2,000-3,000	$ 22.50
Truck	3,001-5,000	$ 32.50
Truck	5,001-5,999	$ 60.75
Truck	6,000-7,999	$ 87.75
Truck	8,000-9,999	$ 103.00
Truck	10,000-14,999	$ 118.00
Truck	15,000-19,999	$ 177.00
Truck	20,000-26,000	$ 251.00
Truck	26,001-34,999	$ 324.00
Truck	35,000-43,999	$ 405.00
Truck	44,000-54,999	$ 773.00
Truck	55,000-61,999	$ 916.00
Truck	62,000-71,999	$ 1,080.00
Truck	>=72,000	$ 1,322.00

In addition, heavy vehicles pay a Heavy Vehicle Use Tax (HVUT), which is an annual Federal Highway Tax imposed on certain heavy motor vehicles, including trucks, truck tractors, and buses using public highways. The tax applies only to vehicles with a taxable gross weight of 55,000 pounds or more. The Federal Government then distributes revenues back to the states for highway construction and maintenance projects. HVUT prices are shown in Table 3-6 [95].

Table 3-6. Heavy vehicle use tax rates.

GROSS TAXABLE WEIGHT	**HEAVY VEHICLE USE TAX RATES**
below 50,000 lb.	no tax
55,000-75,000 lb.	$100 plus $22 per 1,000 lb. over 55,000 lb.
over 75,000 lb.	$550

Another fee is the title fee, also known as the license plate fee, which depends on vehicle classification and net weight in pounds. The Florida License Plate Rate chart is shown in Figure 3-20 [96].

TITLE REQUIRED	TAX CLASS	CLASSIFICATION	NET WEIGHT IN POUNDS	ANNUAL TAX AND OTHER FEES *	
Yes	01	Automobiles, private use	Thru 2499	$ 27.60	The registration taxes in this section are not prorated. The full amount will be charged regardless of when during the registration period the vehicle is registered.
Yes	01	Automobiles, private use	2500-3499	35.60	
Yes	01	Automobiles, private use	3500 Up	45.60	
Yes	31	Trucks, private and commercial use	Thru 1999	27.60	
Yes	31	Trucks, private and commercial use	2000-3000	35.60	
Yes	31	Trucks, private and commercial use	3001-5000	45.60	
Yes	42	Chassis Mount Camper, unit affixed to truck chassis	Thru 4499	38.60	
Yes	42	Chassis Mount Camper, unit affixed to truck chassis	4500 Up	58.85	
Yes	42	Motor Home, living unit self-propelled	Thru 4499	38.60	
Yes	42	Motor Home, living unit self-propelled	4500 Up	58.85	
Yes	42	Private Motor Coach	Thru 4499	38.60	
Yes	42	Private Motor Coach	4500 Up	58.85	
* *	52	Trailers, private use	Thru 500	18.35	
Yes	56	Trailers, drawn by "GVW" series truck-tractors		25.10	
Yes	62	Camp Trailers, constructed with folding walls		25.10	
No	70	Transporter		112.85	
Yes	77	Travel Trailer, up to 35 ft.		38.60	
Yes	96	Boy Scouts, Churches, etc.		15.60	
Yes	97	Exempt Government License Plates		9.80	
Yes	103	Permanent Semi-Trailer		101.80	Flat Rate

TITLE REQUIRED	TAX CLASS	CLASSIFICATION	LENGTH IN FEET	ANNUAL TAX AND OTHER FEES*	HALF YEAR TAX AND OTHER FEES*	QUARTER YEAR TAX AND OTHER FEES *
Yes	51	Mobile Homes	Up to 35	25.10	15.10	10.10
Yes	51	Mobile Homes	36 thru 40	30.10	17.60	11.35
Yes	51	Mobile Homes	41 thru 45	35.10	20.10	12.60
Yes	51	Mobile Homes	46 thru 50	40.10	22.60	13.85
Yes	51	Mobile Homes	51 thru 55	45.10	25.10	15.10
Yes	51	Mobile Homes	56 thru 60	50.10	27.60	16.35
Yes	51	Mobile Homes	61 thru 65	55.10	30.10	17.60
Yes	51	Mobile Homes	66 & Up	85.10	45.10	25.10
No	65	Motorized and Disability Access Vehicles		24.10	17.35	15.60
Yes	65	Motorcycles		24.10	17.35	15.60
No	69	Mopeds, pedal activated (motor NOT in excess of 2 BHP)		19.10	17.35	17.35
No	71	Dealer's License Plates – Franchised, Independent, Trailer Coach, Motorcycle, or Marine Boat Trailer		55.60	27.80	13.90
Yes	76	Park Trailers, regardless of length		36.60	24.10	17.85
Yes	78	Travel Trailers	Over 35	36.60	24.10	17.85
Yes	80	Antiques - Motorcycle		21.60	14.85	13.10
Yes	92	School Buses (privately owned) and Regular Wreckers		52.60	32.10	21.85
Yes	92	Hearses and Ambulances		52.10	31.85	21.73
Yes	94	Tractor Cranes, Power Shovels, Well Drillers and other such vehicles, so constructed and designed as a tool and not a hauling unit, used on the roads and highways incidental to the purpose for which designed.		55.60	33.60	22.61
Yes	95	Antiques - Passenger Cars		20.60	15.48	15.35

Figure 3-20. License plate rate chart.

TITLE REQUIRED	TAX CLASS	CLASSIFICATION	WEIGHT	ANNUAL TAX FLAT (per cwt) SERVICE AND OTHER FEES *
**	54	Trailers, "For Hire"	Thru 1999 lbs.	$ 3.50 + 1.50 + 11.60
Yes	54	Trailers, "For Hire"	2000 lbs. & up	13.50 + 1.50 + 11.60
Yes	09	Automobiles "For Hire"	Passengers up to 8	17.00 + 1.50 + 11.60

TITLE REQUIRED	TAX CLASS	CLASSIFICATION	MONTHLY PRORATION OF TAX											
		GVW	12	11	10	9	8	7	6	5	4	3	2	1
Yes	39	Forestry Trk-Trac	359.15	332.15	305.15	278.15	251.15	224.15	197.15	170.15	143.15	116.15	89.15	62.15
Yes	41	Trk-Trac 5001-5999	72.35	67.29	62.23	57.16	52.10	47.04	41.98	36.91	31.85	26.79	21.73	16.66
Yes	41	Trk-Trac 6000-7999	99.35	92.03	84.73	77.41	70.10	62.79	55.48	48.16	40.85	33.54	26.22	18.92
Yes	41	Trk-Trac 8000-9999	114.60	106.02	97.43	88.85	80.27	71.68	63.10	54.52	45.93	37.35	28.77	20.18
Yes	41	Trk-Trac 10000-14999	139.60	129.77	119.93	110.10	100.27	90.43	80.60	70.77	60.93	51.10	41.27	31.43
Yes	41	Trk-Trac 15000-19999	198.60	183.85	169.10	154.35	139.60	124.85	110.10	95.35	80.60	65.85	51.10	36.35
Yes	41	Trk-Trac 20000-26000	272.60	251.68	230.77	209.85	188.93	168.02	147.10	126.18	105.27	84.35	63.43	42.52
Yes	41	Trk-Trac 26001-34999	345.60	318.60	291.60	264.60	237.60	210.60	183.60	156.60	129.60	102.60	75.60	48.60
Yes	41	Trk-Trac 35000-43999	426.60	392.85	359.10	325.35	291.60	257.85	224.10	190.35	156.60	122.85	89.10	55.35
Yes	41	* Trk-Trac 44000-54999	794.60	730.18	665.77	601.35	536.93	472.52	408.10	343.68	279.27	214.85	150.43	86.02
Yes	41	* Trk-Trac 55000-61999	937.60	861.27	784.93	708.60	632.27	555.93	479.60	403.27	326.93	250.60	174.27	97.93
* For GVW Wreckers 44,000-55,000 lbs., reduce the fee by $1.00. * For GVW wreckers 55,000-62,000 lbs., reduce the fee by $1.00.														
Yes	41	Trk-Trac 62000-71999	1101.60	1011.60	921.60	831.60	741.60	651.60	561.60	471.60	381.60	291.60	201.60	111.60
Yes	41	Trk-Trac 72000-80000	1343.60	1233.44	1123.26	1013.10	902.94	792.76	682.60	572.44	462.26	352.10	241.94	131.76
Yes	91	Antique Trk - 5000 lbs. Net Wt.	20.60	19.98	19.35	18.73	18.10	17.48	16.85	16.76	16.76	16.76	16.76	16.76
Yes	93	Goats	19.10	18.48	17.85	17.23	16.60	15.98	15.35	15.26	15.26	15.26	15.26	15.26
Yes	102	Agri, Trk, Trac thru 43999	109.35	102.03	94.73	87.41	80.10	72.79	65.48	58.16	50.85	43.54	36.22	28.92
Yes	102	Agri, Trk, Trac 44000 – 80000	345.60	318.60	291.60	264.60	237.60	210.60	181.60	156.60	129.60	102.60	75.60	48.60

Figure 3-20. License plate rate chart (continued).

The calculation check-off list for vehicles in Florida contains various requirements. The total registration fee for each vehicle is by individual case. For the purpose of the project, the total annual revenue collected from registration and title fees in Florida would be helpful. Based on a damage assessment model and review of current revenue from the issued permits and other associated fees such as registration and title fees, the recommendation of a new permit fee structure will be proposed for consideration by FDOT.

3.6.3. Fuel Taxes

This report includes federal, state and local tax rates per gallon of gasoline and diesel fuels in Florida. The data is obtained from the Florida Department of Revenue website (Florida Department of Revenue, 2019). All types of fuel taxes, their usage, and their reference codes are summarized in Table 3-7. The aviation fuel tax is not mentioned in this report. An elaboration of each type of tax mentioned in Table 3-7 can be found in Florida's tax sources [97].

A summary of the fuel tax rates imposed between years 2000 to 2019 is presented in Table 3-8. Since the local gasoline fuel tax is different for each county, the tax rate for each county is presented in is different. However, the total diesel fuel tax has a fixed rate for all counties. For example, the total diesel fuel tax in 2019 equals to 57.3 cents per gallon for all counties.

Table 3-7. Fuel Taxation usage and references [98].

Level	Tax Type	Usage	Reference
Federal	Fuel Excise Tax	2.86¢ for mass transit. 0.1¢ for leaking tanks. Remainder for roads and bridges.	Title 26, United States Code
State-For State Use	Fuel Sales Tax	At least 15% of FDOT receipts dedicated to public transportation. Remainder for any legitimate state transportation purpose.	206.41(1)(g), 206.87(1)(e), 206.606, 212.0501, 206.9955(2)(e), F.S.
	SCETS Tax	The net receipt must be spent in the district where generated.	206.41(1)(f), 206.608, 206.87(1)(d), 206.9955(2)(d), F.S.
State (Distributed to Local Governments)	Constitutional Fuel Tax	Acquisition, construction, and maintenance of roads.	206.41(1)(a), (b), (c) ; 206.87(1)(a), 207.003, 206.9955(2)(a), F.S.
	County Fuel Tax	Any legitimate county transportation purpose.	
	Municipal Fuel Tax	Any legitimate municipal transportation purpose.	
Local	Nine-Cent Fuel Tax	Any legitimate county or municipal transportation purpose.	206.41(1)(d), 206.87(1)(b), 336.021, 206.9955(2)(b), F.S.
	Local Option Fuel Tax (1-6¢ and 1-5¢ Fuel Tax)	Local transportation; small counties may also use funds for other infrastructure needs.	206.41(1)(e), 206.87(1)(c), 336.025, 206.9955(2)(c), F.S.

Table 3-8. Gasoline and diesel fuel tax rate per gallon in cent (2000-2019).

Year	Federal Tax		State Tx					Local Tax (Min)						Inspection fee	Total	
			Sale tax		***C, CO, M	SCETS (Min)		9th-Cent		1-6 cents		Min local option	1-5 cents		G (Min)	D
	*G	**D	G	D	G & D	G	D	G	D	G	D	G	G	G		
2019	18.4	24.4	14.1	14.1	4	7.8	7.8	0	1	6	6	13.8	0	0.125	50.425	57.3
2018	18.4	24.4	13.7	13.7	4	7.6	7.6	0	1	6	6	13.6	0	0.125	49.825	56.7
2017	18.4	24.4	13.4	13.4	4	7.4	7.4	0	1	6	6	13.4	0	0.125	49.325	56.2
2016	18.4	24.4	13.3	13.3	4	6.1	7.4	0	1	5	6	11.1	0	0.125	46.925	56.1
2015	18.4	24.4	13.3	13.3	4	6.1	7.3	0	1	5	6	11.1	0	0.125	46.925	56
2014	18.4	24.4	13.1	13.1	4	6	7.2	0	1	5	6	11	0	0.125	46.625	55.7
2013	18.4	24.4	12.9	12.9	4	6	7.1	0	1	5	6	10.9	0	n/a	46.2	55.4
2012	18.4	24.4	12.6	12.6	4	6	6.9	0	1	5	6	10.8	0	n/a	45.8	54.9
2011	18.4	24.4	12.2	12.2	4	6	6.8	0	1	5	6	10.6	0	n/a	45.2	54.4
2010	18.4	24.4	12.1	12	4	6	6.6	0	1	5	6	10.5	0	n/a	45	54
2009	18.4	24.4	12.1	12.1	4	6	6.7	0	1	5	6	10.6	0	n/a	45.1	54.2
2008	18.4	24.4	11.6	11.6	4	5	6.4	0	1	5	6	10.3	0	n/a	44.3	53.4
2007	18.4	24.4	11.3	11.3	4	5	6.2	0	1	5	6	10.2	0	n/a	43.9	52.9
2006	18.4	24.4	10.9	10.9	4	5	6	0	1	5	6	10	0	n/a	43.3	52.3
2005	18.4	24.4	10.5	10.5	4	5	5.8	0	1	5	6	9.9	0	n/a	42.8	51.7
2004	18.4	24.4	10.3	10.3	4	5	5.7	0	1	5	6	9.7	0	n/a	42.4	51.4
2003	18.4	24.4	10.1	10.1	4	5	5.6	0	1	5	6	9.6	0	n/a	42.1	51.1
2002	18.4	24.4	9.9	9.9	4	5	5.5	0	1	5	6	10	0	n/a	42.3	50.8
2001	18.4	24.4	9.6	9.9	4	3	5.3	0	1	5	6	5.7	0	n/a	37.7	50.6
2000	18.4	24.4	9.3	9.3	4	3	5.1	0	1	5	6	5.6	0	n/a	37.3	49.8

*Gasoline Fuel; **Diesel Fuel; ***Constitutional, County, and Municipal Fuel Tax; Min: Minimum

Figure 3-21 illustrates a general trend in the changes in total diesel and gasoline fuel taxes from 2000 to 2019. This figure includes the federal tax for each year. For the gasoline fuel tax, only minimum local options are considered in order to have a consistent and county independent rate for all years.

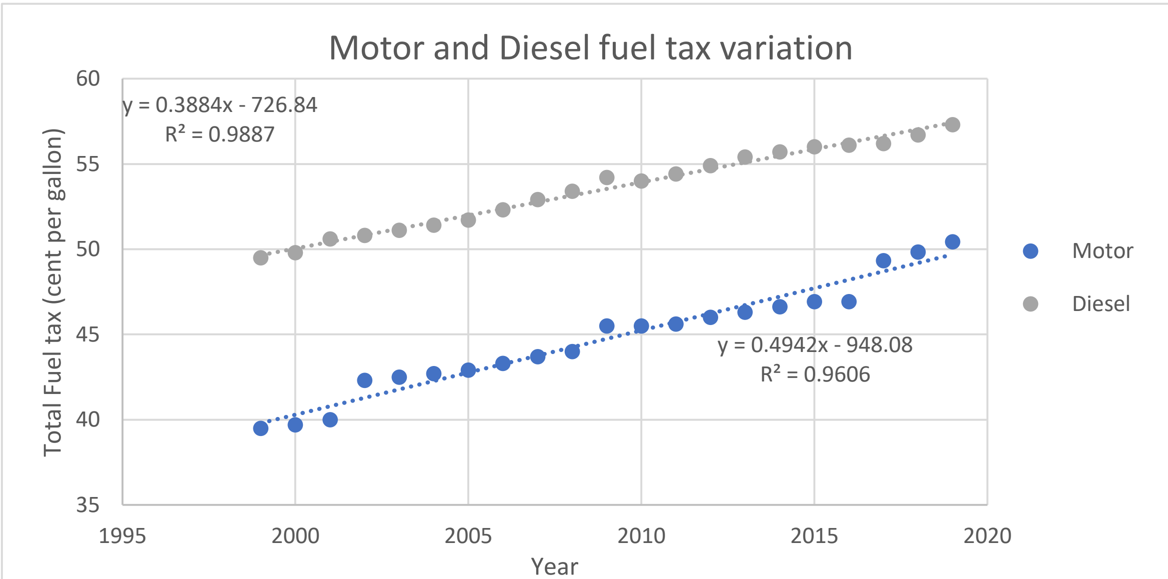


Figure 3-21. Gasoline (motor) and diesel fuel tax increasing trends (2000-2019).

As shown in Figure 3-21, the general trend shows a 0.39-cent increase of diesel fuel tax and a 0.50-cent increase in gasoline fuel taxes per gallon per year based on available data.

3.7. Interim Conclusions

The permit fee structure used in Florida is based on weight and distance traveled by the permitted vehicle. Around 400 - 450 permits are issued every day.

The issued permit data by FDOT for years 2016 to 2019 indicate that on average, 44% of the issued permits are either overweight or a combination of oversize and overweight permits.

Most of the issued permit data (75% of overall issued permit) by FDOT for years 2016 to 2019 are for single trip permits.

The upward trend is noticed for the average daily number of permits on a yearly basis.

The vehicle registration fee in Florida is based on the vehicle weight. The state of Florida collects the highest initial registration fee per vehicle in the U.S.

Fuel taxes in Florida include federal, state and local fuel taxes. The total fuel taxes have increased from the year 2000 to 2019 at a rate of increase of 0.38 and 0.54 cents per gallon per year for diesel and gasoline fuel, respectively.

The above sources of funding will be considered in a subsequent analysis as part of this Project.

PART B: BRIDGE DAMAGE COST ASSESSMENT

4. Damage Assessment Approach

The service life of a bridge depends on many factors such as traffic loads, natural hazards, defects in material production, extreme events, etc. Traffic-induced loads may cause damage to a bridge by fatigue and/or overload. Every passage of a truck across a bridge creates one or more stress cycles in the structural components, which results in the accumulation of fatigue damage over time. A bridge may experience a large number of fatigue loading cycles by heavily loaded trucks over its lifetime. If the stress cycles are of a certain number and magnitude, they will result in fatigue damage. Therefore, the damage caused by permit vehicles needs to be assessed to calculate the accelerated consumption of bridge structures [99].

In the current design code AASHTO LRFD 2017, the design life of a bridge is 75 years. AASHTO defines the design approach for traffic-induced fatigue load. The stress range is calculated for a code-specified fatigue design truck to prevent fatigue cracking caused by the accumulation of damage from repetitive truck loading. The AASHTO fatigue design truck is intended to represent truck traffic. However, in the service life of a bridge, there is the uncertainty of the traffic loads that the bridge experiences. The fatigue truck is expressed as 0.80 of the design truck HL-93. [100].

Bridge consumption may be assumed to be a fatigue process in which each load passage over a given bridge consumes part of the bridge's design life. The passage of each heavy truck uses a small amount of the fatigue life of a bridge. In this research, the goal is to quantify the damage produced by different groups of permit vehicles to assess the consumption in dollars on Florida's highway infrastructure. A permit database and WIM records are utilized as input data for the damage assessment.

FDOT has a database called Permit Application System (PAS), which contains information about all issued Overweight/Oversize (OW/OS) permit vehicles in Florida. The FDOT issues permits for oversized (overlength, overwidth, overweight, or any combination of the three) and overweight vehicles, and for the combination of overweight and oversize vehicles. In Florida, there are three major types of permits that are time-dependent permits: single trip permit and multi-trip permits for 3 and 12 months. In this study, the PAS database will serve as a primary source of information to assess the damage caused by permit vehicles operating on Florida bridges and roads. The data include information about the specific type of permit and, more importantly, about axle spacing, axle weight, and the GVW of issued permit vehicles. The permit data is crucial for this research to assess the damage caused by actual permitted vehicles in Florida. The data for the analysis is from 2016 to 2019, with a lack of data for December 2019.

The fatigue resistance of a material and connection detail is usually presented as a relationship between stress range and the number of fatigue load cycles to failure on a logarithmic scale called an S-N curve. The resistance relates the magnitude of the applied constant-amplitude stress range (S) to the corresponding number (N) of cycles to failure of the fatigue detail. Equation 27 shows a relationship between stress range and the number of cycles to failure.

$$A = N \cdot S^m \qquad \text{Eq. 27}$$

where:
N – Number of cycles to failure,
A – constant for a given category of fatigue details,
S – stress range,
m – fatigue exponent, material dependent, as shown in Table 4-1.

The AASHTO LRFD utilizes a group of S-N curves that were developed by extensive laboratory testing of different detail categories that are commonly used in. These AASHTO S-N curves are shown in Figure 4-1.

Table 4-1. Values of *m* for bridge fatigue analysis [86].

Structure Type	m
Concrete Slab 101	4.1
Concrete Girders 102	3.5
Concrete T Beam 104	4.1
Concrete Box Beam 105	4.1
Concrete Continuous Slab 201	4.1
Concrete Continuous T Beam 204	4.1
Steel Girder 302	3.0
Steel Continuous Girders 402	3.0
Steel Continuous Girder 403	3.2
Steel Continuous Box Beam 405	3.2
Steel Continuous Box Beam 406	3.2
Prestressed Concrete 500	3.5
Prestressed Concrete Slab 501	3.5
Prestressed Concrete Girder 502	3.5
Prestressed Concrete Box Beam 505	3.5
Prestressed Concrete Continuous 601	3.5
Prestressed Concrete Continuous 602	3.5

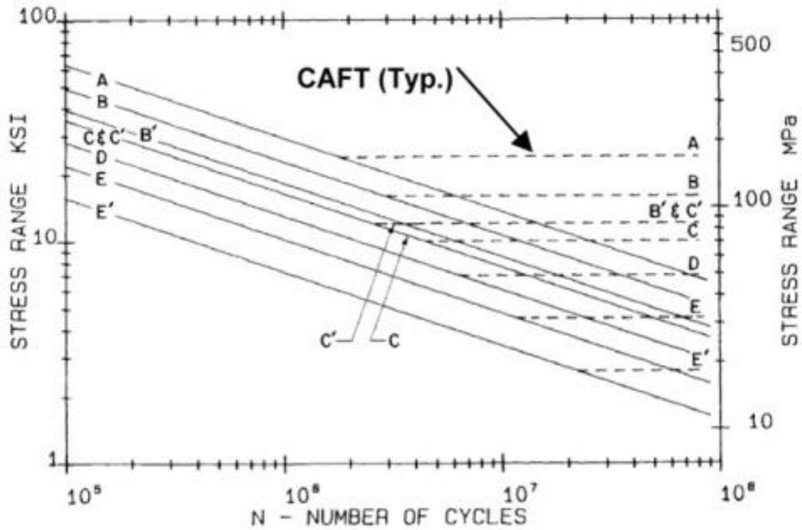


Figure 4-1. Stress range vs. number of cycles (AASHTO 2017).

Bridges are subject to variable amplitude stress cycles. A cumulative damage theory is used to calculate the effective stress range from variable amplitude stress cycles. The Palmgren-Miner (Miner 1945) rule provides a rational method to account for variable amplitude stress cycles on bridges. Miner's rule accounts for the cumulative damage from a spectrum of applied stress ranges of variable amplitude. Using Miner's rule, an equivalent constant amplitude stress range, referred to as the effective stress range S_{eff}, and can be calculated by:

$$S_{\mathrm{eff}} = \left[\sum \frac{n_i}{N} S_i^m\right]^{1/m} \qquad \text{Eq. 28}$$

where:

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

N – total number of cycles

S_i – constant amplitude stress range.

At a specific point along a bridge, the applied range of bending moment can be determined by multiplying the applied stress range by the section modulus. Multiplying each side of Eq. 28 by the section modulus results in the effective moment range.

Each permit truck that passes over a bridge creates bending moment at points along the span, and the bending moment at each point changes as the truck crosses. This change in bending moment may result in a single cycle or multiple cycles of different magnitudes depending on the geometry of the truck and the bridge. In this study, the variation of bending moment at midspan due to a permit truck crossing is determined by passing the truck across an influence line. The rain flow counting method (ASTM E1049-85) is used to determine the number and magnitudes of the individual moment cycles resulting from each permit truck. Eq. 29 is then used to determine the equivalent single cycle bending moment that accounts for all the fatigue damage due to multiple cycles caused by the passage of a truck. The equivalent moment can be calculated by:

$$M_{eq} = \left[\sum n_i M_i^m\right]^{1/m} \qquad \text{Eq. 29}$$

where:
M_i – i^{th} moment range.

In the current code, the number of fatigue cycles defining the service life is represented by the relationship between the bridge design life and the truck traffic volume. The AASHTO LRFD assesses this number of cycles in the 75-year service life as:

$$N = (365)(75)n\,(ADTT)_{SL} \qquad \text{Eq. 30}$$

where:
365 – days in a year,
75 – design life of a bridge in years,
n – number of stress range cycles per truck passage (AASHTO 2017, Table 6.6.1.2.5-2),
$(ADTT)_{SL}$ – single-lane average daily truck traffic (AASHTO 2017, Article 3.6.1.4).

The number of crossings of AASHTO's standard fatigue design truck that will cause the same amount of fatigue damage as a specific permit truck can be found by setting the amount of damage equal, which can be expressed as follows:

$$1 \cdot {M_{permit}}^m = N_f \cdot {M_{fatigue\ truck}}^m \qquad \text{Eq. 31}$$

Where:
M_{permit} – equivalent moment range due to permit truck,
$M_{fatigue\ trauck}$ – equivalent moment range due to fatigue truck,
N_f – number of fatigue truck crossings.
The consumption ratio between permit vehicle and fatigue truck can be expressed as:

$$N_f = \left(\frac{M_{permit}}{M_{fatigue\ truck}}\right)^m \qquad \text{Eq. 32}$$

The purpose of the damage assessment analysis is to find the monetary consumption by the permitted vehicles. The consumption of a bridge's value due to one cycle of loading from the standard fatigue design truck is equal to the total cost of construction of the bridge divided by the number of cycles in the service life. The consumption due to the crossing of a permit vehicle can be expressed as:

$$Consumption_{permit} = \frac{Total\ Cost \cdot N_f}{N} \qquad \text{Eq. 33}$$

Substituting Eq. 30 and Eq. 32, the consumption equation for a permit vehicle can be expressed as:

$$Consumption_{permit} = \left(\frac{Total\ Cost}{(365)(75)n\ (ADTT)_{SL}}\right) \cdot \left(\frac{M_{permit}}{M_{fatigue\ truck}}\right)^m \qquad \text{Eq. 34}$$

The consumption equation (Eq. 34) assesses the damage in dollars caused by a permitted vehicle on a single representative bridge in Florida. Statistical analysis for bridges in Florida will be conducted in order to find representative bridge parameters such as total cost, ADTT in single lane, span length, and also material and structural types that are needed to select a value for the fatigue exponent *m*.

The consumption from Eq. 34 is the total consumption of a permit vehicle. In fairness, it is necessary to subtract the consumption that would be allowed without a permit if the vehicle met the legal load limits. A statistical analysis based on the WIM database was conducted to find a representative legal vehicle in Florida traffic. The consumption caused by the typical legal vehicle can be expressed as:

$$Consumption_{legal} = \left(\frac{Total\ Cost}{(365)(75)n\ (ADTT)_{SL}}\right) \cdot \left(\frac{M_{legal}}{M_{fatigue\ truck}}\right)^m \qquad \text{Eq. 35}$$

where:
M_{legal} – equivalent moment range due to the typical legal vehicle in Florida traffic.

The incremental consumption of the permit vehicle that is associated with the permit fee can be expressed as consumption due to the permit vehicle minus the consumption of a legal vehicle. Equation 36 shows the incremental consumption that is calculated for each permitted vehicle from the PAS database.

$$Incremental\ Consumption = Consumption_{permit} - Consumption_{legal} \qquad \text{Eq. 36}$$

The consumption analysis is conducted for different groups of vehicles, based on GVW ranges according to the current permit fee schedule and permit type: single trip permit, and multi-trip permit for 3 and 12 months.

The damage assessment approach used in this study is formulated as follows:

1- Determine representative bridge parameters: total cost, ADTT in a single-lane, span length, material, and structural type.
2- Find a representative legal vehicle for Florida traffic.
3- Run permit vehicles over an influence line to obtain a bending moment history at midspan.
4- Use rain flow counting to determine the number and magnitudes of cycles from the bending moment history and calculate the equivalent moment value.
5- Determine equivalent moments for representative legal vehicles and the fatigue truck.
6- Calculate the incremental consumption for each permit vehicle and each permit type.
7- Find the average consumption for each permit type and GVW group according to the current permit schedule.
8- Combine the bridge and pavement consumption.
9- Compare the consumption analysis results with the current permit fee schedule in Florida.
10- Introduce a new permit fee schedule.

All steps of the analysis are shown in the subsequent sections of this report.

5. Representative Bridge Parameters for Consumption Assessment

The statistical analysis of bridges in Florida is based on the National Bridge Inventory (NBI) database. The most recent NBI data for 2018 was used. The data shows 12,435 bridges and culverts in Florida. In Figure 5-1, all structures in Florida are shown. The NBI indicates that 42 bridges are closed to traffic, and there are two bridges that are not yet opened to traffic. It contains 12,391 operable bridges and culverts in Florida.

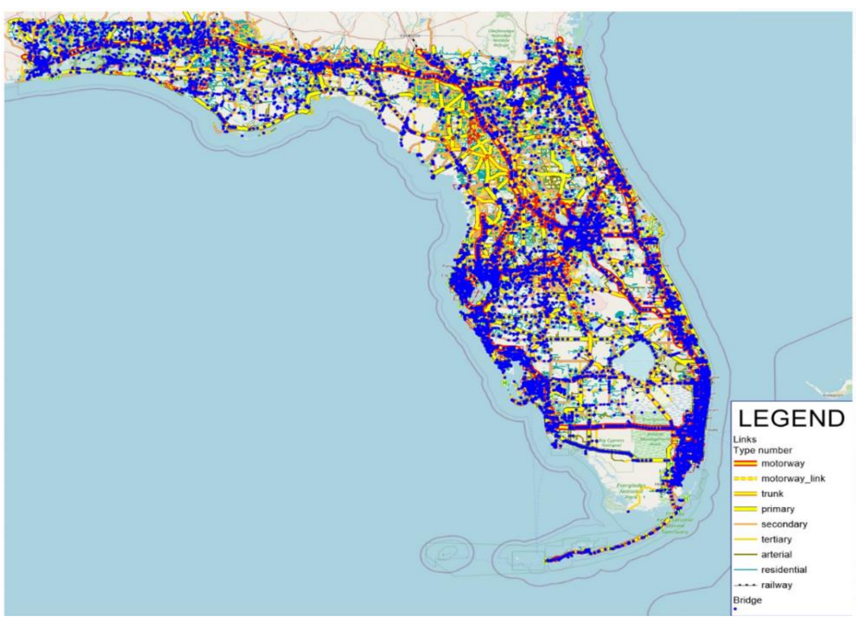


Figure 5-1. Bridges in Florida based on the NBI database.

The NBI is a great source of information about various bridge parameters. The NBI contains information about the structural and material type of bridges, which shows the most common types of bridges in Florida. The statistics show that the most common material type is prestressed concrete (over 50% of bridges). The most common structural type in Florida is stringer/multibeam or girder bridges (43%) and slab bridges (27%). The total length of the bridge and the maximum span length is presented in the database. From the analysis, 80% of bridges have the maximum span length less than 90 ft.

The National Bridge Inventory Data for 2018 indicates that there are 9,970 bridges opened for traffic in Florida. Bridges are placed on different roads, and it is specified by a functional route classification. The number of bridges and the corresponding Average Daily Truck Traffic for each functional classification is shown in Table 5-1.

Table 5-1. Bridges in Florida based on the functional classification of the inventory route.

Functional Classification of Inventory Route	No. of Bridges	% of bridges	Average ADTT
Principal Arterial - Interstate	1,675	17%	4,346
Principal Arterial - Other Freeways or Expressways	1,969	20%	2,263
Other Principal Arterial	1,129	11%	1,388
Minor Arterial	1,286	13%	771
Major Collector	453	5%	160
Minor Collector	1,243	12%	420
Local	2,215	22%	225

The summary of bridges on different inventory routes shows that the operation of the heavy trucks is dominating in the first three functional classes: principal arterial - interstate, principal arterial - other freeways and expressways, and other principal arterials. Bridges considered in this study are bridges in these three classes. Representative bridges that carry heavy traffic are to be utilized in that study.

For this study, it is necessary to determine the length of the selected roads. Based on the Florida Transportation Trends and Conditions Report [101], which considers the roadway system, the total centerline miles for functional classification are provided in Table 5-2.

Table5-2. Florida public road centerline miles by functional classification [101].

	Principal Arterials			Minor Arterials	Urban/Rural Major Collectors	Rural Minor Collectors	Local	Total
	Interstate	Turnpike & Freeways	Other					
2001	1,472	455	6,448	5,720	10,117	4,103	88,985	117,301
2002	1,472	470	6,245	5,915	10,129	4,089	91,464	119,785
2003	1,471	470	6,145	6,017	10,143	4,052	92,078	120,376
2004	1,471	548	6,415	6,427	10,927	3,456	90,280	119,525
2005	1,471	550	6,414	6,431	10,915	3,352	91,423	120,556
2006	1,470	578	6,434	6,426	10,935	3,352	92,799	121,995
2007	1,471	576	6,448	6,423	10,951	3,353	92,305	121,526
2008	1,470	584	6,454	6,453	10,950	3,339	92,136	121,387
2009	1,471	770	6,294	6,485	11,072	3,337	92,017	121,446
2010	1,496	746	6,292	6,505	11,186	3,310	92,167	121,702
2011	1,496	747	6,289	6,520	11,227	3,296	92,185	121,759

Permit vehicles primarily operate on the main roads of Florida due to the overweight and oversize limitations. The total centerline miles of the main roads are 8,532 miles based on the data in Table 5-2 for 2011 (interstate 1,496 miles, Turnpike and freeways 747 miles, and 6,289 miles for others).

In the previous chapter, the consumption equation was derived. The consumption is to be calculated for a representative bridge in Florida. The NBI database is the main source of data for selecting the representative bridge parameters. To assess bridge consumption in dollars, equivalent moments must be calculated, which requires a bridge span length. The span length will be assessed based on NBI data. Also, the material and structural type of the bridge is required for the selection of the *m* constant shown in Table 5-1. Moreover, traffic data such as Average Daily Traffic (ADT) and the percentage of Average Daily Truck Traffic (ADTT) is provided for each bridge in the NBI database. In the consumption equation, ADTT per single line is required. The distribution of the heavy traffic per lanes needs to be assessed for typical bridges in Florida. This is to be evaluated using traffic distribution information available in the WIM database. The last parameters necessary for the analysis are the total construction cost of representative bridges. The data for the construction cost is not available in the NBI database.

The Florida Department of Transportation released the transportation cost report that shows the cost of a new bridge construction per square foot [102]. The bridge cost is defined for short-span (20 to 45 feet), medium-span (45 to 150 feet), and long-span (over 150 feet) bridges. Bridges are grouped by structural and material types. The cost per square foot is given as low and high. The cost was estimated based on the FDOT experience and the contract/bid databases. In recent years, the overall trend has been an increase in bridge construction costs. However, a few categories of costs have decreased. FDOT indicated that a large proportion of the statewide highway construction budget, usually more than 20%, is devoted to bridge construction.

Typically, FDOT completes between 100 and 200 bridges each year. Figure 5-2 shows the asset values of the new bridge construction costs in Florida.

New Construction

(Cost per Square Foot)

Bridge Type	Low	High
Short Span Bridges:		
Reinforced Concrete Flat Slab Simple Span*	$115	$160
Pre-cast Concrete Slab Simple Span*	$110	$200
Reinforced Concrete Flat Slab Continuous Span*	NA	NA
Medium and Long Span Bridges:		
Concrete Deck/ Steel Girder - Simple Span*	$125	$142
Concrete Deck/ Steel Girder - Continuous Span*	$135	$170
Concrete Deck/ Pre-stressed Girder - Simple Span	$90	$145
Concrete Deck/ Pre-stressed Girder - Continuous Span	$95	$211
Concrete Deck/ Steel Box Girder – Span Range from 150' to 280' (for curvature, add a 15% premium)	$140	$180
Segmental Concrete Box Girders - Cantilever Construction, Span Range from 150' to 280'	$140	$160
Movable Bridge - Bascule Spans and Piers	$1,800	$2,000
* Increase the cost by twenty percent for phased construction.		

Figure 5-2. New bridge construction costs by FDOT [102].

The construction cost data can be used along with the NBI database to compile costs with other bridge parameters needed for damage assessment. In this study, the NBI data for 2018 is used to find bridges filtered by the span length and the structural bridge type and material to match with cost categories indicated by FDOT (Figure 5-2). Table 5-3 shows the number of bridges for selected functional road classification and cost categories.

Table 5-3. Statistics of representative bridges in Florida.

Type	**No. of Bridges**	**% of bridges**
1	**2**	**3**
RC Slab, Simple Span	194	4%
Precast Slab	580	12%
Steel Girder, Simple Span	269	6%
Steel Girder, Continuous Span	246	5%
P/C Girder, Simple Span	2747	58%
P/C Girder, Continuous Span	63	1%
Steel Box	108	2%
Box Girder	45	1%
Others	521	11%
Total	4,773	100%

The total number of bridges considered by a functional class of roads matching the cost categories is 4,773. This is called the *bridge sample database,* and it will be used in the following subchapters to find the representative bridge parameters for the consumption equation.

5.1. Total Construction Cost

Using the bridge sample database and corresponding asset values in dollars per square foot from Table 5-2, the average cost for each bridge can be calculated. The average area of the bridge is computed using deck width and the total length of the bridge from the NBI database. The area was calculated for each bridge, and afterward, the average of each group was determined. The average cost of each bridge group can be calculated using the average area of the bridge in square feet and asset value in dollars per square feet.

The parameter required for the damage assessment analysis is the average cost of a representative bridge in Florida in dollars per mile of road. As previously mentioned, the centerline length of main roads in Florida is used. The total centerline miles of main roads are 8,532 miles. The total cost of bridges on selected roads in Florida needs to be assessed to find the cost of a bridge in dollars per mile.

Bridge cost calculation needs to be adjusted to the centerline length of the roads. In this case, bridges are divided into three bridge groups: two traffic directions and one traffic direction, on the right and left sides. The total cost for each group is computed. Bridges that were not assigned to any cost category are called “others.” The asset value of the “others” bridges was calculated as a weighted average of known asset values. In Tables 5-4, 5-5, and 5-6, the total cost of bridges in dollars is calculated.

Table 5-4. Group A, bridge structures for two traffic directions.

Type	No. of Bridges	Asset Value [$/ft^2]	Average Area [ft^2]	Total Cost [$]
1	2	3	4	2*3*4
RC Slab, Simple Span	90	165	7,172	106,499,941
Precast Slab	199	186	12,419	459,674,549
Steel Girder, Simple Span	92	160	29,860	439,538,236
Steel Girder, Continuous Span	151	183	52,193	1,442,241,108
P/C Girder, Simple Span	773	118	30,274	2,761,432,157
P/C Girder, Continuous Span	25	153	141,550	541,429,832
Steel Box	82	160	41,584	545,588,192
Box Girder	15	150	28,220	63,493,936
Others	269	143	54,179	2,084,121,472
Total	1,696		397,451	8,444,019,421

Table 5-5. Group B, parallel bridge structures, right side.

Type	No. of Bridges	Asset Value [$/ft^2]	Average Area [ft^2]	Total Cost [$]
1	2	3	4	2*3*4
RC Slab, Simple Span	56	165	5,696	52,635,374
Precast Slab	181	186	8,054	271,135,891
Steel Girder, Simple Span	91	160	33,338	485,398,008
Steel Girder, Continuous Span	53	183	71,583	694,280,856
P/C Girder, Simple Span	973	118	21,404	2,457,432,862
P/C Girder, Continuous Span	18	153	133,616	367,977,852
Steel Box	13	160	60,819	126,503,791
Box Girder	18	150	14,482	39,100,953
Others	130	143	19,294	358,683,236
Total	1,533		368,285	4,853,148,822

Table 5-6. Group C, parallel bridge structures, left side.

Type	No. of Bridges	Asset Value [$/ft^2]	Average Area [ft^2]	Total Cost [$]
1	2	3	4	2*3*4
RC Slab, Simple Span	48	165	6,241	49,425,697
Precast Slab	200	186	7,589	282,312,645
Steel Girder, Simple Span	86	160	35,592	489,747,310
Steel Girder, Continuous Span	42	183	65,618	504,336,933
P/C Girder, Simple Span	1001	118	19,675	2,323,928,826
P/C Girder, Continuous Span	20	153	186,342	570,207,383
Steel Box	13	160	59,982	124,762,084
Box Girder	12	150	15,160	27,288,488
Others	122	143	21,303	371,654,487
Total	1,544		417,501	4,743,663,853

The cost of sample bridges for different groups was computed. The total cost of bridges for parallel or non-parallel structures needs to be calculated. The total cost of the two-direction bridges is shown as half the cost. The cost of the non-parallel structures is calculated as a weighted average based on the bridge deck area. The final cost analysis is shown in Table 5-7.

Table 5-7. Total cost of bridge sample per direction.

Type	**Total Cost [$] Group A**	**Total Cost [$] Group B**	**Average Area B [ft2]**	**Total Cost [$] Group C**	**Average Area C [ft2]**	**Total Cost [$]**
1	**2**	**3**	**4**	**5**	**6**	**0.5*2+ (3*4+5*6)/ (4+6)**
RC Slab, Simp. Span	106,499,941	52,635,374	5,696	49,425,697	6,241	104,207,350
Precast Slab	459,674,549	271,135,891	8,054	282,312,645	7,589	506,395,546
Steel Girder, Simp. Span	439,538,236	485,398,008	33,338	489,747,310	35,592	707,412,898
Steel Girder, Cont. Span	1,442,241,108	694,280,856	71,583	504,336,933	65,618	1,324,558,585
P/C Girder, Simp. Span	2,761,432,157	2,457,432,862	21,404	2,323,928,826	19,675	3,774,206,481
P/C Girder, Cont. Span	541,429,832	367,977,852	133,616	570,207,383	186,342	756,470,430
Steel Box	545,588,192	126,503,791	60,819	124,762,084	59,982	398,433,070
Box Girder	63,493,936	39,100,953	14,482	27,288,488	15,160	64,806,509
Others	2,084,121,472	358,683,236	19,294	371,654,487	21,303	1,407,550,498
Total	8,444,019,421	4,853,148,822	68,285	4,743,663,853	417,501	**9,044,041,366**

The total cost of the sample bridge database is $9,044,041,366. The cost per mile of road is approximately **$1M/mile**. This value is used as the representative cost of a bridge in Florida for permit vehicle operation.

5.2. Average Daily Truck Traffic

Average Daily Truck Traffic is used in the NBI database 2018. For each bridge group in the sample bridge database, the average ADTT was found. In NBI, ADTT is used for a cross-section of the road, and for both traffic/bridge directions. The weighted average ADTT was calculated for two-direction bridges. The results of the analysis are shown in Table 5-8.

Table 5-8. Weighted average ADTT for a representative bridge in Florida.

Type	No. of Bridges	Average ADTT [vehicles/day]
1	**2**	**3**
RC Slab, Simple Span	194	1806
Precast Slab	580	1742
Steel Girder, Simple Span	269	3595
Steel Girder, Continuous Span	246	2081
P/C Girder, Simple Span	2747	3337
P/C Girder, Continuous Span	63	1670
Steel Box	108	1274
Box Girder	45	2839
Others	521	1778
Weighted Average		**2787**
ADTT per direction		**1394**

The weighted average was computed for the road cross-section and then determine the average for one direction. The weighted average ADTT per direction is 1,394 [vehicles/day].

In AASHTO LRFD, the frequency of the fatigue load is used as the single-lane average daily truck traffic $ADTT_{(SL)}$. The single-lane ADTT is shown in Eq. 37.

$$ADTT_{(SL)} = p\ ADTT \qquad \text{Eq. 37}$$

where:

p – a fraction of traffic in a single lane specified in Table 5-9.

Table 5-9. A fraction of truck traffic in a single lane by AASHTO 2017.

Number of Lanes Available to Trucks	*p*
1	1.00
2	0.85
3 or more	0.80

An average number of lanes for sample bridges was estimated as three lanes. Using the AASHTO LRFD recommendations, the fraction of truck traffic is designated as 0.80. That value is conservative and might not reflect the real traffic distribution per single lane, which is why the Auburn Team decided to utilize the WIM data for Florida to assess the actual traffic distribution.

In Florida, there are 33 WIM station locations. Figure 5-3 shows the WIM station locations. In this study, data from 2012 and 2014-2017 was used to assess the traffic lane distribution.

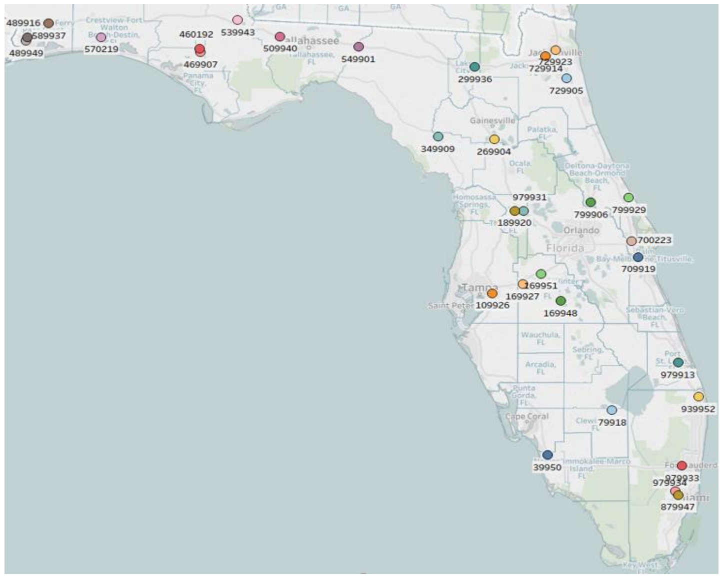


Figure 5-3. WIM stations in Florida.

WIM data recognizes traffic for each lane. Each WIM station has a different number of lanes. The traffic distribution for all WIM stations was only considered for lanes one, two, and three. The fraction of the truck traffic was determined to be 67%. Next, only the WIM stations that had three lanes were considered, and the fraction of the truck traffic was found to be 66%. Based on the WIM database analysis of traffic lane distribution, the fraction of traffic in one lane is assumed to be 70%. Thus, the results of the ADTT per single lane for a representative bridge in Florida is 1,000 trucks per day.

5.3. Span Length

The maximum span length for each bridge type category in the sample bridges is computed. Then, a weighted average span length for a representative bridge is determined. Table 5-10 shows the results of the span length analysis.

Table 5-10. Weighted average span length of a representative bridge in Florida.

Type	No. of Bridges	Average Max Span [ft]
1	**2**	**3**
RC Slab, Simple Span	194	29
Precast Slab	580	33
Steel Girder, Simple Span	269	149
Steel Girder, Continuous Span	246	178
P/C Girder, Simple Span	2747	89
P/C Girder, Continuous Span	63	129
Steel Box	108	213
Box Girder	45	122
Others	521	76
Weighted Average		**89**

The weighted average span length for a representative bridge in Florida is designated in this study as 90 ft.

5.4. Material and Structural Types of Bridges

Using the sample bridge data statistics, it is evident that the most common bridges in Florida are prestressed concrete (P/C) bridges. The P/C bridges account for about 60% of all bridges in Florida. The consumption equation includes the fatigue exponent *m* that is dependent on material and structural types. Table 5-1 shows the values of *m* for various material and structural types. In the consumption analysis, the value of *m* is designated as 3.50, as indicated for the prestressed concrete bridge.

5.5. Typical Legal Vehicles in Florida

In order to find the typical legal vehicle in Florida, available WIM data is used. The first step is to check the FHWA classification distribution of vehicle classes. The WIM data for all stations was filtered by vehicle class, and it was found that the class 9 vehicles account for over 50% of all vehicles in Florida traffic. The statistics of that analysis are shown in Table 5-11.

Table 5-11. Number of class 9 vehicles in Florida traffic.

Year	Class 9 vehicles	All vehicles	% of class 9 vehicles
2012	23,250,873	40,515,574	57%
2014	24,094,406	42,004,699	57%
2015	25,136,370	44,384,905	57%
2016	23,306,032	43,282,958	54%
2017	22,344,784	41,625,651	54%
Sum	118,132,465	211,813,787	56%

The vehicle class 9 is the most common truck in Florida traffic. The legal gross vehicle weight in Florida is set as 80 kip. Based on this information, the typical legal vehicle configuration was checked for legal GVW and typical class 9 vehicle characteristics based on available WIM data. Tables 5-12 and 5-13 show the average spacings and axle weights for each year of WIM data.

Table 5-12. Average axle spacing for FHWA Class 9 vehicle.

Year	Spacing 1	Spacing 2	Spacing 3	Spacing 4
2017	16.8	4.3	32.6	5.0
2016	16.6	4.3	32.5	4.6
2015	16.8	4.3	32.0	4.8
2014	16.7	4.3	32.6	4.7
2012	16.8	4.3	32.8	4.7
Average	**16.7**	**4.3**	**32.5**	**4.8**

Table 5-13. Average axle weights for FHWA Class 9 vehicle.

Year	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
2017	11.8	17.1	16.7	17.3	17.2
2016	11.8	17.1	16.7	17.3	17.2
2015	11.7	17.0	16.7	17.3	17.4
2014	11.7	17.0	16.7	17.2	17.4
2012	11.7	17.0	16.7	17.2	17.3
Average	**11.7**	**17.0**	**16.7**	**17.3**	**17.3**

The Truck Empty Backhaul report [103] shows that class 9 vehicles are 60-80% of all trucks passing through WIM stations in Florida. Based on WIM data analysis, the FDOT found that the average spacings and weights for the class 9 trucks included the five-axle semi-truck. Table 5-14 shows a summary of the average parameters for the class 9 truck.

The average loaded class 9 vehicle has the following average axle spacings: 17, 4, 27, 7 feet, and the axle loadings: 12.25, 15.6, 17.4, 19 18.5 kip. These axle weights give the vehicle a total gross weight of 82.75 kip. These parameters describe the typical legal class 9 vehicle.

Table 5-14. Axle spacing and weights for FHWA Class 9 vehicle [103].

	Weight (lb), by Type of Axle or Vehicle								Spacing (ft), by Type of Axle			
Statistic	Steer	Drive No. 1	Drive No. 2	Trailer No. 1	Trailer No. 2	GVW (lb)	NVW (lb)	Log Weight (lb)	Steer to Drive No. 1	Drive No. 1 to Drive No. 2	Drive No. 2 to Trailer No. 1	Trailer No. 1 to Trailer No. 2
Loaded												
Average	12,225	15,610	17,369	19,020	18,478	82,701	32,331	50,370	17	4	27	7
SD	2,856	4,668	2,785	3,287	2,570	4,064	1,879	4,528	1.5	0.2	2.6	2.5
Maximum	18,540	25,900	22,680	22,660	25,300	91,900	36,120	60,380	19	4.5	32.5	10.5
Minimum	9,030	5,660	10,300	8,160	13,230	78,060	30,860	44,070	14	4	24	4
Sample	20	20	20	20	20	20	20	20	20	20	20	20
Empty												
Average	9,930	6,953.3	6,736	4,011	4,493	32,257	32,158	0	16	4	28	6
SD	609	657	714	573	515	1,904	1,954	0	1.7	0.2	3.1	1.7
Maximum	10,640	8,180	7,940	5,010	5,080	35,560	35,560	0	19	4.5	32.5	8.5
Minimum	8,650	6,220	6,000	3,220	3,490	30,860	30,860	0	14	4	24	4
Sample	12	12	12	12	12	12	12	12	12	12	12	12

NOTE: No. = number; SD = standard deviation.

Considering the above-mentioned typical class 9 vehicle characteristics based on the FDOT study and the WIM data analysis, equivalent moments as defined in Eq. 29 are computed. The equivalent moment for the typical class 9 vehicle using the characteristics from FDOT is 1117.5 kip-ft, and 1025.5 kip-ft from the WIM data analysis. The next step is to calculate the equivalent moments of the class 9 vehicles for available WIM data. The vehicles selected from the WIM database are 80 kip +/- 5%. The distribution for equivalent moments is plotted and shown in Figure 6-4.

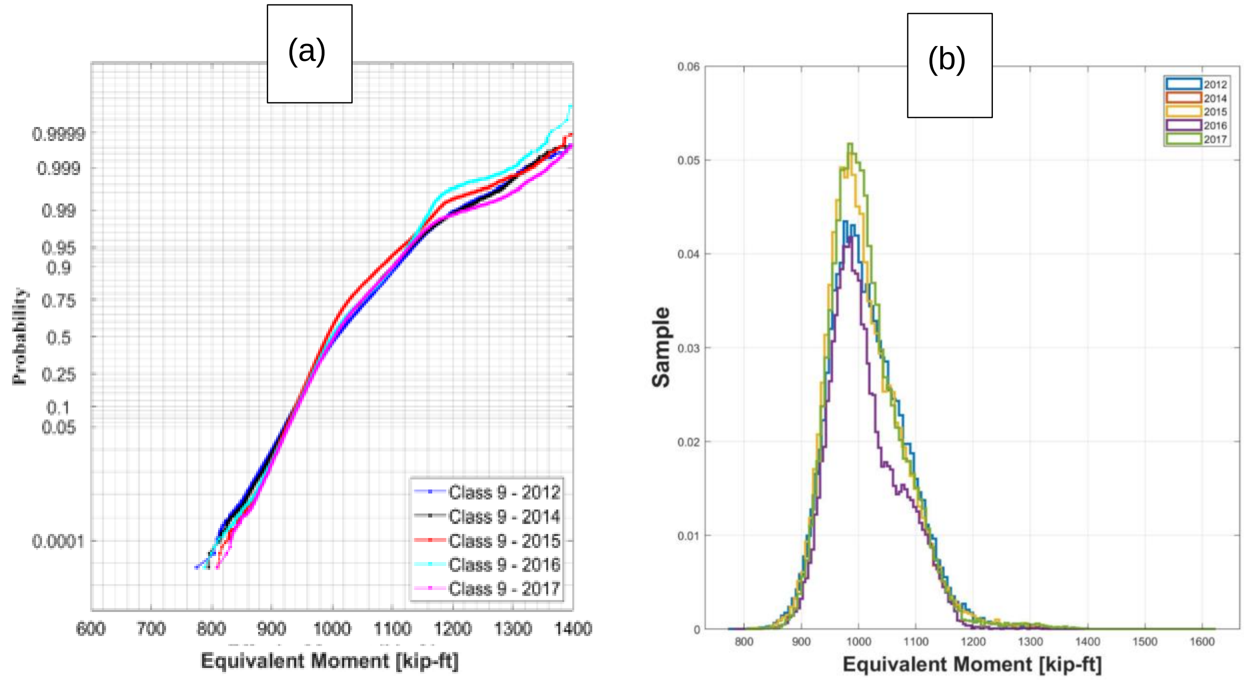


Figure 5-4. CDF of equivalent moment distribution for class 9 vehicles: (a) CDF; (b) histogram.

From the analysis, it was decided to consider 95 quantiles of the equivalent moment, which is 1130 kip-ft. This means that the upper tail value is designated as a representative legal vehicle.

The consumption of the representative legal vehicle will be used to calculate $Consumption_{legal}$ defined in Eq. 35 and then utilized to find the incremental consumption for each issued permit vehicle in Florida.

5.6. Length of the Permit Trip Using the GIS System

It was found in the permit database that each permitted vehicle has an assigned origin and destination that specify the route that the vehicle is allowed to operate on. Using that information, it is possible to compute the routes from the origin to the destination using the GIS system.

Using the dedicated software, a very detailed road network was input. Figure 5-5 shows the Florida map with all specified roads.

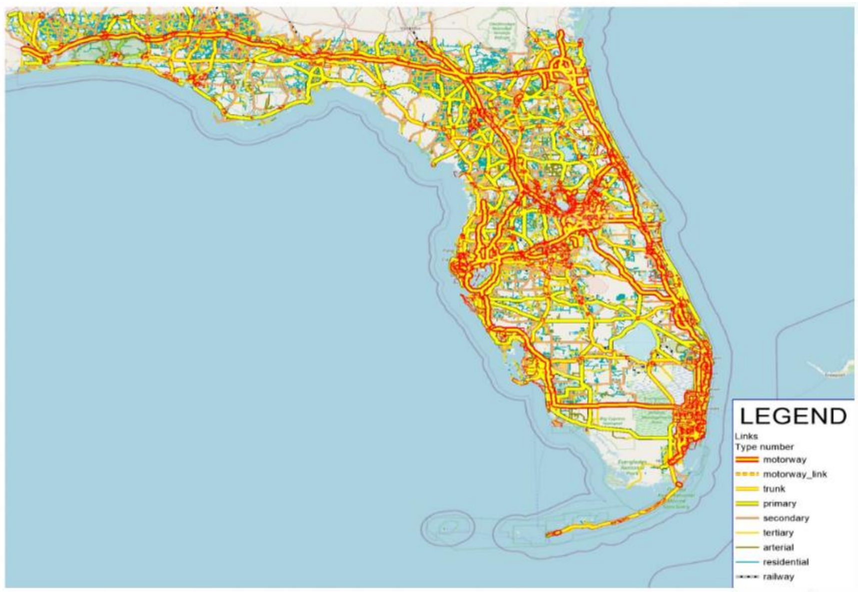


Figure 5-5. Road network in Florida.

Based on the permit database, the algorithm was developed to find the possible routes for permits and calculate the length of the route (Figure 5-6). The calculation was conducted for all types of permits.

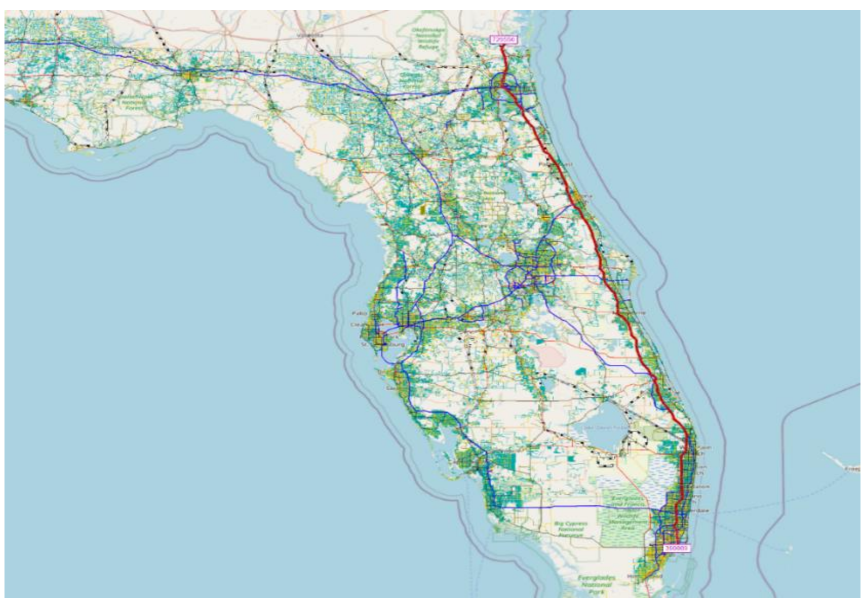
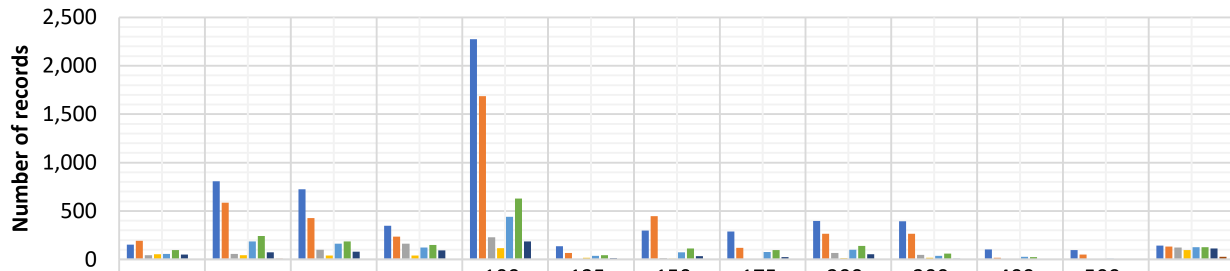


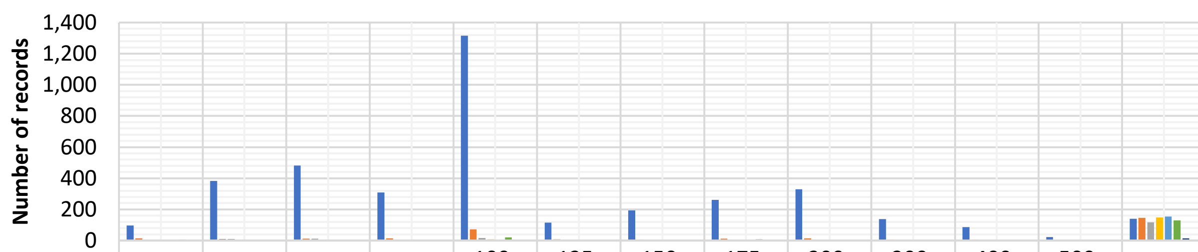
Figure 5-6. The route between the selected trip's origin and destination calculated by the dedicated software.

Figure 5-7 shows the length of the possible routes for permitted vehicles computed for every GVW category according to the actual permit fee structure. Calculated lengths are given in ranges from 11 to 600 miles. The average for each GVW group is also given.



	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-300	300-400	400-500	500-600	average
95	153	806	726	348	2,275	137	298	290	396	395	104	97	143
112	194	585	428	236	1,687	67	448	121	266	264	16	49	134
122	44	57	99	163	229	6	15	4	68	47	0	8	125
142	53	45	40	39	117	16	12	1	14	17	0	0	97
162	56	186	164	123	442	37	72	78	99	37	28	11	126
152	97	241	185	151	630	44	113	97	141	59	24	9	125
199	49	73	80	95	185	13	35	23	53	10	8	2	112
>199	4	10	0	0	0	0	0	0	0	0	0	0	29

(a)



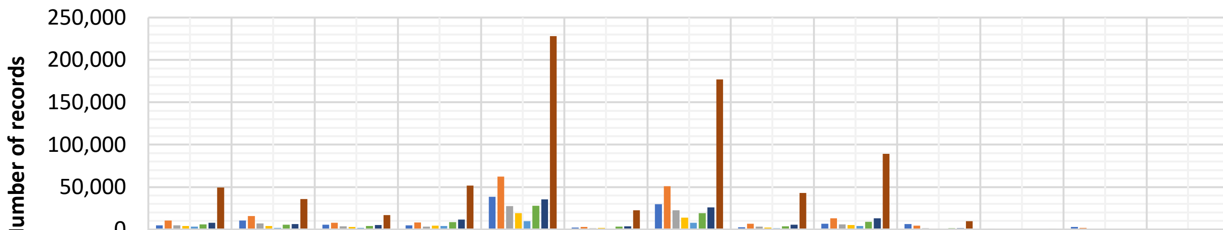
	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-300	300-400	400-500	500-600	average
95	96	382	481	308	1,315	115	194	261	329	138	87	22	139
112	14	11	13	15	71	9	6	12	15	6	6	2	146
122	0	10	13	1	17	2	1	2	4	0	2	1	118
142	0	1	3	1	8	3	1	0	3	0	1	0	148
162	1	2	2	0	5	0	1	1	1	1	1	0	155
152	5	5	3	2	20	1	2	8	1	2	1	0	129
199	7	0	0	0	0	0	0	0	0	0	0	0	13
>199	0	0	0	0	0	0	0	0	0	0	0	0	0

(b)

Figure 5-7. Permit vehicles route lengths: (a) Multi-trip 12-month permit, type 800; (b) Multi-trip 12-month permit, type 804.

	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-300	300-400	400-500	500-600	average
95	2	0	1	0	5	0	0	1	1	2	0	0	0
112	19	20	39	17	160	1	71	34	54	0	0	2	147
122	22	0	11	1	22	0	0	0	11	0	0	0	87
142	78	2	41	2	87	0	4	2	41	1	0	0	92
162	2	0	1	1	2	0	0	0	1	0	0	0	87
152	5	13	95	4	18	3	2	0	6	0	0	0	74
199	212	0	106	1	216	0	4	0	106	0	0	0	88
>199	472	275	516	151	3,046	104	789	1,080	749	31	0	3	144

(c)



	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-300	300-400	400-500	500-600	average
95	4,976	10,392	5,567	4,698	38,556	2,321	29,634	2,725	6,825	6,395	873	2,912	205
112	10,617	15,848	8,017	8,216	62,200	3,035	50,921	6,699	13,287	4,350	677	1,815	184
122	4,940	7,116	3,557	3,160	27,485	1,315	22,717	3,361	6,050	1,561	199	628	183
142	3,970	4,108	2,777	4,523	19,077	1,950	13,822	2,326	5,230	955	75	160	180
162	3,313	1,869	1,799	3,891	9,935	756	7,681	1,515	3,960	444	46	59	210
152	6,037	5,402	3,887	8,762	28,072	3,371	19,262	3,635	8,854	1,559	74	201	197
199	7,872	6,418	5,324	11,482	35,615	3,764	26,205	5,569	13,338	1,514	188	122	218
>199	49,582	35,883	16,919	51,882	228,20	22,766	177,11	43,064	89,197	9,800	1,043	160	186

(d)

Figure 5-7. Permit vehicles route lengths: (c) Multi-trip 3-month permit, type 803;
(d) Single-trip permit, type 801(continued).

Figure 5-7 indicates a large number of calculated permitted routes. For the multi-trip types 800, 803, and 804, the average length of the route is consistent and varies from 130 to 140 miles. For the single trip permit, the average route is approximately 190 miles. The average length of the multi-trip permits was used in the monetary consumption calculations.

6. Damage Assessment Analysis

The damage assessment was based on the equivalent moment calculations. Each permit truck that crosses 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 the bending moment may result in multiple moment cycles of different magnitudes depending on the geometry of the truck and the bridge. In this study, the variation of the bending moment at midspan due to a permit truck crossing was determined by passing the truck across an influence line. The rain flow counting method (ASTM E1049-85) [104] was used to determine the number and magnitude of the individual moment cycles resulting from each permit truck. Equation 29 was used to determine the equivalent bending moment. The distribution of equivalent moments within the permit types is presented in sections 6.1, 6.2, and 6.3 of this report.

6.1. Single-trip Permits

Based on the permit database in Florida, single trip permits are valid from one point of origin to one destination, and the hauler is allowed up to ten days to complete the trip. Single trip permits are analyzed for weight and distance based upon the route provided by an applicant. The statistics of permit data from 2016 to 2019 for the single trip permits are shown in Table 6-1. Single trip permits are the largest group of issued permits in Florida.

Table 6-1. Statistics for single-trip permits.

GVW groups	No. of permit vehicles	% of GVW group
95	24,851	24%
112	26,720	26%
122	10,819	11%
132	9,530	9%
142	6,091	6%
152	5,828	6%
162	3,354	3%
199	5,174	5%
>199	10,551	10%

Total	102,918

There are 102,918 single trip permits stored in the used permit database for overweight and a combination of overweight and oversize vehicles. The first two GVW groups that included vehicles up to 95 kip and 112 kip are the most common. Those groups account for 50% of all single permits in Florida.

The equivalent moment was computed for each vehicle in the database. Figure 6-1 shows the Cumulative Distribution Function, CDF of equivalent moments within GVW groups according to the current permit fee structure.

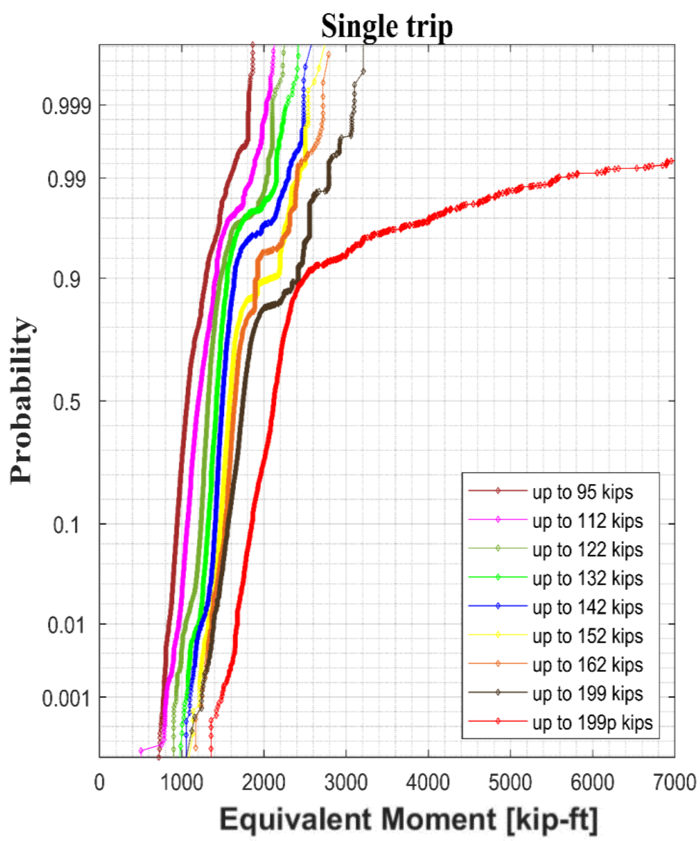


Figure 6-1. Equivalent moment distribution for a single trip.

The distribution shown in Figure 6-1 indicates that equivalent moments for the last group that represents permit vehicles above 199 kip cause large equivalent moments.

Another step of the analysis is to check the GVW distribution within the permit groups to show if the maximum loading is fully utilized by the permits. The cumulative distribution functions are plotted on normal probability paper to show GVW distribution within each permit group. Figure 6-2 shows the CDF plots for single trip permits.

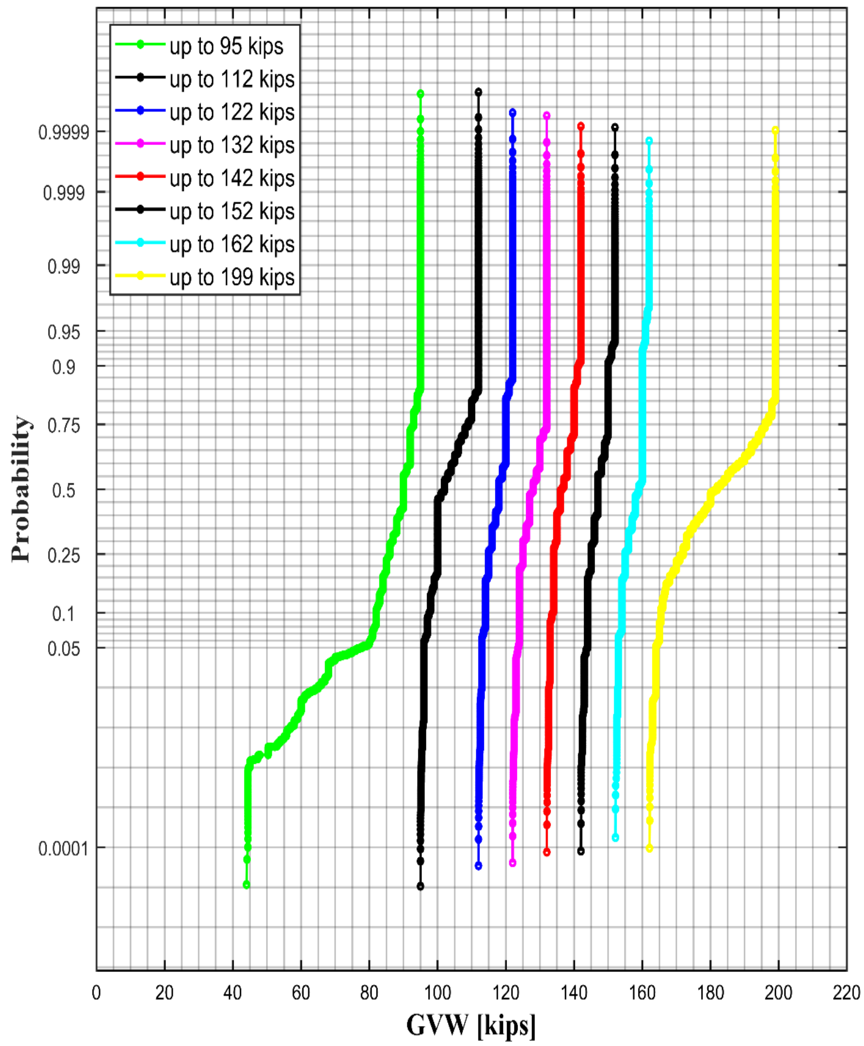


Figure 6-2. CDF distribution of GVW for single trip permits by groups.

The first three GVW groups up to 95, 112, and 122 kip show that about 85% of the vehicles are below the weight limit, and only 15% are at the limit of GVW. For the next group, where the maximum GVW is 132 kip, about 25% of the vehicles are at that limit. The GVW group up to 142 kip shows that approximately 10% of vehicles are at the limit. For the next groups up to 152 and 162 kip, less than 10% of vehicles are at the limit, and 90% of vehicles in that group are below the limiting value. For the group up to 199 kip, 25% of the vehicles are at the limiting value. The last group above 199 kip is shown in a separate figure. The GVW for that vehicle group ranges from 200 kip up to 2,000 kip. Figure 6-3 shows the CDF plot for that group.

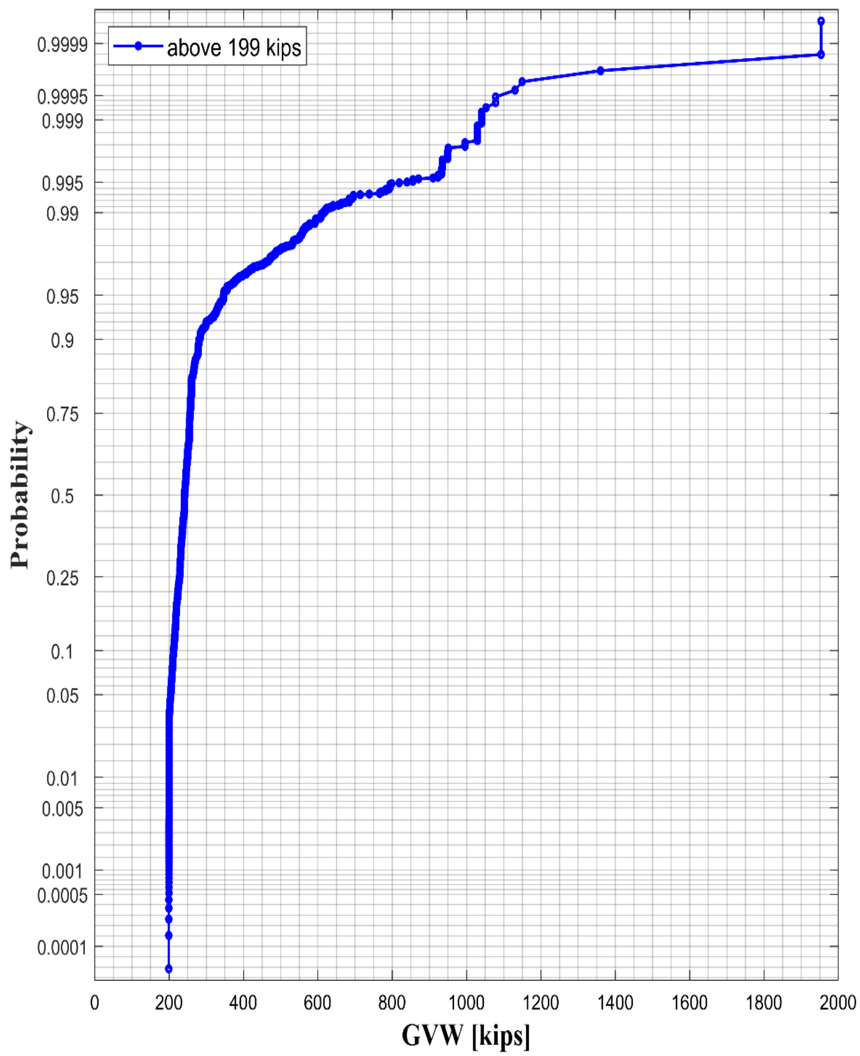


Figure 6-3. CDF distribution of GVW for single trip permits above 199 kip.

The GVW distribution in Figure 6-3 shows that 50% of permits are below 225 kip, 75% are below about 240 kip, and 95% are below 350 kip.

All single trip permits were plotted on CDF to interpret the total weight distribution of that type in Florida. Figure 6-4 shows that about 50% of permit vehicles are below 90 kip, 75% are below 110 kip, and 90% are below 140 kip.

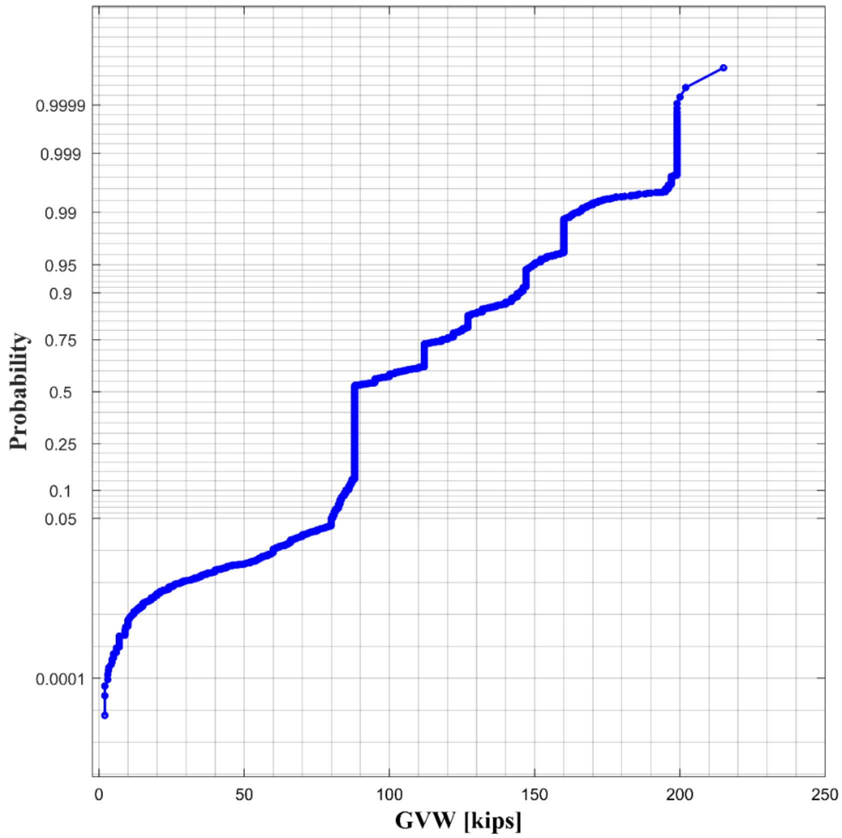


Figure 6-4. CDF distribution of GVW for single permits.

The damage assessment is calculated for each vehicle in the permit database. The equivalent moment is a measure of fatigue damage caused by permit vehicles. The relationship between the calculated equivalent moment and GVW within each group is shown in Appendix A. It is evident that for some groups, there is no clear correlation between those two parameters. The damage assessment by equivalent moment is axle weight and axle spacing dependent. In this case, another set of figures were prepared to show the relationship between the equivalent moment and the total vehicle length that is shown in Appendix A.

The equivalent moment vs. total vehicle length shows that there is a correlation between those parameters. In some GVW groups, the correlation is very clear. That relationship is due to the fact that the longer the vehicle, the more weight can be spread through the length. Another consideration is a number of axles - the weight is spread among the axles. Hence, the more axles there are, the better the distribution of weight.

An additional set of figures shows the relationship between the number of axles and equivalent moments, which is presented in Appendix A.

The above-mentioned series of comparisons between different parameters to the equivalent moment demonstrate that damage caused by vehicles to bridges depends on the overall vehicle weight, its length, and the number of axles. The damage is dependent on axle weight and axle spacing. The most critical cases are observed when the vehicle is very heavy and the axle spacing is small, but the weight distribution on the adjacent axles is large. The vehicle configuration and hence the weight distribution are very important factors in a damage assessment analysis.

6.2. Multi-trip Permits for – 12 Months

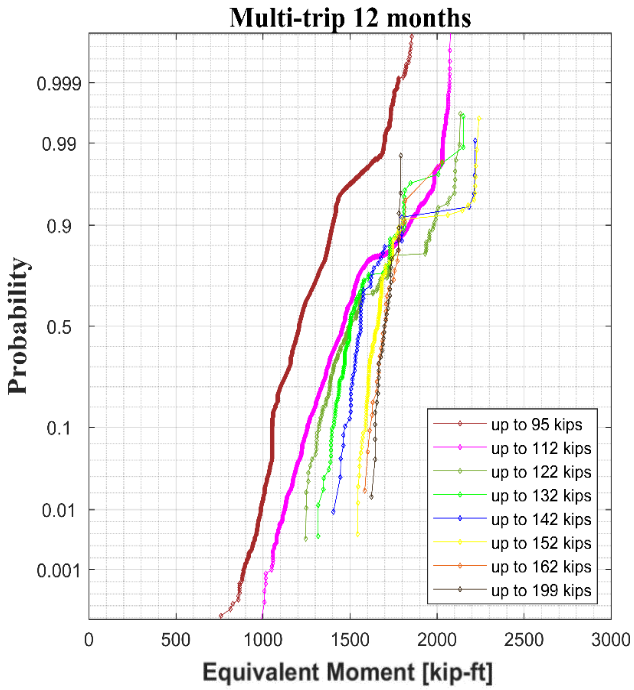
The annual multi-trip permits are valid for 12 months and for an unlimited number of trips. In Florida, there are two types of 12-month multi-trip permits. First, type 800 multi-trip permits are not restricted to one vehicle. The second, type 804, is restricted to one vehicle only. The issued permit is non-transferable among vehicles in the fleet. This type 804 permit was introduced in Florida in mid-2017. The statistics of permit data issued between 2016 and 2019 for the 12-month multi-trip permits type 804 and 800 are shown in Table 6-2 and Table 6-3, respectively.

Table 6-2. Statistics for multi-trip permits for 12 months restricted to one vehicle (type 804).

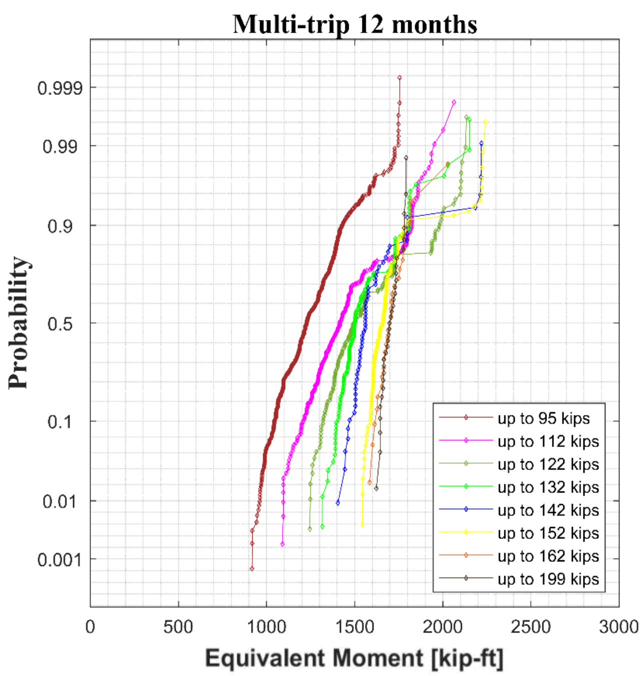
GVW groups	No. of permit vehicles	% of GVW group
95	768	51%
112	262	17%
122	141	9%
132	127	8%
142	50	3%
152	115	8%
162	21	1%
199	26	2%
>199	0	0%
Total	1,510	

The statistics show that the first two GVW groups are the most common for both the type 800 and type 804 permits. Note that annual permits are not issued to vehicles above 199 kip. Table 6-2 and Table 6-3 also show that the unrestricted type 800 permits are much more common than the type 804 permits, which are limited for use by a single vehicle.

For each vehicle in the database, the equivalent moment was computed. Figure 6-5 shows the CDF distribution of equivalent moment within GVW groups according to the current permit fee structure.



(a)



(b)

Figure 6-5. Equivalent moment distribution for annual multi-trip permits: (a) type 800; (b) type 804.

The distribution shown in Figure 6-5 indicates that permits type 800 and 804 have consistent distribution within GVW groups. For each permitted vehicle in those groups, the consumption is calculated. The results are discussed and shown in the next chapter.

Another step in the analysis is to check the GVW distribution within the permit groups to show if the maximum loading is fully utilized by the permits. The cumulative distribution functions (CDF) on normal probability paper are plotted to show GVW distribution within each permit group. Figure 6-6 shows the CDF plots for type 800 permits.

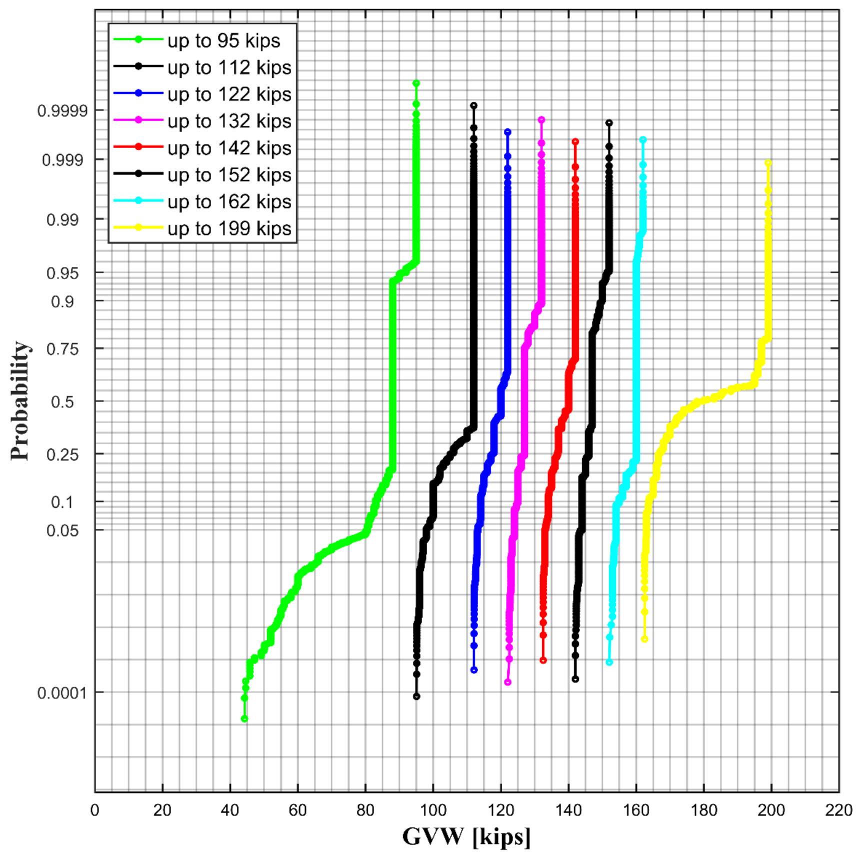


Figure 6-6. CDF distribution of GVW for multi-trip permits for 12 months unrestricted to one vehicle by groups (type 800).

Figure 6-6 shows the percentage of vehicles at the maximum weight limit. The first GVW group up to 95 kip shows that 95% of the vehicles are below the 95 kip limit, and only 5% are at the limit of GVW. For the next group, where the maximum GVW is 112 kip, about 60% of the vehicles are at that limit. The GVW group up to 122 kip shows that 40% of vehicles are at the limit, the remaining 60% are below that limit. For the next group up to 132 kip, only 10% are at the limit, and 90% of the vehicles in that group are below the limit value. For the group up to 142 kip, 30% of the vehicles are at the limiting value, and the next group up to 152 kip shows that less than 5% of the vehicles are at the limit. Another group of 162 kip indicates that 75% of the vehicles are at the limit. The last group for the 12-month multi-trip permits demonstrates that 45% of the vehicles are at the limit of 199 kip.

The gross vehicle weight for all type 800 permits was plotted as a CDF to present the total weight distribution of permits in Florida (Figure 6-7). It shows that 50% of the permit vehicles are below 90 kip, 75% are below 120 kip, and 90% are below 140 kip.

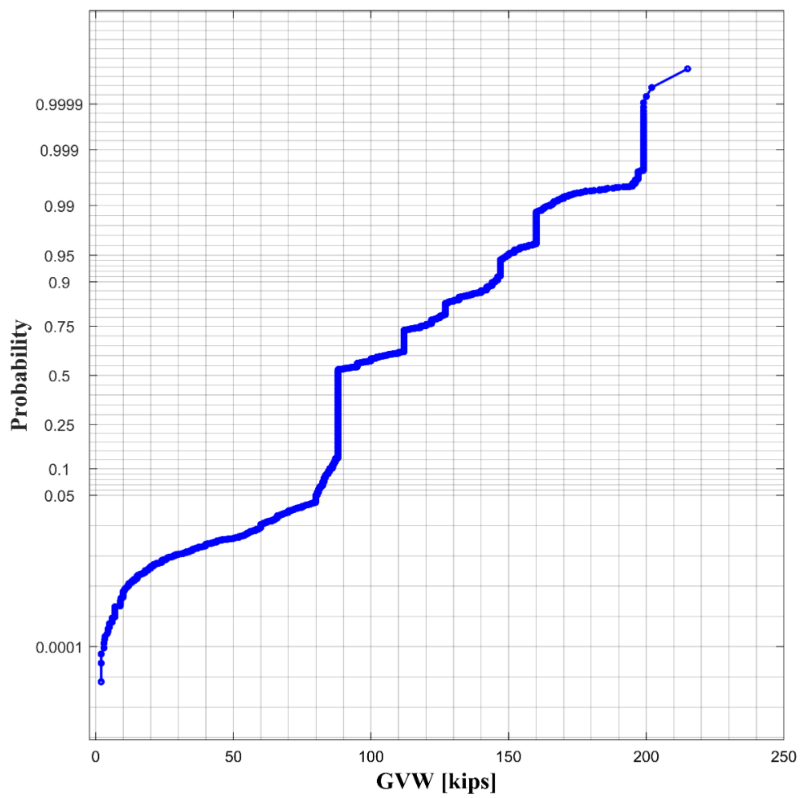


Figure 6-7. CDF distribution of GVW for multi-trip permits for 12 months unrestricted to one vehicle (type 800).

Figure 6-8 shows that all of the GVW distributions on the CDF plots for type 804 permits for different permit groups indicate the percentages of vehicles at the maximum weight limit. The first GVW group up to 95 kip shows that 95% of the vehicles are below the 95 kip limit, and only 5% are at the limit of GVW. For the next group, where the maximum weight is 112 kip, about 45% of the vehicles are at the limit. For the GVW group up to 122 kip, 60% of the vehicles are at the limit; the remaining 40% are below the limit. For the next group up to 132 kip, 40% are at the limit. Another group up to 142 kip shows that 20% of the vehicles are at the limiting value, and the next group up to 152 kip indicates that less than 20% of the vehicles are at the limit. The next group of 162 kip shows that 55% of the vehicles are at the limit. The last group for the 12-month multi-trip vehicles demonstrates that less than 10% of vehicles are at the limit of 199 kip.

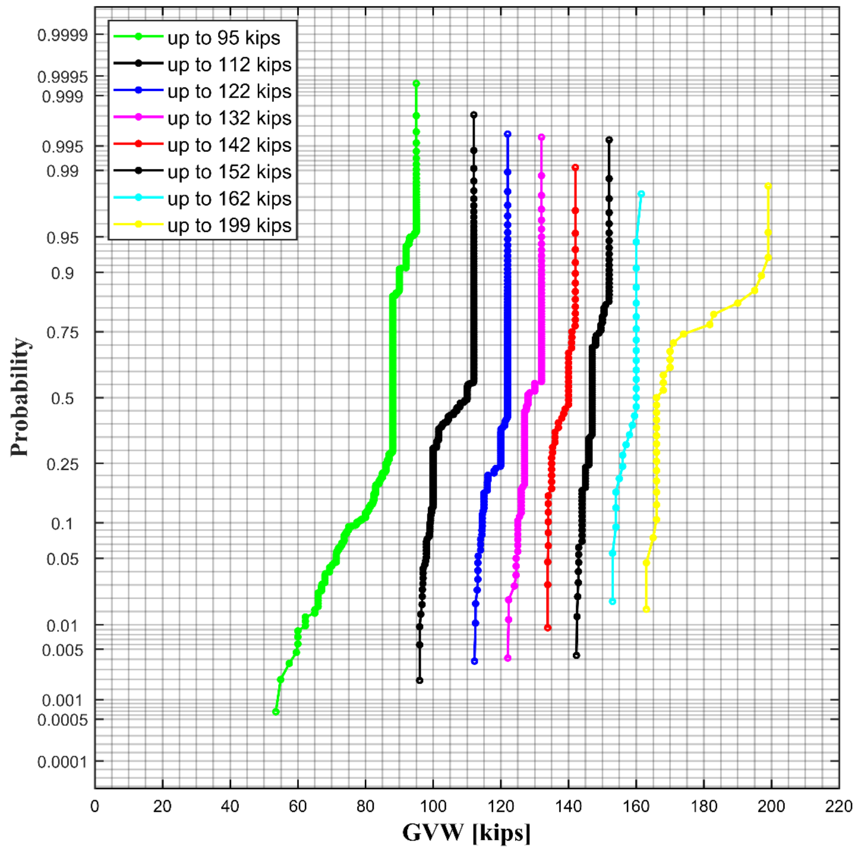


Figure 6-8. GVW distribution multi-trip permits for 12 months unrestricted to one vehicle (804).

The GVW for all type 804 permits was plotted on a CDF to illustrate the total weight distribution for this type of permit in Florida. Figure 6-9 shows that 50% of the permit vehicles are below 90 kip, 75% are below 120 kip, and 90% are below 140 kip. The overall distribution for type 804 is consistent with type 800. The target permit vehicles for those two types have similar overall weight distributions.

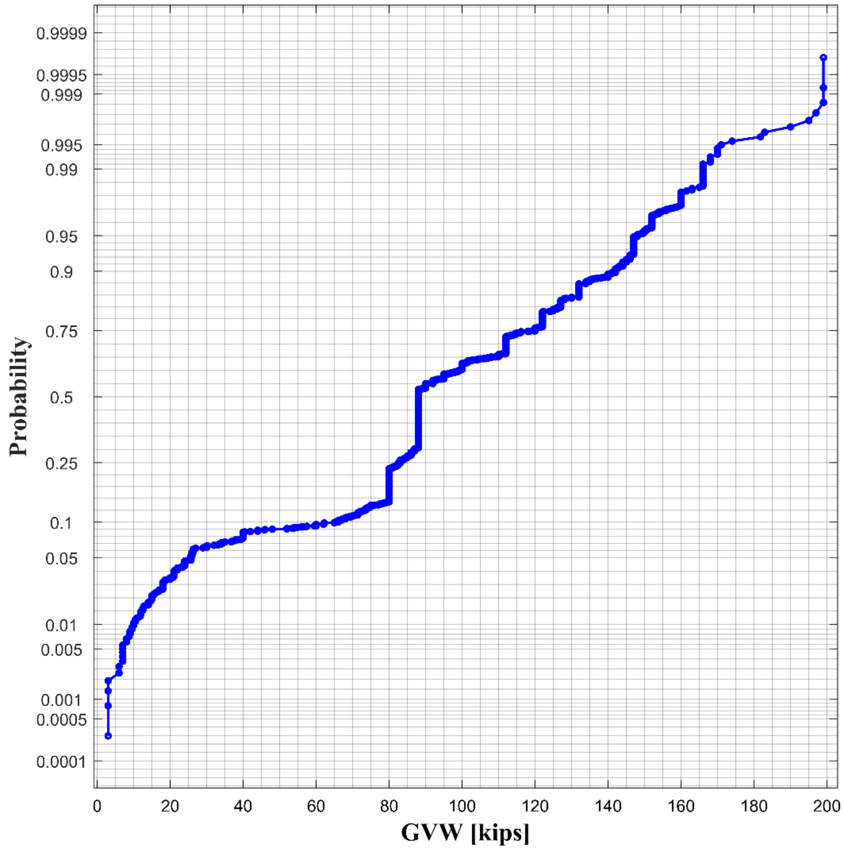


Figure 6-9. CDF distribution of GVW for multi-trip permits for 12 months unrestricted to one vehicle (type 804).

The damage assessment is calculated for each vehicle in the permit database. The equivalent moment is a measure of fatigue damage caused by permit vehicles. The relationship between the calculated equivalent moment and GVW, total length of the vehicle and number of axles for multi-trip permits type 800 and type 804 is shown in Appendix A. These series of comparisons between different parameters to the equivalent moment demonstrate that the damage caused by vehicles to bridges depends on the overall vehicle weight, its length, and the number of axles. The damage is dependent on axle weight and axle spacing. The most critical cases are observed when the vehicle is very heavy and the axle spacing is small, but the weight distribution on the adjacent axles is large. The vehicle configuration and hence the weight distribution are important factors in a damage assessment analysis.

6.3. Multi-trip Permits for 3 Months

The current permit fee schedule in Florida includes a type 803 multi-trip permit that is valid for 3 months for an unrestricted number of uses. Three-month multi-trip permits are route-specific, and specific allowable routes are assigned to the permit. The statistics of permit data from 2016 to 2019 for the multi-trip permits are shown in Table 6-3. Three-month multi-trip permits are the smallest group of issued permits in Florida.

Table 6-3. Statistics for type 803 multi-trip permits for 3 months.

GVW groups	No. of permit vehicles	% of GVW group
95	24	5%
112	28	5%
122	9	1%
132	62	12%
142	36	6%
152	17	2%
162	22	3%
199	116	22%
>199	225	43%
Total	539	

A total of 539 multi-trip 3-month permits were issued for overweight and a combination of overweight and oversize vehicles. For these route-specific permits, the heaviest two weight groups are most common. Those groups account for 65% of all type 803 permits.

For each vehicle in the database, the equivalent moment was computed. Figure 6-10 shows the CDF distribution of equivalent moment within GVW groups according to the current permit fee structure.

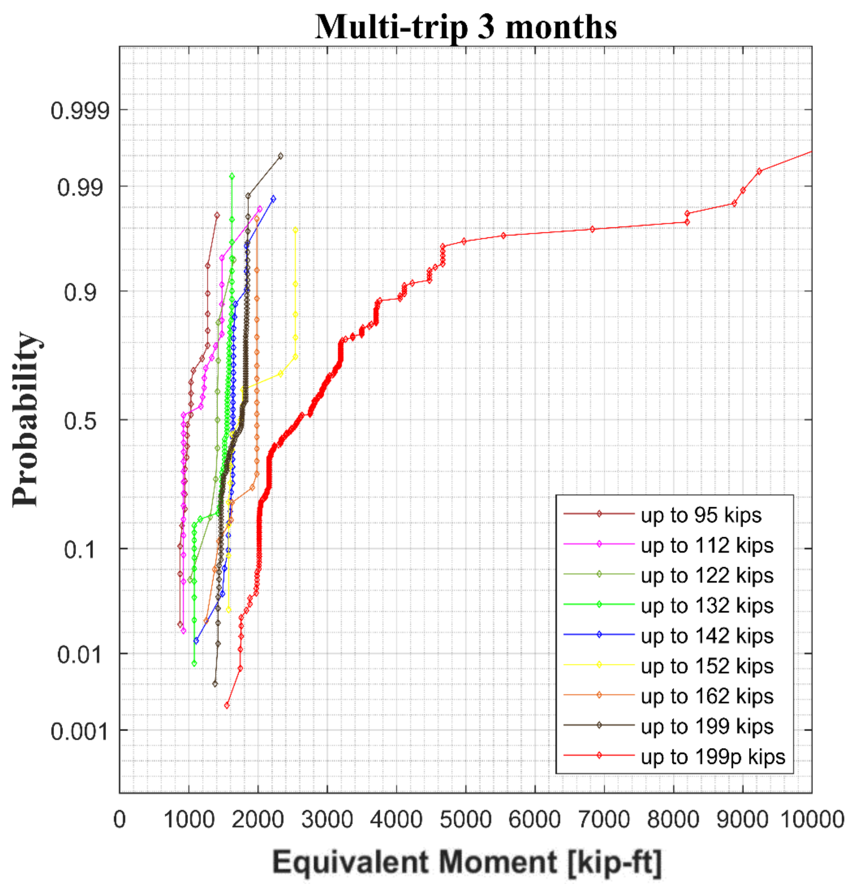


Figure 6-10. Equivalent moment distribution for 3-month multi-trip permits (type 803).

The distribution shown in Figure 6-10 indicates that equivalent moments for the last group that represents permit vehicles above 199 kip cause large equivalent moments.

Another step in the analysis was to check the GVW distribution within the permit groups to show if the maximum loading is fully utilized by the permits. The cumulative distribution functions (CDF) on normal probability paper were plotted to show GVW distribution within each permit group. Figure 6-11 shows the CDF plots for multi-trip 3-month permits.

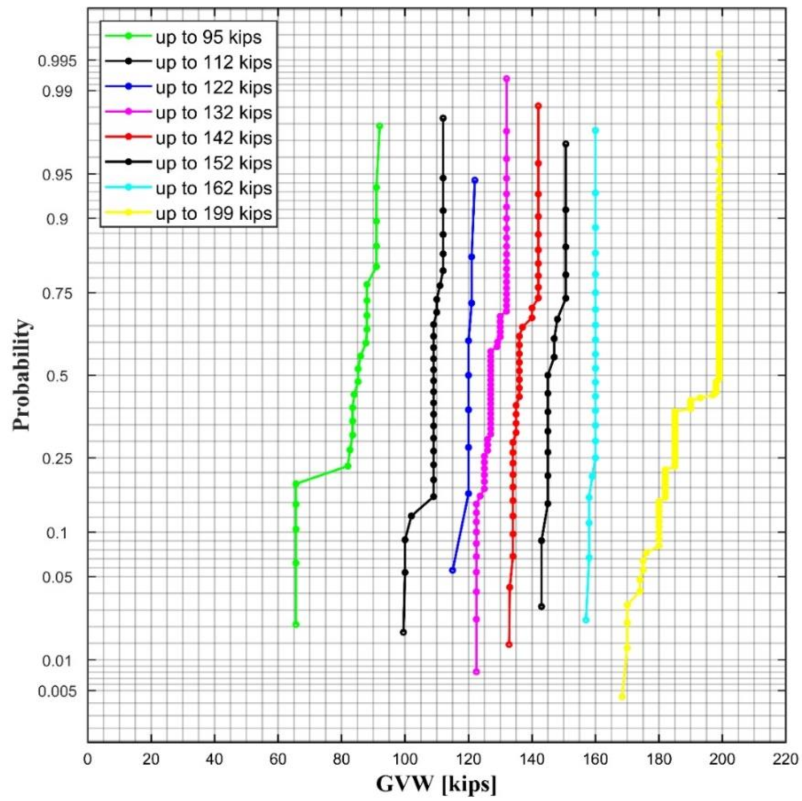


Figure 6-11. CDF distribution of GVW for multi-trip 3-month permits by groups.

The first GVW group up to 95 kip shows that about 80% of the vehicles are below the 95 kip limit, and 20% are at the limit of GVW. For the next group, where the maximum GVW is 112 kip, about 20% of the vehicles are at that limit. The GVW group up to 122 kip shows that less than 10% of the vehicles are at the limit. For the next group up to 132 kip, about 30% are at the limit, and 70% of the vehicles in that group are below the limit value. For the group up to 142 and 152 kip, 25% of the vehicles are at the limiting value, and for the next group up to 162 kip, 75% of the vehicles are at the limit. The GVW group up to 199 kip demonstrates that over 50% of the vehicles are at the limit of 199 kip. The last group above 199 kip is shown on a separate figure to illustrate how heavy the vehicles within that group are. The GVW ranges from 200 kip up to 1,500 kip. Figure 6-12 shows the CDF plot for that group. The GVW distribution shows that 50% of the permits are below 300 kip, 75% are below 350 kip, and 90% are below 450 kip. This observation might help to establish the GVW groups according to the existing permit traffic in Florida.

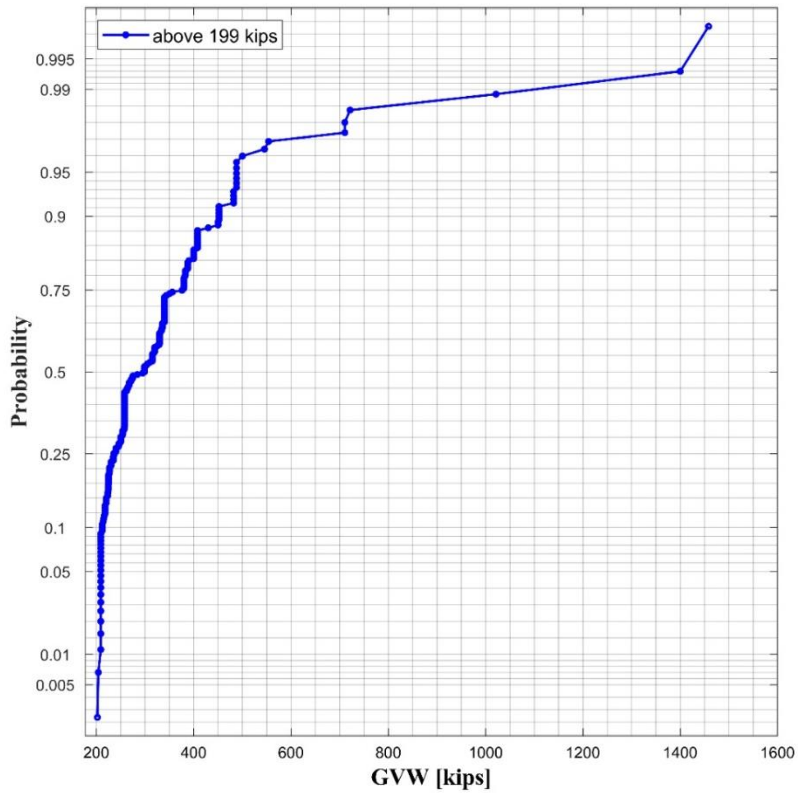


Figure 6-12. CDF distribution of GVW for multi-trip permits for 3 months – a group of vehicles above 199 kip.

All 3-month permits were plotted as a CDF to interpret the total weight distribution of that truck type in Florida. Figure 6-12 shows that about 50% of permit vehicles are below 200 kip, 75% are below 250 kip, and 90% are below 350 kip. Figure 6-13 shows the GVW for 3-month permits. The heaviest group is a major group in the various permit types and consists of very heavy vehicles that contribute large amounts of fatigue damage to Florida infrastructure.

The damage assessment was calculated for each vehicle in the permit database. The equivalent moment is a measure of fatigue damage caused by permit vehicles. The relationship between the calculated equivalent moment and GVW, total length of the vehicle and number of axles for 3-month multi-trip permits is shown in Appendix A. These series of comparisons between different parameters and the equivalent moment demonstrate that damage caused by vehicles to bridges depends on the overall vehicle weight, its length, and the number of axles. The damage is dependent on axle weight and axle spacing. The most critical cases are observed when the vehicle is very heavy, and the axle spacing is small, but the weight distribution on the adjacent axles is large.

The vehicle configuration and hence the weight distribution are important factors in a damage assessment analysis.

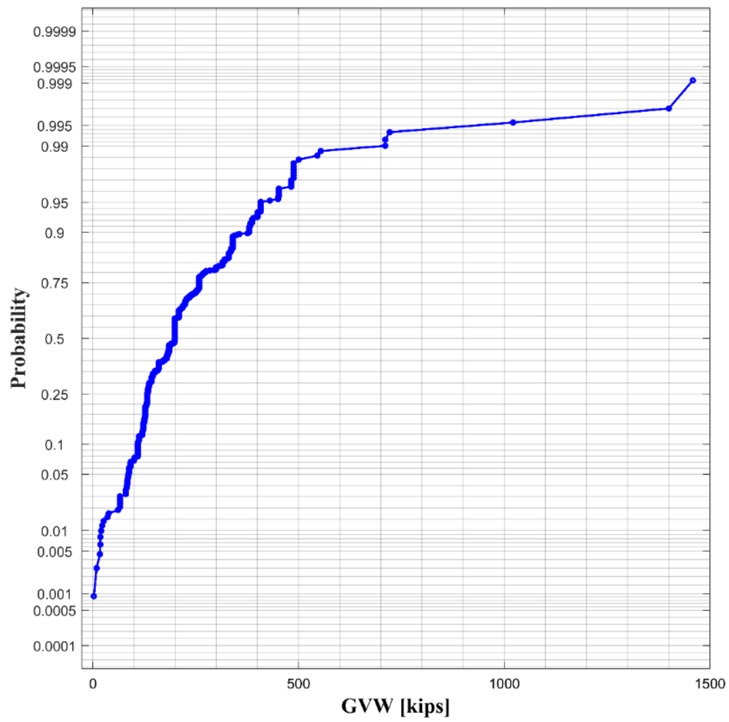


Figure 6-13. CDF distribution of GVW for multi-trip 3-month permits.

7. Monetary Consumption

The damage assessment analysis was conducted to assign fair costs to the various vehicles and permit types in Florida. This analysis is based on the issued permit database from 2016 to 2019. The existing permit vehicles operating on the roads and bridges in Florida are utilized to determine bridge consumption. The consumption cost is assessed for each permit type and group.

Fatigue damage caused by the permit vehicles in Florida was calculated. The damage is represented by incremental consumption shown in Eq. 36. The derived consumption equation contains representative bridge parameters such as total cost, ADTT in a single lane, material, and structural types of bridges. An extensive study was performed in order to find representative bridge parameters. Those parameters were established for the sample bridge database based on the FDOT new bridge construction cost table, the National Bridge Inventory database, and the WIM database. The representative parameters are used in the consumption equation to calculate the monetary damage by permit vehicles on bridges in Florida.

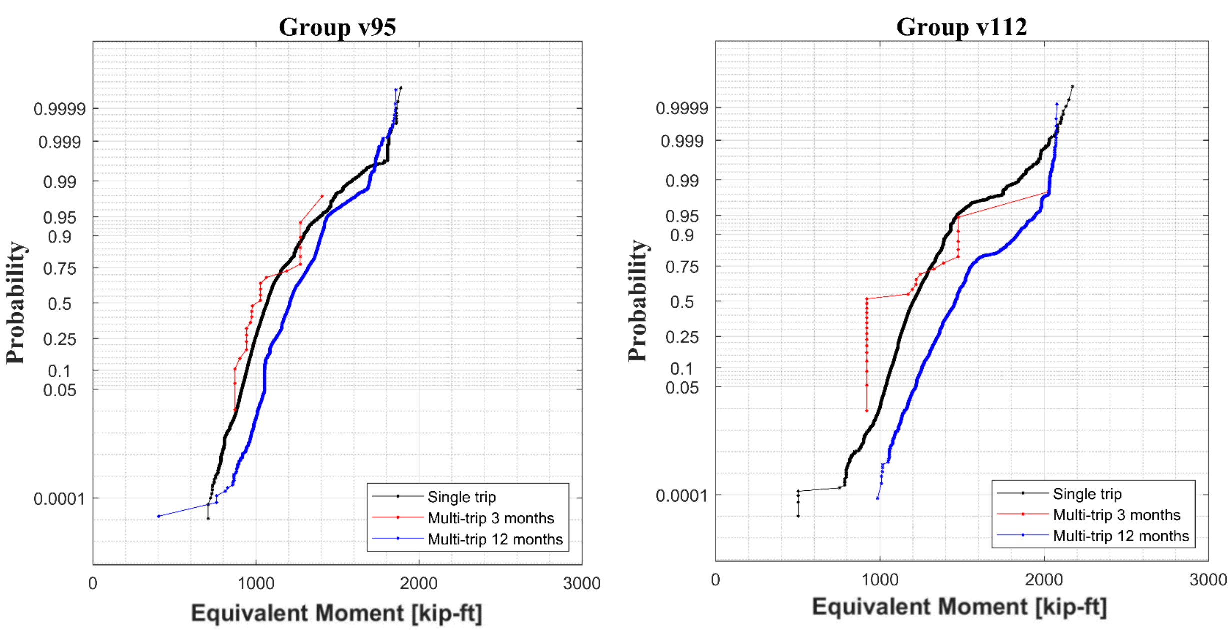
The types of permits included in the analysis are taken from the current permit fee schedule presented in Table 3-3. There are three types of permits: single trip, annual multi-trip, and route-specific three-month multi-trip. Single trip permits are analyzed for weight and distance based upon the route provided by the applicant. Multi-trip permits are weight-based fees. Those types of permits are divided into groups based on nine main GVW groups. In this study, an average consumption is calculated based on the current valid permit schedule for each permit type and GVW group (Table 3-3).

The damage assessment analysis is based on the fatigue damaged measured by the equivalent moment on a representative bridge in Florida. The consumption analysis was conducted separately for each GVW group, and the average consumption in dollars per mile was found. The results of the bridge consumption analysis for single trip permits are shown in Figure 7-1. The consumption results are compared with the current permit fee schedule for Florida.

Figure 7-1. Bridge consumption for single trip permits vs. current permit fees in Florida.

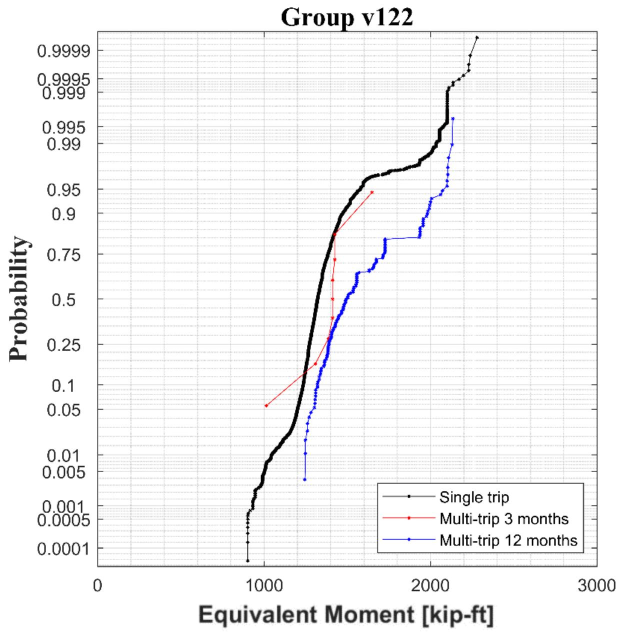
Figure 7-1 summarizes the consumption in dollars to bridges in Florida by each GVW group for the single trip permits. It is evident that dollar consumption is not increasing linearly along with the GVW groups. Further discussion of bridge consumption for a single trip will be reviewed and combined with a pavement damage assessment. Analysis of the multi-trip permits requires an estimated number of trips and the distance of the route to determine the consumption of such a permit. A study conducted in Ohio collected information from the trucking industry about the estimated number of trips in a period of 90 days of a permitted vehicle. It was reported that an average number of permit vehicle trips in 3 months is 25 trips [105]. In this study, the assumption is designated as 25 trips for 3-month permits and 100 trips for annual permits.

The length of the trip for different permit types was computed using the developed algorithm along with the GIS system. It was found that the average length of the trip for multi-trip permits is about 130 to 140 miles. The incremental consumption (Eq. 36) in dollars per mile was computed for a multi-trip permit. Afterward, that consumption is multiplied by the estimated number of trips and the average length of the trip. In this study, the average length of the trip is designated as 130 miles and the numbers of trips are 25 for three months and 100 for one year.
The total permit data sample used in this study is 141,579 permitted vehicles. Single trip permits dominate, and they represent 72% of all permits. There are three types of multi-trip permits for 12-month permits: type 800 and type 804 and 3-month permits. The annual permits, type 800, account for about 26% of all permits, but type 805 is 1%, and the 3-month permits account for only 0.5%. The equivalent moment distribution for a multi-trip 12-month permit (type 800 and type 804), 3-month permit, and single trip permit for different GVW groups are shown in Figure 7-2.

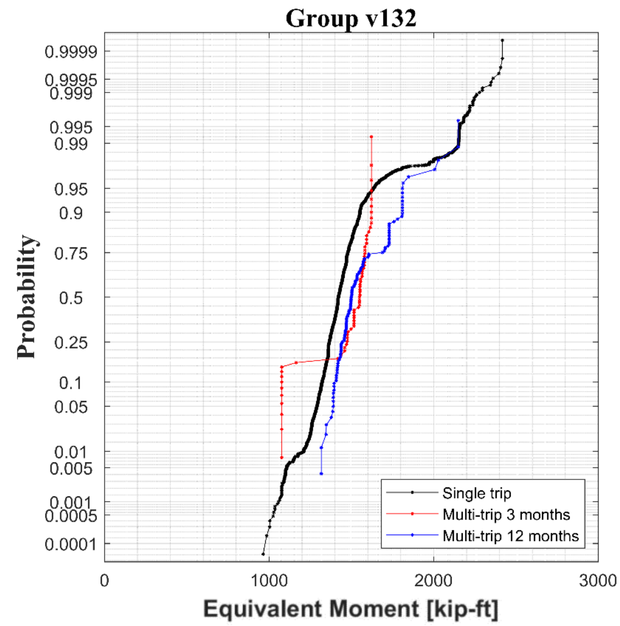


(a) (b)

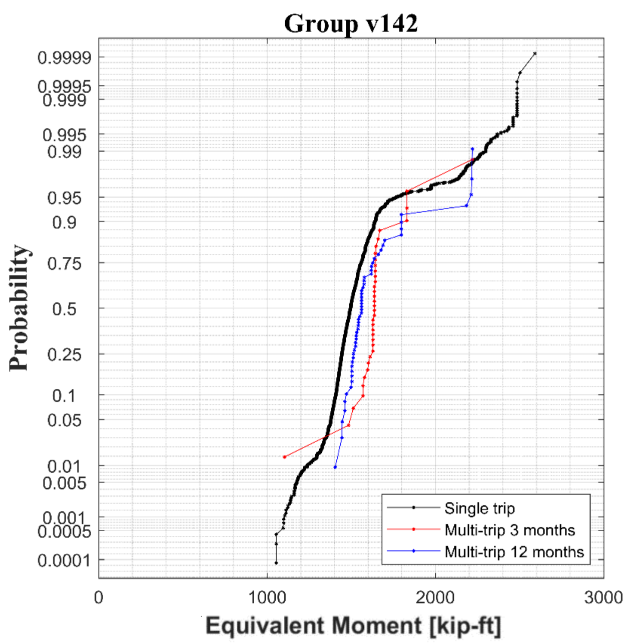
Figure 7-2. Equivalent moment distribution for a group: (a) up to 95 kip; (b) up to 112 kip.



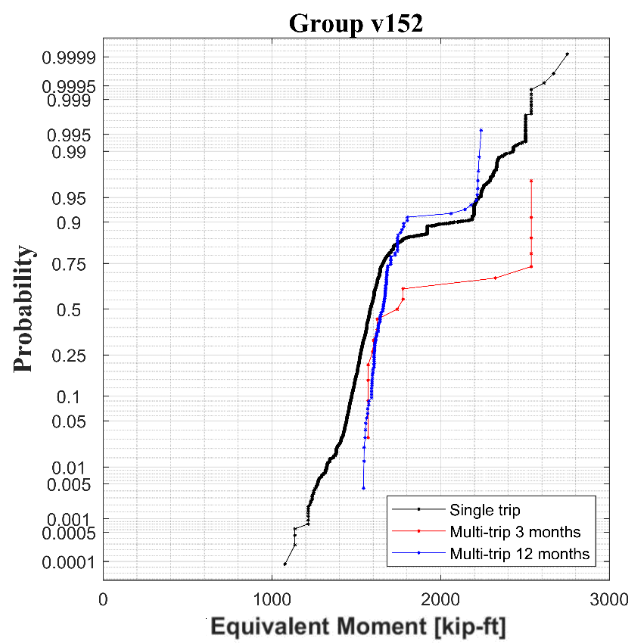
(c)



(d)

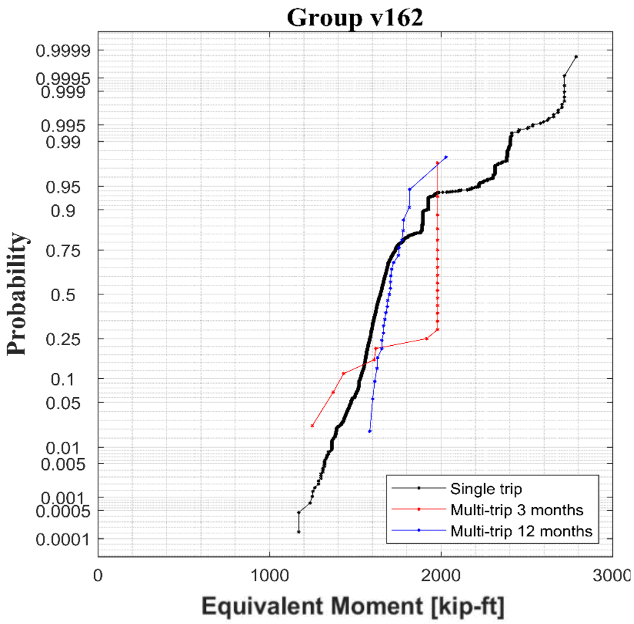


(e)

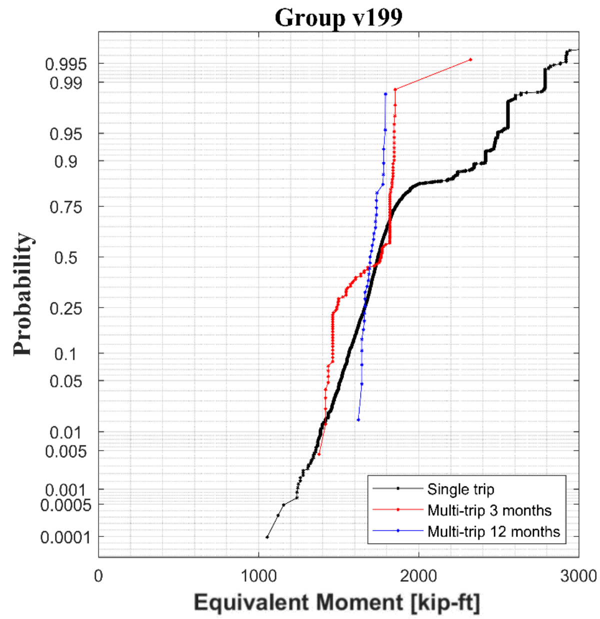


(f)

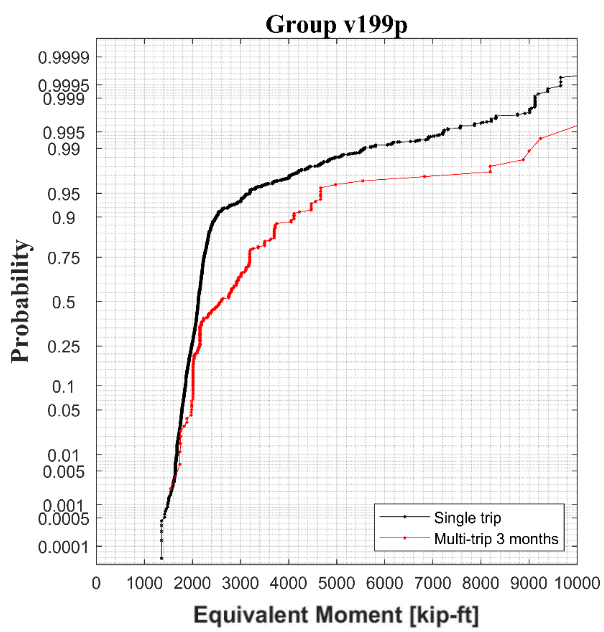
Figure 7-2. Equivalent moment distribution for a group: (c) up to 122 kip; (d) up to 132 kip; (e) up to 142 kip; (f) up to 152 kip (continued).



(g)

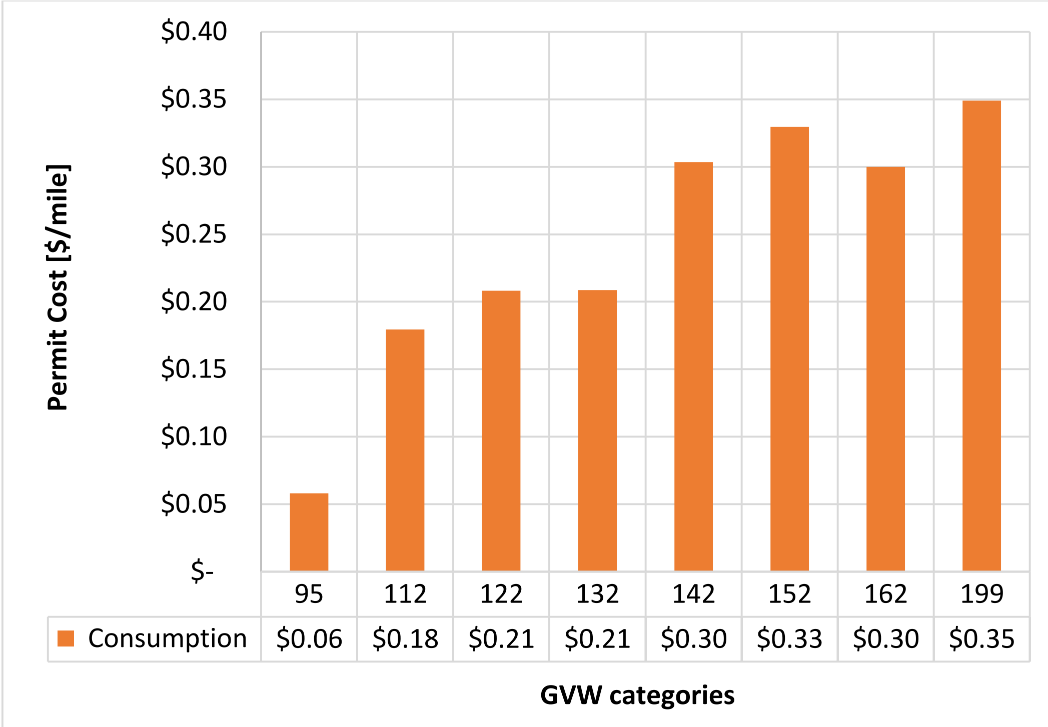


(h)



(i)

Figure 7-2. Equivalent moment distribution for a group: (g) up to 162 kip; (h) up to 199 kip; (i) above 199 kip (continued).



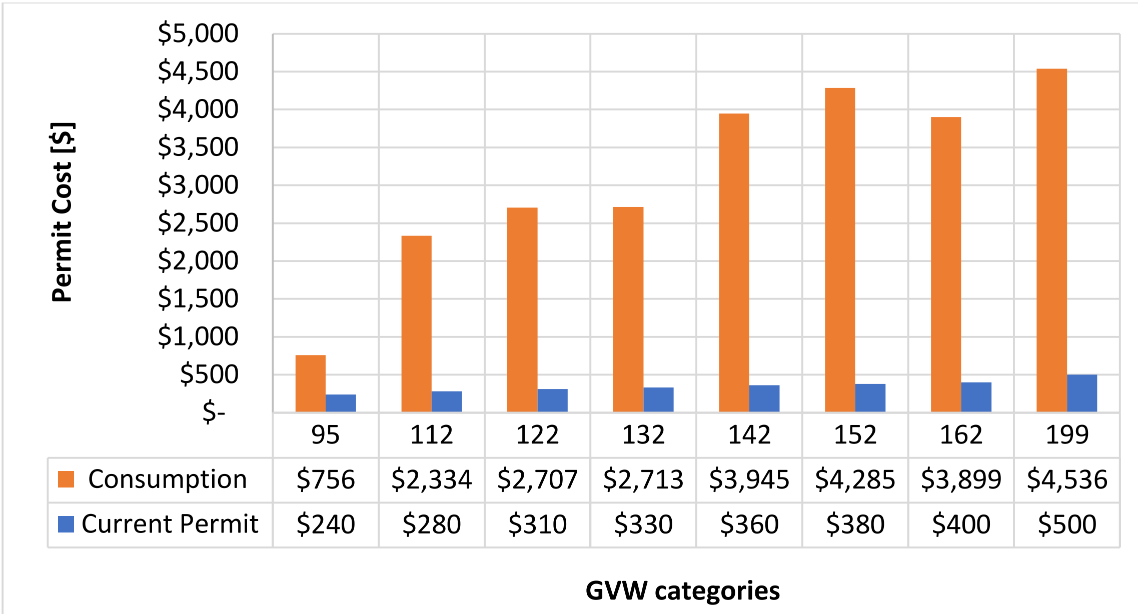
	95	112	122	132	142	152	162	199
Consumption	$0.06	$0.18	$0.21	$0.21	$0.30	$0.33	$0.30	$0.35

Figure 7-3. Bridge consumption for multi-trip permits in $/miles.

It is evident that the sample of the multi-trip 3-month permit is not sufficient to determine the monetary consumption. For multi-trip permits, the incremental consumption is calculated for 12-month permits. The consumption analysis was conducted separately for each GVW group, and the average consumption in dollars was found. The results of the bridge consumption analysis for multi-trip permits are shown in Figure 7-3.

Results show that consumption does not increase linearly with GVW. The average consumption in dollars per mile was computed. It is clear that vehicle geometry and weight distribution have an impact on fatigue consumption, which will be discussed in the next task of the project.

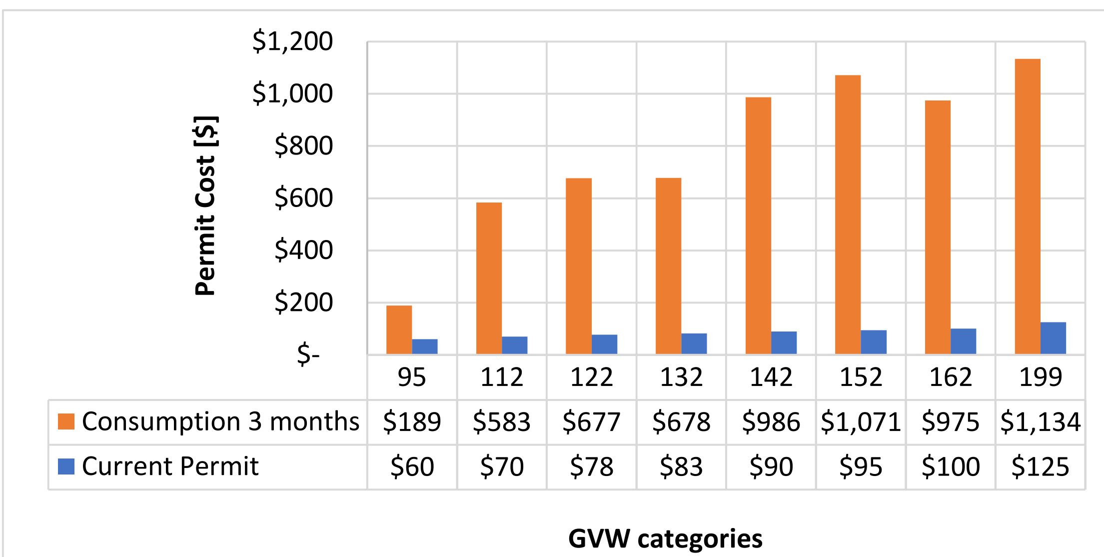
The annual consumption is calculated by using the average length of the trip and the estimated number of trips. In the current permit fee structure, there is a discount for multi-trip permits. The consumption shown in Figure 7-4 is an annual consumption with <u>no discount</u> for annual permits.



	95	112	122	132	142	152	162	199
Consumption	$756	$2,334	$2,707	$2,713	$3,945	$4,285	$3,899	$4,536
Current Permit	$240	$280	$310	$330	$360	$380	$400	$500

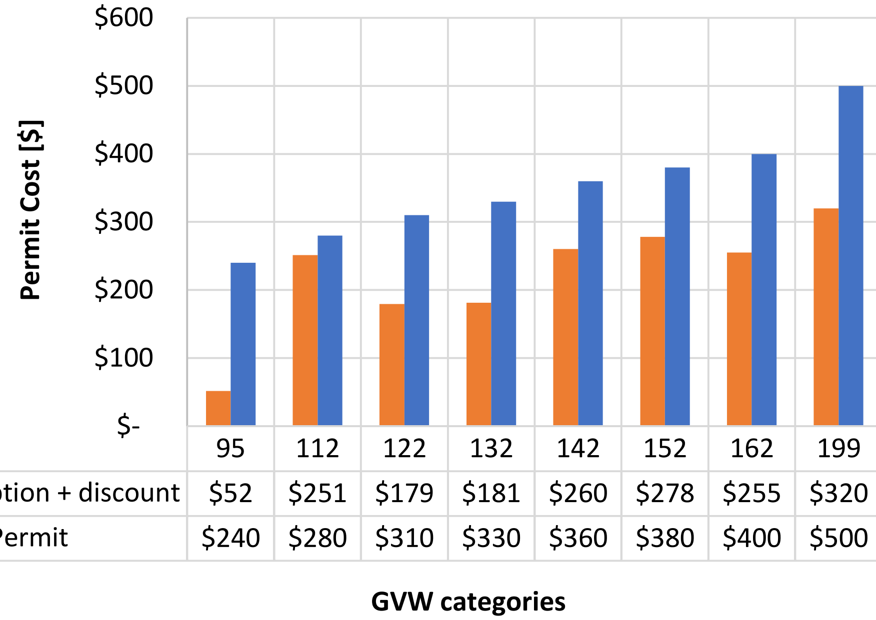
. Figure 7-4. Bridge consumption for multi-trip 12-month permits vs. current permit fees in Florida.

The bridge consumption for multi-trip permits was calculated by using the current FDOT proportions between the single trip and multi-trip permits. The present discount was used to calculate the consumption. Figure 8-5 shows the consumption with the discount for multi-trip permits.



	95	112	122	132	142	152	162	199
Consumption 3 months	$189	$583	$677	$678	$986	$1,071	$975	$1,134
Current Permit	$60	$70	$78	$83	$90	$95	$100	$125

Figure 7-5. Bridge consumption for the multi-trip 12-month permits with current discount vs. current permit fees in Florida.



	95	112	122	132	142	152	162	199
Consumption + discount	$52	$251	$179	$181	$260	$278	$255	$320
Current Permit	$240	$280	$310	$330	$360	$380	$400	$500

Figure 7-6. Bridge consumption for the multi-trip 3-month permits vs. current permit fees in Florida.

The multi-trip permit consumption for 3-month permits is designated as a quarter of the annual permit. The results of the bridge consumption analysis with no discount for the 3-month multi-trip permits are shown in Figure 7-6.

The bridge consumption discounted by the current fee schedule for the 3-month multi-trip permits is presented in Figure 7-7.

	95	112	122	132	142	152	162	199
Consumption + discount	$13	$63	$45	$45	$65	$70	$64	$80
Current Permit	$60	$70	$78	$83	$90	$95	$100	$125

Figure 7-7. Bridge consumption for multi-trip 3-month permits with current discount vs. current permit fees in Florida.

Currently, multi-trip 3-month permits are issued for vehicles above 199 kip. This group was not shown in the calculation since vehicles above 199 kip are not issued for annual permits. The equivalent moment calculations and incremental consumption for 3-month vehicles show that this group is causing significant damage to bridges. The calculated incremental consumption in dollar per mile for the average 3-month permit above 199 kip is $3.87/mile. Equivalent moments caused by those vehicles are seven times more than a representative legal vehicle.

The damage assessment analysis is based on the fatigue damage measured by the equivalent moment on a representative bridge in Florida. The consumption analysis was conducted separately for each GVW group, and the average consumption in dollars was found. The results of the bridge consumption analysis for single-trip permits is given in $/miles. Hence, multi-trip permits are designated as a fixed price; the $/mile is multiplied by the average length of the trip and the estimated number of trips.

8. Summary

A damage assessment approach was developed to calculate the monetary consumption caused by overweight permitted vehicles on bridges in Florida. The consumption is computed for the representative bridge in Florida. The representative bridge parameters were established based on the sample bridge database, the FDOT new bridge construction cost data, the National Bridge Inventory database, and WIM datasets. An extensive study was conducted to find parameters such as bridge cost, ADTT, span length, and material and structural type. The permit database was used to determine the total damage on bridges. Existing permit vehicles operating on the roads and bridges in Florida are utilized to determine the damage. Monetary consumption caused by permitted overweight vehicles was calculated according to the current permit fee schedule in Florida.

The monetary consumption results will be combined with a pavement damage assessment. The new permit fee schedule will be proposed and compared with the current permit fee schedule. Based on the consumption cost analysis and research findings, the recommendation of a new permit fee structure are proposed for consideration by FDOT.

PART C. PAVEMENT DAMAGE COST ASSESSMENT

9. Damage Assessment Approach

This part evaluates the impact of the overweight trucks on the pavement life to estimate the pavement damage cost (PDC). Based on the literature, there are two major methods to estimate the PDC. One is the empirical method that seeks the statistical correlation between road-use of the pavement and the costs of the pavement, such as reconstruction and rehabilitation costs. The other is the so-called “engineering” approach, which seeks the theoretical relationship between road-use and pavement damage [106]. This study uses the “engineering” approach to find the relationship between the damage and the cost. The outline of the approach is presented in Figure 9-1. In this study, the roads are categorized based on their function, traffic level, and structure. Then, ESALs for each road category are calculated, and a life cycle cost analysis (LCCA) was conducted for thirty-seven different road segments. The damage in this study is determined by converting all of the loads throughout the pavement life cycle to an equivalent single-axle load (ESAL). Then, the cost for construction and rehabilitation is estimated for each road category by conducting a LCCA. Finally, the average pavement damage cost (APDC) is calculated based on the life cycle cost and the ESALs for each road segment [7].

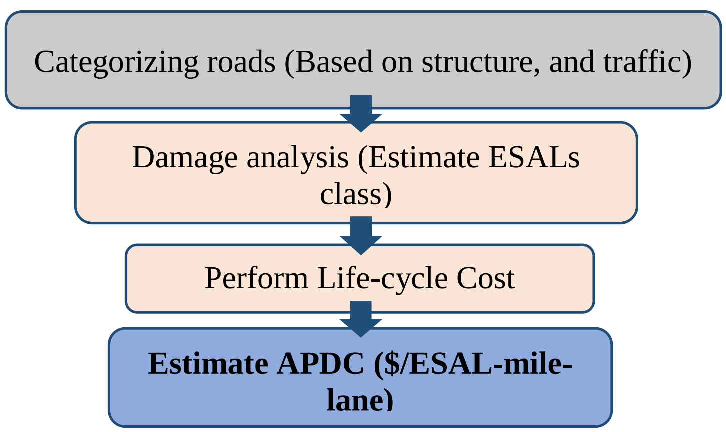


Figure 9-1. The framework for estimating the APDC.

10. Pavement Categories (Traffic and Structure)

Traffic load, specifically truck traffic, has a major impact on the structure of the pavement and LCCA of the roads. The traffic data used in this study was obtained from WIM data provided by the Florida Department of Transportation (FDOT). The WIM system can continuously monitor and measure the type and weight of the axles for each truck. Using this system, the percentage of each type of truck at each road from each category was determined. Figure 10-1 shows the annual average daily truck traffic (AADTT) for different road categories and truck classes. Truck classes are based on the

FHWA vehicle classifications (Appendix B) [107]. From henceforth, the vehicle classes 5 to 13 are referred to as trucks.

Because of the significant difference between truck traffic at each road functional class, this study categorizes the roads to Interstates (IS), principal arterials (PA) (expressways, Other), and minor roads (MR) (minor arterial, major collector). These three categories are also different in the structural aspect. As shown in Table 10-1, the average thickness of the pavement layers of the major roads (IS, PA) are more than the minor roads; therefore, it has a stronger structure. Figure 10-2 shows the typical section of Florida's pavement. The average structural number (SN) for each road category is also presented in Table 10-1 for comparison purposes. The Resilient Modulus (MR) of the roadbed soil is 10,000 psi based on the average modulus of the 37 different road segments in Florida. FC-5 has no structural value and is 3/4-in thick [108].

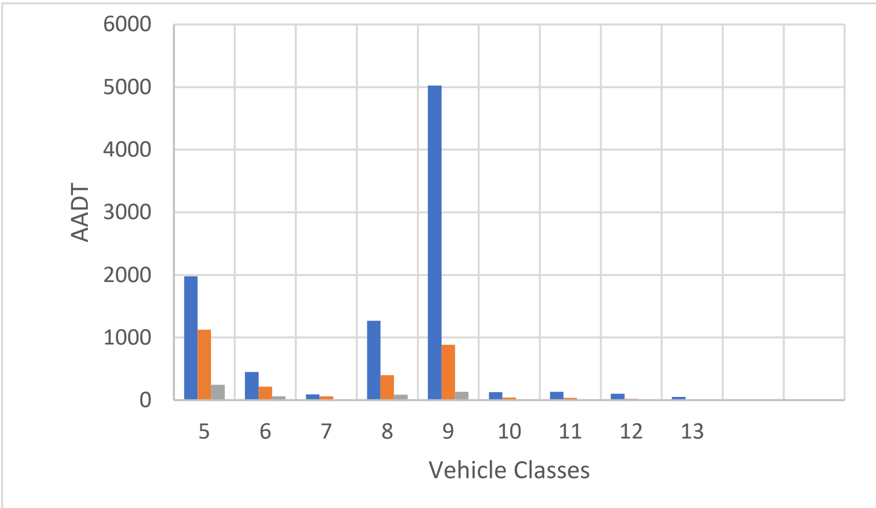


Figure 10-1. The AADT of the FHWA vehicle classes for IS, PA, and MR.

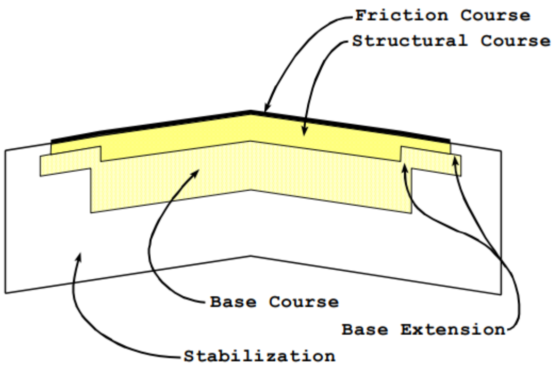


Figure 10-2. Roadway typical section.

Table 10-1. Representative pavement structures for different road categories.

Road Function	Layer Type	Material Character	Thickness (in.)	Ave SN
IS	Friction Course	Asphalt Concrete (PG 76-22)	0.75	5
	Structural Course	Asphalt Concrete (PG 76-22)	6.5	
	Base	LBR* 100	11	
	Stabilization	LBR 40	12	
PA	Friction Course	Asphalt Concrete (PG 76-22)	0.75	4.3
	Structural Course	Type SP Structure Course; Traffic C (3")	4	
	Base	LBR 100	10	
	Stabilization	LBR 40	12	
MR	Friction Course	FC-5, Traffic Level C	0.75	3.7
	Structural Course	Type SP-Traffic level C	2.5	
	Base	LBR 100	8	
	Stabilization	LBR 40	12	

*LBR: lime rock bearing ration, $\mathrm{MR(PSI)} = 809 * 10^{0.7365*\log(\mathrm{LBR})}$

11. Pavement Damage Analysis

There are two common methods to estimate the damage in the “engineering” approach: mechanistic-empirical (M-E), and the concept of equivalent single axle load (ESALD). The mechanistic-empirical pavement design (MEPDG) and related software (AASHTO’s Pavement M-E) was developed as part of the NCHRP. However, due to several major upcoming revisions to the models used in this software, the FDOT has not yet adopted MEPDG for flexible pavement design [108]. To have an estimation of the M-E analysis in this study, the PaveXpress software is used to analyze the damage caused by an incremental increase in the axle load for the different axle configurations (single, tandem, tridem). The data in Table 10-1 is used as input for the software for material characteristics. PaveXpress uses the following transfer functions for the M-E damage analysis:

National Center for Asphalt Technology (NCAT) model for fatigue cracking:

$$N_f = (2.83 \times 10^{-6})(\frac{1}{\varepsilon_t})^{3.148}$$ Eq. 38

Asphalt Institute model for rutting:

$$N_d = (10.77 \times 10^{15})(\frac{10^{-6}}{\varepsilon_v})^{4.4843}$$ Eq. 39

N_f and N_d are the number of cycles to failure. ε_t is the asphalt tensile strain, and ε_v is the subgrade compressive strain.

In this analysis, the loads on each of the axle configurations were incrementally increased and the number of cycles to pavement failure for different distress types (fatigue, rutting) were calculated. Then, Eq. 40 was used to calculate the Load Equivalency Factor (LEF). The LEF is damage caused by one single pass of an axle divided by damage caused by one single pass of the standard 18-kip single dual tires axle load [45]. A power function was used to find the correlation between the axle loads and LEF (Figure 11-1).

$$\text{LEF} = \frac{1/N}{1/n} = \frac{n}{N} = a(axle\ load)^b$$ Eq. 40

n = Allowable number of load cycles to failure under a standard 18-kip single axle

N = Allowable number of load cycles to failure under different axle configuration and magnitudes

a, b = constants obtained from the correlation between LEF and axle load

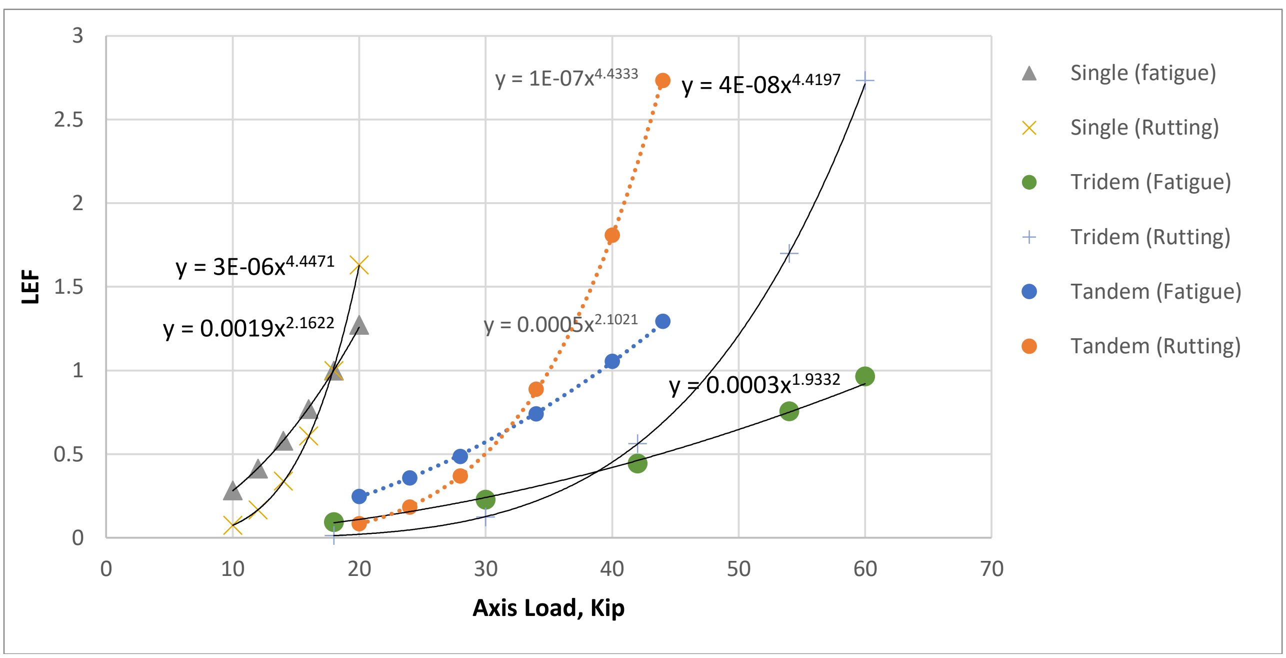


Figure 11-1. Load equivalence factor for single, tandem, and tridem axle configurations.

This study follows the flexible pavement design manual (FPDM) [108] for relating the relative damage caused by different axle loadings. This method provides a procedure to calculate the accumulated damage caused by mixed vehicle loadings during the pavement design period. A 4-tire, single axle, with a load of 18-kip is used as the base of calculations. Eq. 13 is used estimate the damage for Flexible pavement:

The LEF from the AASHTO road test indicates that damage to the pavement roughly increases by the power of four, which is known as the fourth-power law. However, the exact value of LEF varies depending on the SN and ΔPSI [109]. It should be noted that according to a research study conducted by Purdue University, the final calculated fee has a negligible sensitivity to the power value as long as it is in a range of 4±1 [110]. Thus, in this study, damage estimations are conducted based on the fourth-power law.

12. Road-use Measure

In this study, the ESAL-mile is used as the measure for road-use. ESALs used in this study are obtained from 37 road segments in Florida (Appendix C) and represent different road categories (9 IS, 15 PA, 13 MR). Data is collected from Pavement type selection reports (PTS) for each of the segments. All of the PTS reports have used Eq. 41 to estimate the total ESALs during the design period of 20 years. Equation 42 is used to estimate the ESALs for a full life cycle period of 40 years. The length of the life cycle is adopted from the FDOT pavement type selection manual (PTSM) [111]. The AADT growth rates were determined to be corresponding with each of the road segments' traffic regimes. All of the ESALs were calculated using the base ESALs of the year 2020, as this report is being prepared in the same year. The estimated number of ESALs for each of the road segments are presented in Appendix C.

$$ESAL = \sum AADT * T_{24} * D_F * L_F * 365 * LEF \qquad \text{Eq. 41}$$

$$ESAL = Base\ ESALs * G_f \qquad \text{Eq. 42}$$

where:
ESAL = Total ESAL during one life cycle (40 years)
AADT= Annual average daily traffic
T_{24} = Percent Heavy Trucks during a 24-hour period
D_F = Directional distribution factor (0.5)
G_f = Growth factor during the analysis period = $\frac{(1+i)^k}{i}$, i= AADT growth rate
L_d = Lane distribution factor = (1.567-0.826*ln(One Way AADT)-0.12368*LV), LV is equal to 1 if the number of lanes in one direction is 3 or more [108]
LEF_i = Load equivalency factor, which is the damage caused by one average heavy truck measured in 18-Kip ESALs. This factor is obtained from FPDM and is calculated based on WIM data (Table 12-1) [108].

Table 12-1 LEF for different types of facilities [108]

	Freeways	Arterial and Collectors
Rural	1.05	0.9
Urban	0.96	0.89

13. Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) is used to calculate the monetary equivalency of all benefits and costs at their respective time of occurrence throughout the analysis period. The most common methods used to conduct the LCCA analysis are Net Present Value (NPV), the Cost-Benefit ratio (B/C), Internal Rate of Return (IRR), and the Equivalent Uniform Annual Cost (EUAC). Depending on the context of the analysis, each of the methods has its advantages and disadvantages. The NPV indicator accounts only for differential costs and/or benefits while keeping the consistency in the evaluation effort [45], and is used in this section.

Since this study deals with the entire Florida road network, the analysis needs to provide a sound estimation based on various factors such as soils, weather, materials, maintenance, etc. A 40-year analysis period and a discount rate of 3.5% were used in the study. These values are recommended by PTSM, NCHRP [111], [112]. All of the life cycle costs are obtained from PTS reports for each of the road segments. The advantage of using PTS report data is that each LCCA corresponds to a specific road segment. Thus, it reflects the design and M&R properties of a specific segment. The rehabilitation practice considered in this study is M&R. The frequency of M&R varies between 13 to 16 years. The indirect costs such as maintenance of traffic, construction engineering inspection, mobilization, contingency, and design are also included in the final cost.

The FDOT Historical Cost Average Report was used to estimate the cost of construction and M&R (Table 13-1). The material costs presented in Table 13-1 are based on the executed contracts and are annual statewide averages. Before calculating NPV, the indirect costs are added to initial construction cost and M&R cost separately using Eq. 43. This equation is adopted from the Metropolitan Planning Organization (MPO) cost estimating methodology [113].

$$FC = C * (1 + MOT + Mob) * (1 + Cont + CEI) * (1 + Des) \quad \text{Eq. 43}$$

Where:
FC = Final cost; initial construction or M&R costs after applying the indirect costs
C = Initial construction or M&R cost per mile-lane (based on historical cost average)
MOT= Maintenance of traffic (10%),
CEI = Construction engineering inspection (15%),
Mob = Mobilization (10%)
Cont = Contingency (15%)
Des = Design (15%)

The NPV for one mile of the road segments was calculated using Eq. 44. The costs presented in Table 13-1 are from December 31, 2019. However, some of the PTS reports are from early 2020. The discount rate of 3.5% was used to calculate the current (2020) values of the costs that belong to after or before the year 2020. The results are reported in Appendix C.

Table 13-1. Pavement unit costs for construction and rehabilitation.

Description	Unit	Weighted Average	No. of Contracts
Type B stabilization	Sq. Yd	$3.79	136
Optional base, base group 01	Sq. Yd	$13.95	92
Optional base, base group 09	Sq. Yd	$19.33	79
Optional base, base group 11	Sq. Yd	$17.64	22
Milling exist asphalt pavement, 1" avg depth	Sq. Yd	$2.19	46
Milling exist asphalt pavement,1 1/2" avg depth	Sq. Yd	$2.05	108
Milling exist asphalt pavement, 2 3/4" avg depth	Sq. Yd	$1.84	21
Milling exist asphalt pavement, 3" avg depth	Sq. Yd	$1.97	40
Superpave asphalt concrete, traffic B, PG 76-22	Ton	$111.36	30
Superpave asphalt concrete, traffic D, PG 76-22	Ton	$106.29	28
Asphalt concrete, FC, FC-5, PG 76-22	Ton	$135.91	60
Asphalt concrete, FC, traffic B, FC-9.5, PG 76-22	Ton	$117.92	16

$$NPV = I + M\left(\frac{1}{1+r}\right)^{ni} + \cdots Mj\left(\frac{1}{1+r}\right)^{nj} - S\left(\frac{1}{1+r}\right)^{N} \quad \text{Eq. 44}$$

Where:
NPV = Net present value per mile
I = Present cost of initial construction per mile
M_i = Cost of the i^{th} M&R alternative per mile

r = Discount rate (3.5%)
n_i = Number of years from the present to the i[th] M&R activity
N = Length of the analysis period in years (40)
S = Salvage value at the end of the analysis period per mile.

14. Pavement Damage Cost

Pavement construction costs and M&R costs were derived from thirty-seven different road segments, as previously described. The APDC was calculated by dividing the total cost (NPV) per lane mile to the total road usage (ESALs) for each of the road segments. Then, to be able to calculate the APDC corresponding to the desired number of ESALs, Eq. 45 was developed by conducting a regression analysis between APDC and the average annual number of ESALs. By using Eq. 45, one can interpolate between the data points used in this study. This function could be used for all road categories and traffic levels.

$$\text{APDC}=\beta_1(ESALs)^{\beta_2} \qquad \text{Eq. 45}$$

where:
APDC = average pavement damage cost in dollars (consumption)
ESALs = the average annual number of equivalent single axle load, the average annual ESALs was calculated based on traffic data
β_1 and β_2 = regression constants. Based on the data set used, they were found to have the following values β_1=3610.3 and β_2=-0.866.

The APDC was lowest for IS and highest for the MR. Results were consistent with Indiana's and Louisiana's studies [30], [106]. It should be noted that each road is designed based on the magnitude of the load that it is expected to carry during its design life. However, when the traffic volume is high, the economy of scale causes the APDC to be lower. This observation is also related to environmental damage. Environmental damage impacts the roads regardless of load damage. Thus, more load applications on the same road will lower the cost per ESAL applied. In many cases, the construction and M&R cost per lane mile of an MR is about 75 percent of that of an IS, but the AADTT of an IS is significantly higher than that of the MR (more than 10 times), which results in a smaller APDC among the IS users.

To calculate average ESALs for each road category, the average AADT and average truck percentage were calculated for IS, PA, and MR using 2017 traffic data published by FDOT. Equation 44 was then used with a growth rate of 2% to estimate ESALs. Finally, the corresponding APDC is calculated using Eq. 45. The results are presented in Table 14-1.

Table 14-1. APDC estimation for three road categories.

Road Categories	Average AADT (2020)	Average T_{24}	ESALs (×1000)	APDC($/mile-ESAL-lane)
IS	65,628	16.78%	52,327	0.018
PA	34,565	10.01%	16,567	0.049
MR	8,746	8.86%	4,703	0.147

15. Proposed Permit Fee Structure

Table 15-1 presents part of the proposed fee structure related to pavement damage, which compares the proposed fee to the existing permit fee used by FDOT at three road categories. The complete Table is presented as Appendix D. The PDCs in red exceed the existing permit fee. It should be noted that Table 15-1 is only based on pavement damage and does not include bridge damage costs. The GVW of the 80,000 lbs. is considered the weight limits above which the truck is subjected to overweight fees. It should be noted that FDOT has a restriction of 22,000 lbs. for a single axle load. Therefore, Table 15-1 begins with 4-axle trucks.

Table 15-1. Proposed permit fee structure for single-trip.

(A) Number of Truck axles	(B) Avg ESAL	(C) Max Allowable ESAL	(D) Excess ESALs	(E) IS	(F) PA	(G) MR
				$ Per Mile Per Truck		
80-95 Kip (Current permit fee= $.27/mile)						
4	7.6	4.8	2.8	0.05	0.14	0.42
5	4.7	3.0	1.7	0.03	0.08	0.25
6	2.9	1.9	1.0	0.02	0.05	0.14
7	1.9	1.2	0.6	0.01	0.03	0.09
8+	1.1	0.9	0.3	0.00	0.01	0.04
95-112 Kip (Current permit fee= $.32/mile)						
4	19.6	4.8	14.8	0.27	0.73	2.17
5	7.5	3.0	4.5	0.08	0.22	0.66
6	5.0	1.9	3.1	0.06	0.15	0.45
7	3.3	1.2	2.1	0.04	0.10	0.31
8+	2.4	0.9	1.6	0.03	0.08	0.23

The overall procedures adopted to develop Table 15-1 are:

1- Break down the trucks' GVW to the same brackets currently used by the FDOT permit fee structure. Then, estimate the ESALs for the overweight trucks using the fourth-power law explained in the Damage Analysis section and the distribution of the loads on each axle of trucks. The permit fee data includes the distribution of loads on each axle. The GVW for each axle number is increased to the point that none of the axles exceed 22-kip. The average ESALs for an overweight truck with an axle number in column A is reported in column B.

2- Estimate the maximum allowable ESALs for 80-kip trucks using the permit fee data (column B).

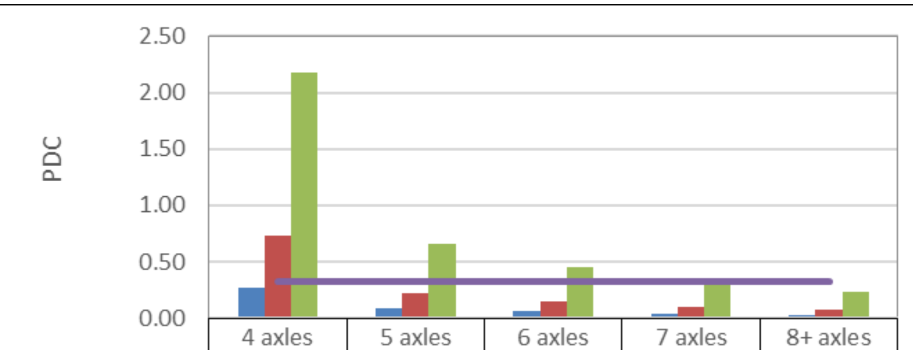
3- To estimate the additional damage caused by the overweight truck, the maximum allowable ESAL is subtracted from the average ESAL (Column D).

4- Estimate the fee per mile for an overweight truck by multiplying the APDC at each axle number and road category, and by the additional ESALs at column D (Columns E, F, G).

15.1. Comparison of the Existing Permit Fee and the PDC

In this section, PDCs are compared with existing permit fees for the two GVW categories of 95-112 Kip and 132-142 Kip.

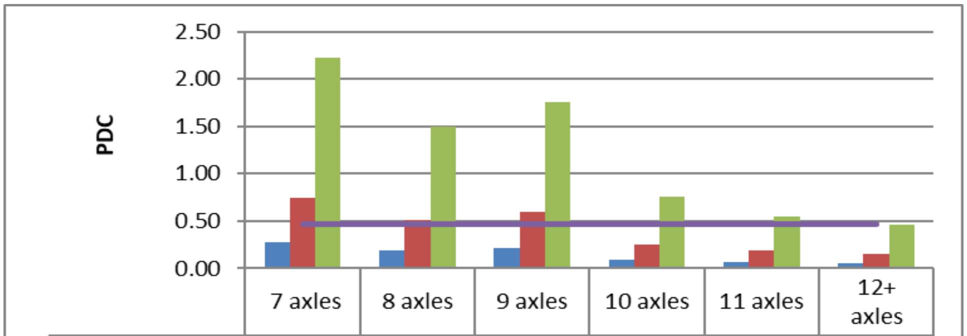
GVW 95-112 Kip: Figure 15-1 illustrates that in the case of 4-axle trucks, the PDCs are greater than the existing permit fee for MR and PA, but lower for IS. However, in all other cases, trucks are overpaying in PA and IS road categories based on existing permit fees. By increasing the number of axles, the PDC decreases for all road categories. This trend was observed for almost all GVW categories.



	4 axles	5 axles	6 axles	7 axles	8+ axles
IS	0.27	0.08	0.06	0.04	0.03
PA	0.73	0.22	0.15	0.10	0.08
MR	2.17	0.66	0.45	0.31	0.23
Current Fee	0.32	0.32	0.32	0.32	0.32

Figure 15-1. Comparing the PDC with existing fee for trucks with GVW 80-95 kip.

GVW 132-142 Kip: In the case of trucks with 7, 8, and 9 axles, the PDCs are greater than the current permit fee for MR and PA. Thus, based on existing permit fees, trucks are underpaying compared to the PDC. In the case of IS, and for all axles, trucks are still overpaying based on existing permit fees.



	7 axles	8 axles	9 axles	10 axles	11 axles	12+ axles
IS	0.28	0.19	0.22	0.09	0.07	0.06
PA	0.75	0.51	0.59	0.25	0.18	0.16
MR	2.23	1.50	1.76	0.76	0.55	0.46
Current Fee	0.47	0.47	0.47	0.47	0.47	0.47

Figure 15-2. Comparing the PDC with existing Fee for trucks with GVW 152-162 kip.

The diagrams above (Figures 15-1,15-2) are plotted to illustrate the shortcomings of the existing permit fees. Depending on the number of axles and the type of roads, trucks are either overpaying or underpaying compared to the proposed permit fee. It is evident that as the number of axles increase, damage costs decrease for all road categories. It should be mentioned that the permit fees used in this comparison are only based on pavement damage costs and do not include the bridge damage costs.

15.2.Merging Pavement Damage Costs

To enhance the convenience of monitoring, it is possible to merge the costs associated with different road types (IS, PA, MR) and the number of axles. This report has proposed two levels of merging.

Level one: Merging the proposed permit fees related to the three road categories based on the average annual truck distance traveled in miles.

According to the highway statistics published by the FHWA website, it is estimated that roughly 44% of the total annual truck distance traveled in miles uses an IS class road, 33% uses PA roads, and 23% uses MR roads [114]. Table 15-2 shows the outcome of this level of convergence. The red numbers indicate that the proposed permit fees exceed the existing fee.

Table 15-2. Proposed permit fees (PDC) after merging level one ($/mile).

Number of the axles		4	5	6	7	8	9	10	11	12	13
GVW Range	Existing Fee										
80-95 Kip	0.27	0.16	0.10	0.06	0.04	0.02					
95-112 Kip	0.32	0.86	0.26	0.18	0.12	0.09					
112-122 Kip	0.36		0.52	0.34	0.24	0.16	0.15				
122-132 Kip	0.38		0.87	0.50	0.36	0.24	0.15				
132-142 Kip	0.42		1.21	0.82	0.45	0.34	0.34				
142-152 Kip	0.45			1.05	0.64	0.46	0.51	0.23	0.18		
152-162 Kip	0.47				0.88	0.59	0.70	0.30	0.22	0.18	
*162-199Kip	0.54				1.18	0.82	1.10	0.56	0.52	0.43	0.24
*200-240 Kip	0.67					1.56	2.26	1.00	0.79	0.76	0.63
*241-260 Kip	0.75								1.51	1.04	0.94
*260-280 Kip	0.80								1.95	1.43	1.19

*The existing permit fee for GVW more than 162 kip is calculated by multiplying the 0.003$ per mile per 1,000 lbs. (from the existing permit fee) to the average GVW at each load category.

Level two: Merging permit fees associated with road types and the number of axles.

The number of trucks at each axle group was obtained from the permit fee database. Figure 15-3 presents an example of the distribution of trucks in three GVW groups. Fees were weight averaged based on the percentage of the trucks at each axle and GVW group.

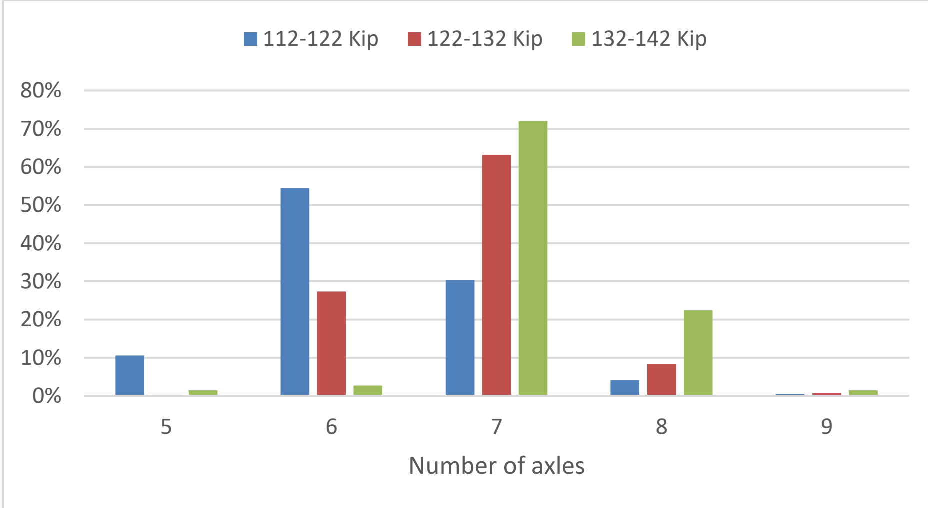
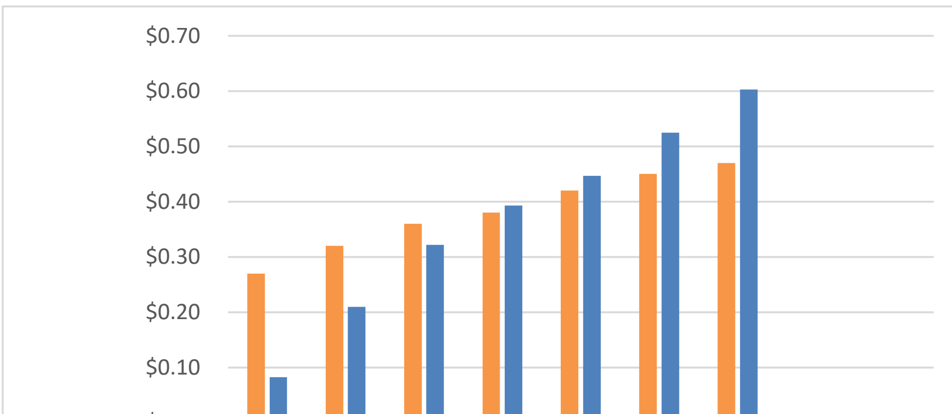


Figure 15-3. Percentage of each axle group for three GVW groups of 112-122,122-132, and 132-142 Kip.



	95	112	122	132	142	152	162	199	>199
Current Permit	$0.27	$0.32	$0.36	$0.38	$0.42	$0.45	$0.47	$0.003	$0.003
Consumption	$0.08	$0.20	$0.32	$0.39	$0.44	$0.52	$0.60	$0.00	$0.00

Figure 15-4. Proposed permit fees (PDC) for single trip permits vs. current permit fees (merging level two).

Due to the difficulties of determining the route that a truck may take during a trip, merging level one (Table 15-2) is a more convenient method for overweight enforcement, compared to the permit fee structure presented in Table 15-1. However, the number of axles should still be determined. According to the permit fee database, when issuing a permit, the character of the trucks and the number of their axles and their weight is registered in the system. In merging level two, there is no need to determine the route and the number of axles. However, it compromises the accuracy of the proposed permit fee. Figure 15-4 presents the PDC after merging level two and places it in the same format as the existing overweight permit fee. It should be taken into consideration that although merging fees related to each type of road and the number of axles could enhance the convenience of monitoring, it will reduce the equitability of charged fees, as users are not charged a fee consistent with the damage they cause, but a fee based on an average value of the damage across various road and vehicle types. It is noted that the damage varies significantly based on type of road and number of axles, given the same gross vehicle weight.

15.3.Multi-trip Permits (12 and 3 months)

An average trip length is required for pavement multi-trip permit calculation, which is the same as the multi-trip permit analysis for bridges. The average length of the trip is estimated as 130 miles, and the number of trips is designated as 25 for three-month permits and 100 trips for 12-month permits. These estimates were based on Permit Data statistics, presented in Part B.

By multiplying the average length of the trip to the PDCs of the merging level two and applying the 90% discount adopted from the existing permit fee, the multi-trip permits were calculated and presented in Figures 15-5 and 15-6.

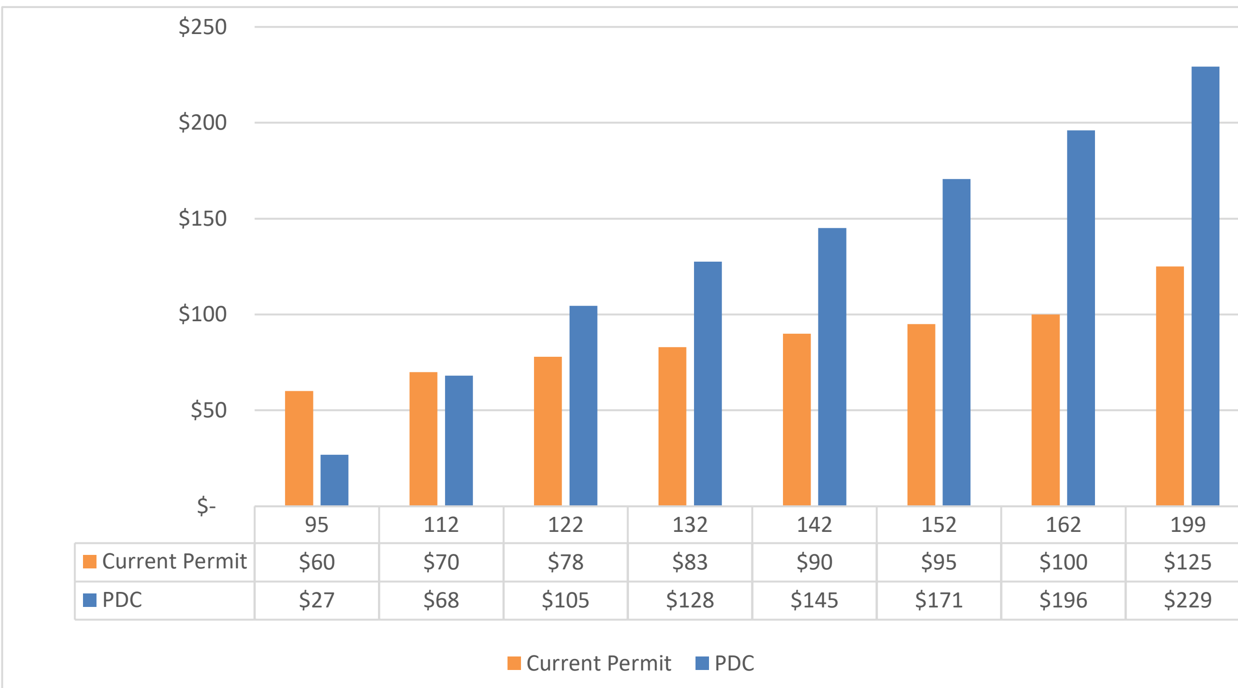


Figure 15-5. PDC for multi-trip 3-month permits vs. current permit fees in Florida.

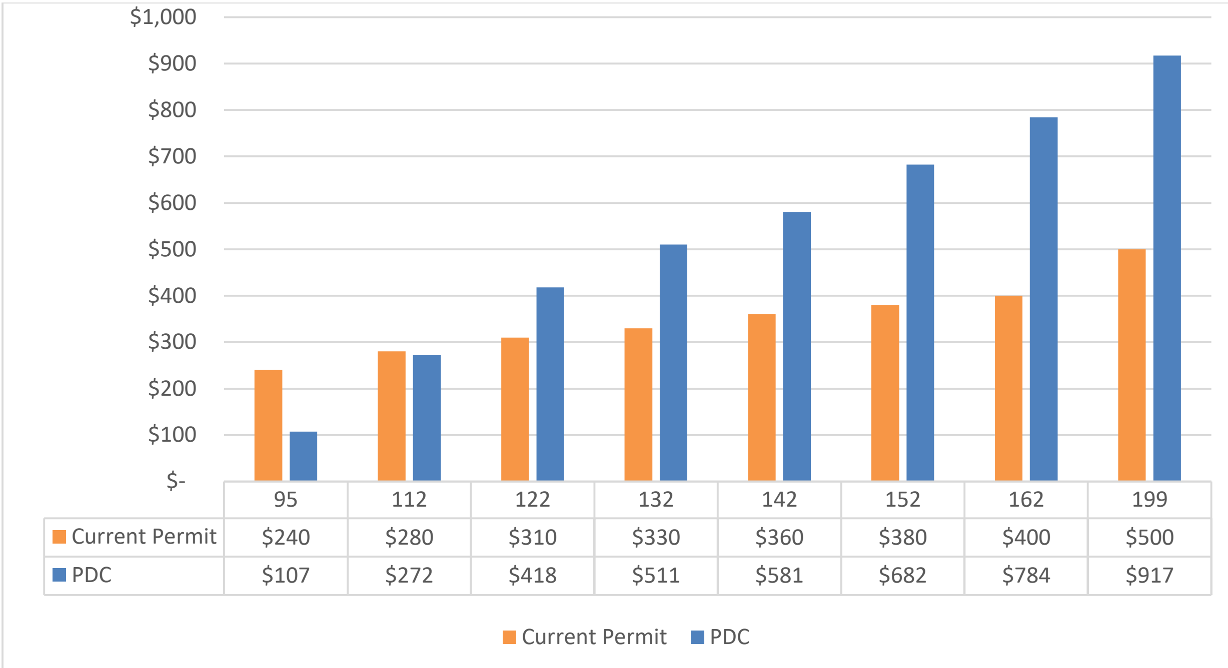


Figure 15-6. PDC for multi-trip 12 months permits vs. current permit fees in Florida.

16. Summary

In this section, roads are categorized based on their structure and their traffic level. Thirty-seven different scenarios (different road functional classes, traffic levels, construction costs, and M&R practices) were selected to estimate APDC. The results showed that APDC is higher for the minor roads compared to the interstates and principal arterials. In this study, the type of roads that a truck will use from the starting point to the destination and its number of axles are the determining factors in the calculation of the permit fee associated with each truck. Compared to the proposed permit fees (Appendix D), some trucks are currently paying more than the damage that they cause, and some pay less.

The proposed permit fee may have some enforcement complications due to the consideration of three types of road (IS, PA, and MR) and a different number of axle loads for each GVW group. To enhance the convenience of monitoring and enforcement, two levels of merging are proposed to simplify the proposed structure. First, the estimated length of the trip that a truck may travel on each road category is used to merge the fees associated with each of road type (Table 15-2). Second, in addition to merging level one, the fees associated with the axel groups at each GVW category are merged (Figure 15-4). Both levels of merging decrease the accuracy of the issued permit fee, but merging level two offers the least accuracy. The level two merging yields a permit fee structure identical to the current fee structure used in Florida.

PART D: COMPILATION OF BRIDGE AND PAVEMENT DAMAGE COSTS

17. Pavement and Bridges Monetary Consumption

The damage assessment analysis was conducted to assign fair costs to the various vehicles and permit types in Florida. This study is based on the issued permit database from 2016 to 2019. The existing permit vehicles operating on the roads and bridges in Florida are utilized to determine monetary damage. The consumption cost is assessed separately for pavement and bridges. Consumption assessment results for bridges and pavements are compiled for single trip and multi-trip permits. Table 17-1 shows the consumption in dollars per mile for each GVW group according to current permit fee schedule for bridges and pavements and for a combination of both bridges and pavements.

Table 17-1. Consumption for single trip permits in dollars per mile.

Single Trip			
GVW group	**Bridge**	**Pavement**	**Consumption**
[kip]	**[$/mile]**	**[$/mile]**	**[$/mile]**
80-95	$ 0.05	$ 0.08	$ 0.13
95-112	$ 0.06	$ 0.21	$ 0.27
112-122	$ 0.09	$ 0.32	$ 0.41
122-132	$ 0.14	$ 0.39	$ 0.53
132-142	$ 0.19	$ 0.45	$ 0.64
142-152	$ 0.29	$ 0.52	$ 0.81
152-162	$ 0.32	$ 0.60	$ 0.92
162-199	$ 0.003 / 1,000 lb	$ 0.004 / 1,000 lb	$ 0.007 / 1,000 lb
>199	$ 0.005 / 1,000 lb	$ 0.004 / 1,000 lb	$ 0.009 / 1,000 lb

The total consumption on bridges and pavements caused by permitted vehicles in Florida is presented as a summation of both consumptions. Further analysis of those results will be shown in the following sections.

Analysis of the multi-trip permits considers the number of trips and the distance of the trip to determine the consumption of such a permit. The calculation for pavements and bridges is consistent, and it is assumed that the average length of the trip is 130 miles. The number of trips for an annual permit is 100 and is 25 trips for a 3-month permit. Table 17-2 shows the summed-up bridge and pavement consumption for annual permits.

Table 17-2. Total consumption for annual multi-trip permits in dollars.

Multi-trip 12 months					
GVW group	Current permit fee	Bridge	Pavement	Consumption	Rounded Consumption
80-95 kip	$ 240	$ 756	$ 1,072	$ 1,828	$ 1,830
95-112 kip	$ 280	$ 2,334	$ 2,723	$ 5,057	$ 5,060
112-122 kip	$ 310	$ 2,707	$ 4,181	$ 6,888	$ 6,890
122-132 kip	$ 330	$ 2,713	$ 5,105	$ 7,818	$ 7,820
132-142 kip	$ 360	$ 3,945	$ 5,807	$ 9,752	$ 9,760
142-152 kip	$ 380	$ 4,285	$ 6,825	$ 11,110	$ 11,110
152-162 kip	$ 400	$ 3,899	$ 7,848	$ 11,747	$ 11,750
162-199 kip	$ 500	$ 4,536	$ 9,173	$ 13,709	$ 13,710
>199	NOT ISSUED				

In order to allow flexibility in freight transport operations, a discount needs to be assigned to multi-trip permits. The permit fees with a discount varying from 90 – 50% is shown in Table 17-3.

Table 17-3. Discounted consumption for annual multi-trip permits in dollars.

Multi-trip 12 months			Discount for multi-trip permits				
GVW group	Current permit fee	Consumption	90%	80%	70%	60%	50%
80-95 kip	$ 240	$ 1,830	$ 190	$ 370	$ 550	$ 740	$ 920
95-112 kip	$ 280	$ 5,060	$ 510	$ 1,020	$ 1,520	$ 2,030	$ 2,530
112-122 kip	$ 310	$ 6,890	$ 690	$ 1,380	$ 2,070	$ 2,760	$ 3,450
122-132 kip	$ 330	$ 7,820	$ 790	$ 1,570	$ 2,350	$ 3,130	$ 3,910
132-142 kip	$ 360	$ 9,760	$ 980	$ 1,960	$ 2,930	$ 3,910	$ 4,880
142-152 kip	$ 380	$ 11,110	$ 1,120	$ 2,230	$ 3,340	$ 4,450	$ 5,560
152-162 kip	$ 400	$ 11,750	$ 1,180	$ 2,350	$ 3,530	$ 4,700	$ 5,880
162-199 kip	$ 500	$ 13,710	$ 1,380	$ 2,750	$ 4,120	$ 5,490	$ 6,860
>199	NOT ISSUED						

The discount is to be assigned by FDOT officials. The impact analysis of the considered discount will be presented later in this report.

A similar analysis of the consumption for the 3-month multi-trip permits was conducted. The number of trips in the case of a 3-month permit is designated as 25. Table 17-4 presents the consumption in dollars assigned to different GVW of permitted vehicles. The discount computation of the 3-month multi-trip is shown in Table 17-5.

Table 17-4. Total consumption for 3-month multi-trip permits in dollars.

Multi-trip 3-month					
GVW group	**Current permit fee**	**Bridge**	**Pavement**	**Consumption**	**Rounded Consumption**
80-95 kip	$60	$189	$268	$457	$460
95-112 kip	$70	$584	$681	$1,264	$1,270
112-122 kip	$78	$677	$1,045	$1,722	$1,730
122-132 kip	$83	$678	$1,276	$1,955	$1,960
132-142 kip	$90	$986	$1,452	$2,438	$2,440
142-152 kip	$95	$1,071	$1,706	$2,777	$2,780
152-162 kip	$100	$975	$1,962	$2,937	$2,940
162-199 kip	$125	$1,134	$2,293	$3,427	$3,430
>199	$250	NOT CONSIDERED			

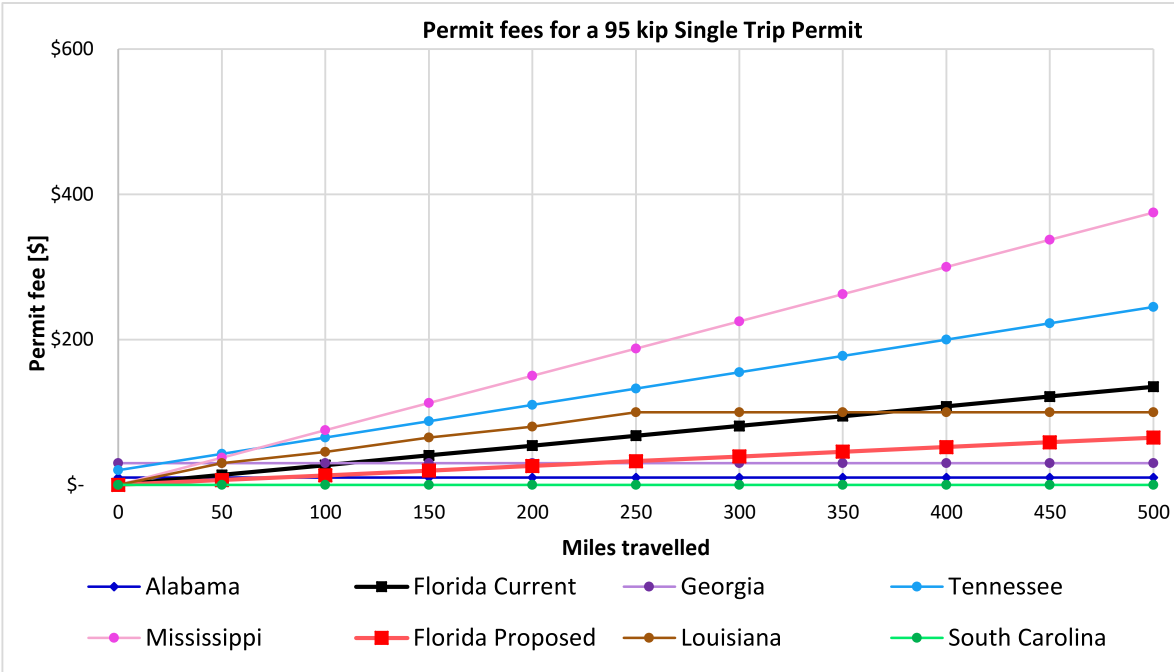
Table 17-5. Discounted consumption for 3-month multi-trip permits in dollars.

Multi-trip 3-month			Discount for multi-trip permits				
GVW group	**Current permit fee**	**Consumption**	**90%**	**80%**	**70%**	**60%**	**50%**
80-95 kip	$60	$460	$50	$100	$140	$190	$230
95-112 kip	$70	$1,270	$130	$260	$390	$510	$640
112-122 kip	$78	$1,730	$180	$350	$520	$700	$870
122-132 kip	$83	$1,960	$200	$400	$590	$790	$980
132-142 kip	$90	$2,440	$250	$490	$740	$980	$1,220
142-152 kip	$95	$2,780	$280	$560	$840	$1,120	$1,390
152-162 kip	$100	$2,940	$300	$590	$890	$1,180	$1,470
162-199 kip	$125	$3,430	$350	$690	$1,030	$1,380	$1,720
>199	$250	NOT CONSIDERED					

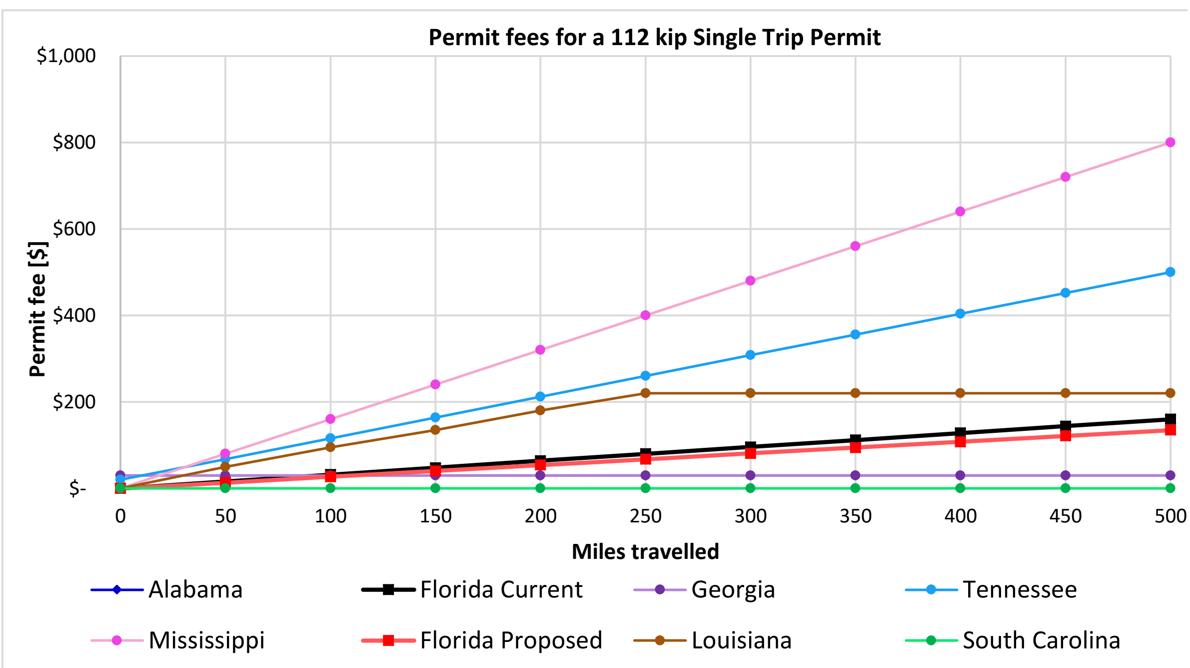
It is noted that the actual consumption is significantly higher than current multi-trip fees. In fact, the current fees charged by Florida are lower than those charged by other states. The current fees are offering more than 90% discount. This may be an incentive to reduce the admin and enforcement burden and other economic factors. FDOT should select the discount rate based on economic and other considerations.

18. Permit Fee Comparisons with Other States

The combined consumption of bridges and pavement was shown in the previous section. The results for single trip permits and multi-trip permits are compared with other states. The single trip permit in Florida is weight and distance dependent. Thus, the comparison between states is presented in terms of miles traveled by the permitted vehicles. In this analysis, six neighboring states are compared with Florida. Each state has a different permit fee schedule, but the comparative analysis was adjusted to GVW groups in Florida. Figure 18-1 shows the relationship between the price and miles traveled for single trip permits in Alabama, Mississippi, Georgia, Louisiana, South Carolina, Tennessee, and Florida.

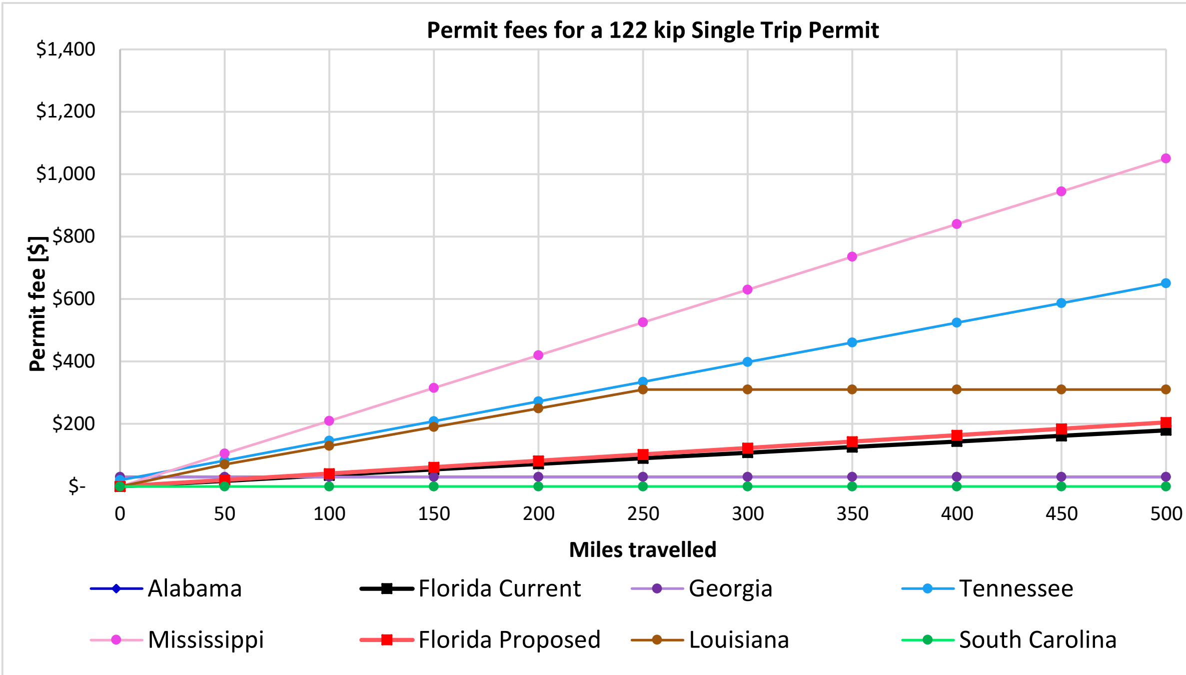


(a)

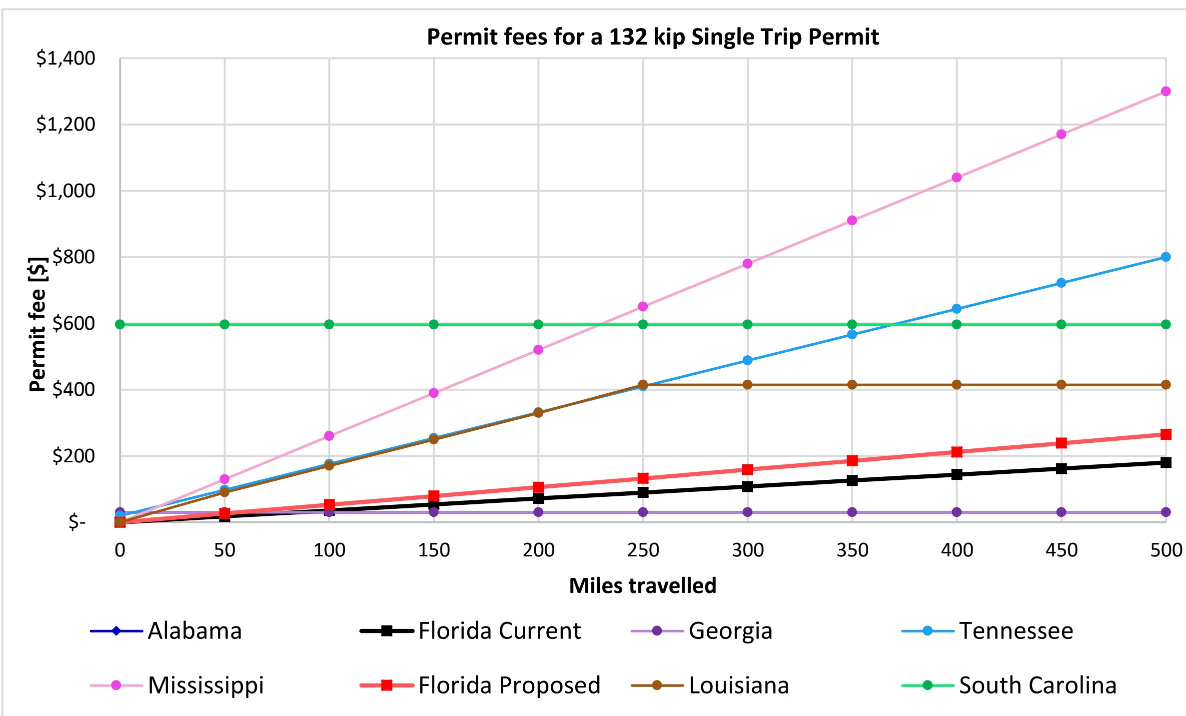


(b)

Figure 18-1. Comparative analysis of permit fees within states for single trip permits for the following GVW groups(a) up to 95 kip, (b) up to 112 kip.

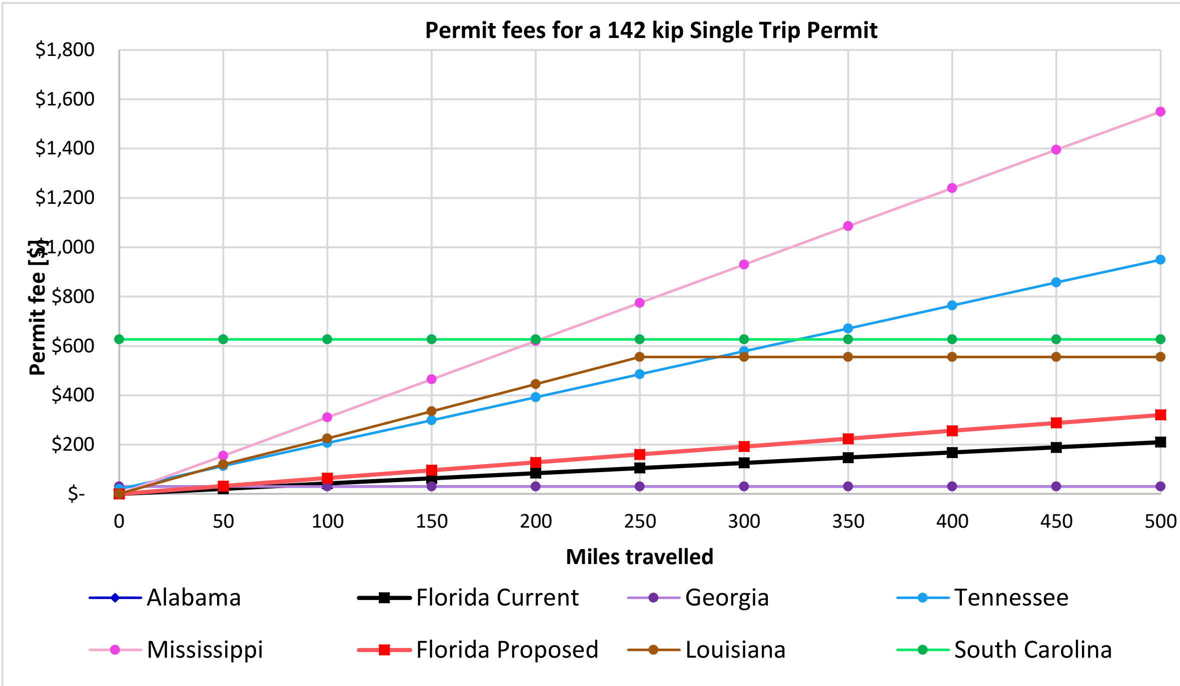


(c)

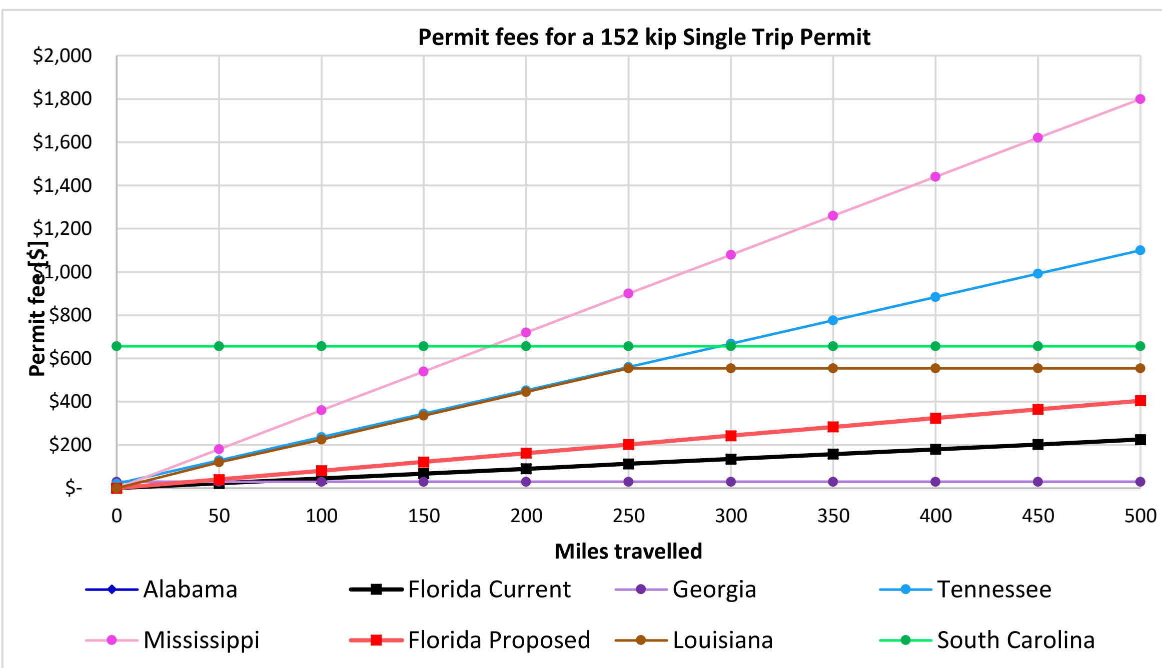


(d)

Figure 18-1. Comparative analysis of permit fees within states for single trip permits for the following GVW groups, (c) up to 122 kip, (d) up to 132 kip (continued).

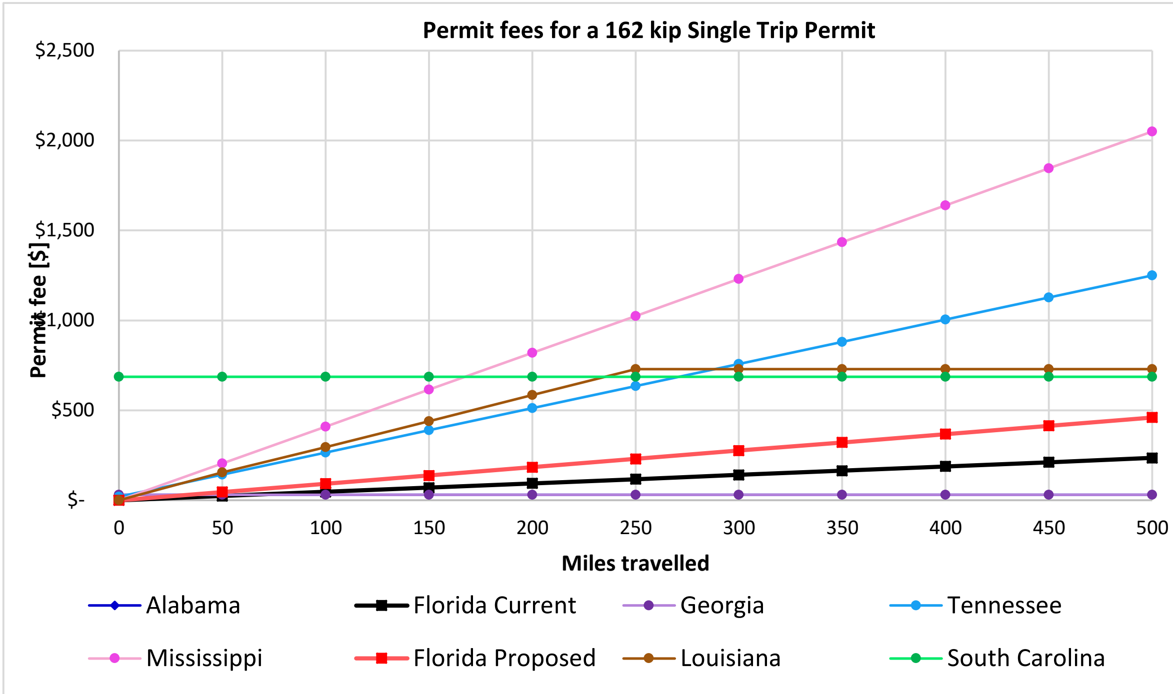


(e)

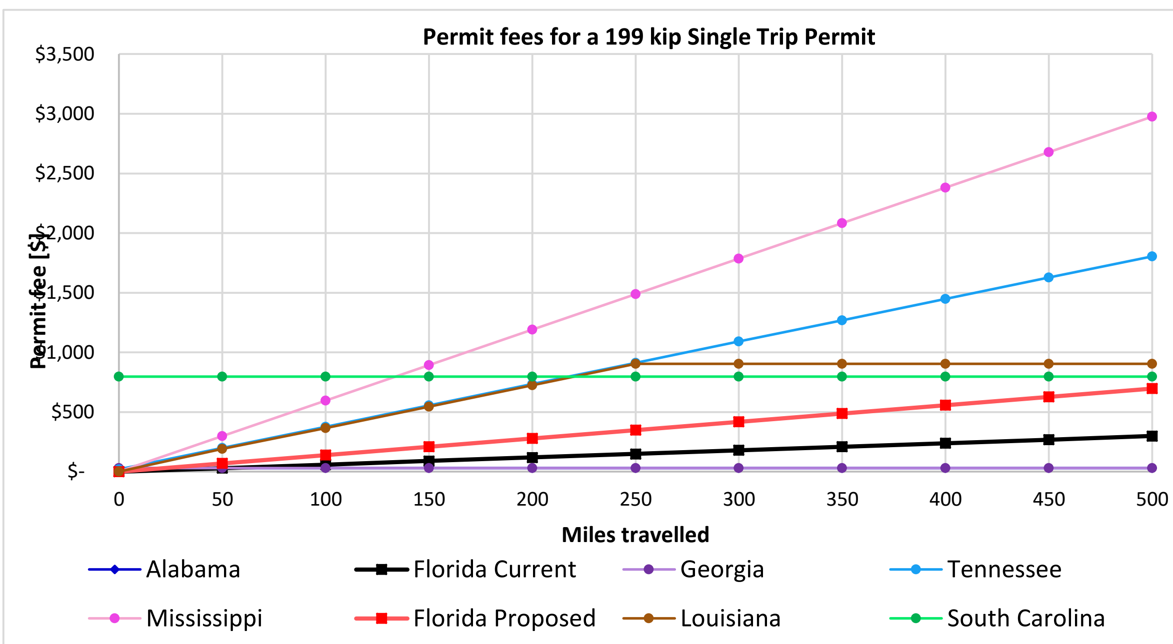


(f)

Figure 18-1. Comparative analysis of permit fees within states for single trip permits for the following GVW groups (e) up to 142 kip, (f) up to 152 kip, (g) up to 162 kip, (h) up to 199 kip, (i) above 199 kip (continued).

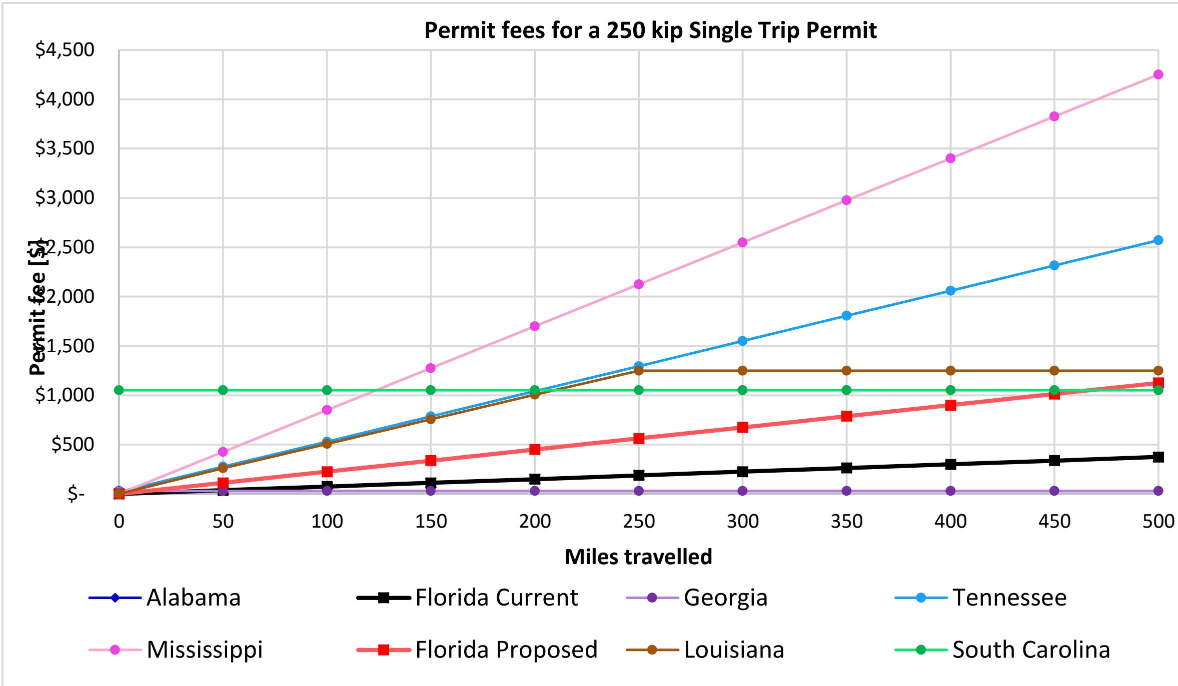


(g)



(h)

Figure 18-1 Comparative analysis of permit fees within states for single trip permits for the following GVW groups (g) up to 162 kip, (h) up to 199 kip, (i) above 199 kip. (continued)

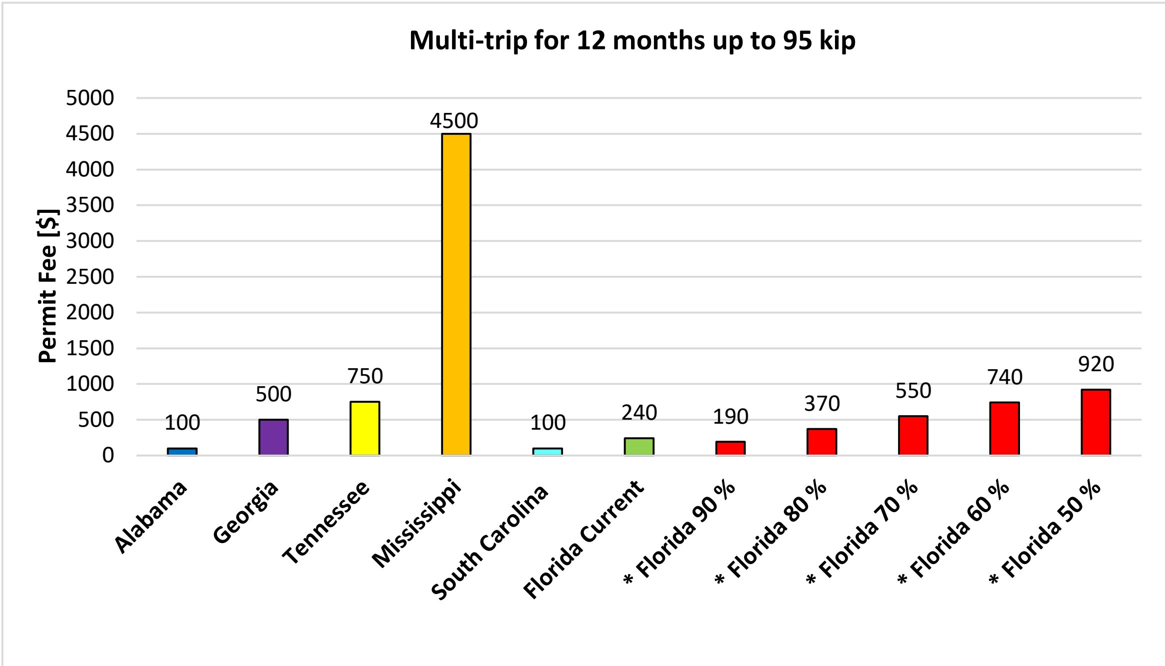


(i)

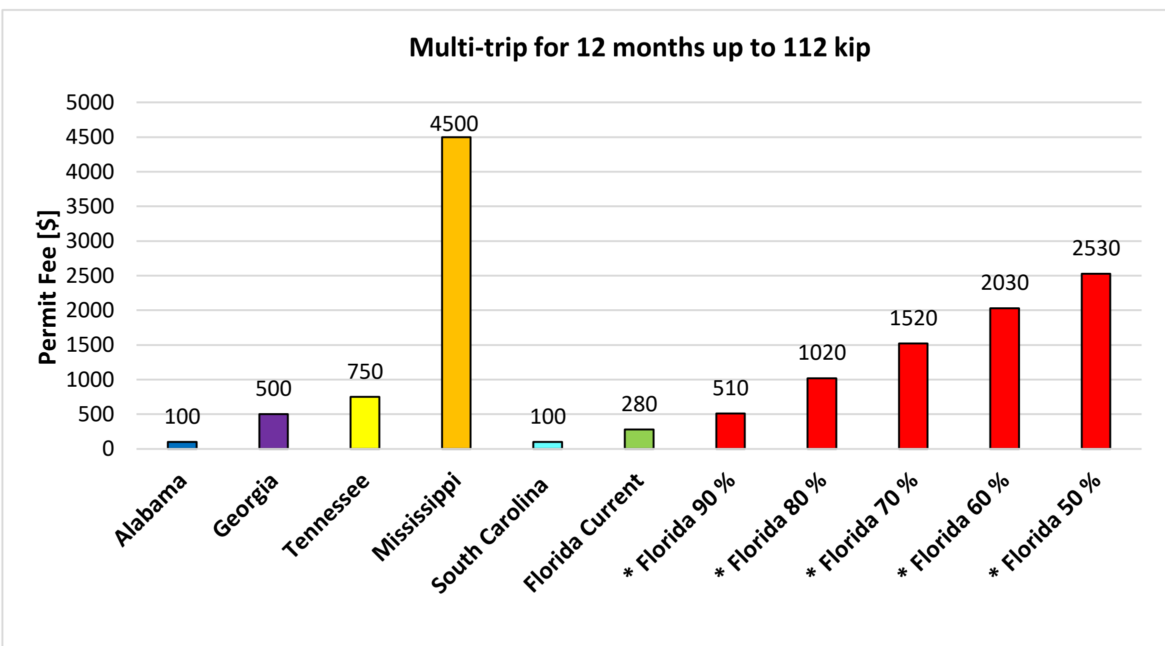
Figure 18-1 Comparative analysis of permit fees within states for single trip permits for the following GVW groups, (i) above 199 kip (continued).

The comparison shown in Figure 18-1 indicates that Florida has relatively low permit fees. The proposed fees are not significantly higher from the current permit fee schedule. Florida charges the lowest permit fee in dollars per mile in comparison to other considered states. The cost for Alabama and Georgia is lower than Florida in some GVW groups, but the permit fee is a fixed price. Alabama and Georgia do not consider the distance in a single trip permit issuance. It is evident that the proposed Florida fees are up to three times higher than the current permit fees in certain weight categories. Compared to other states, the proposed fees are not excessive.

A similar comparison is conducted for multi-trip permits. Multi-trips in Florida are weight dependent. The annual permit is a fixed price that does not depend on miles traveled. The comparison between states is shown for GVW groups according to the current permit fee schedule in Florida. Figure 18-2 presents the proposed discounted multi-trip permit fees compared to other states.

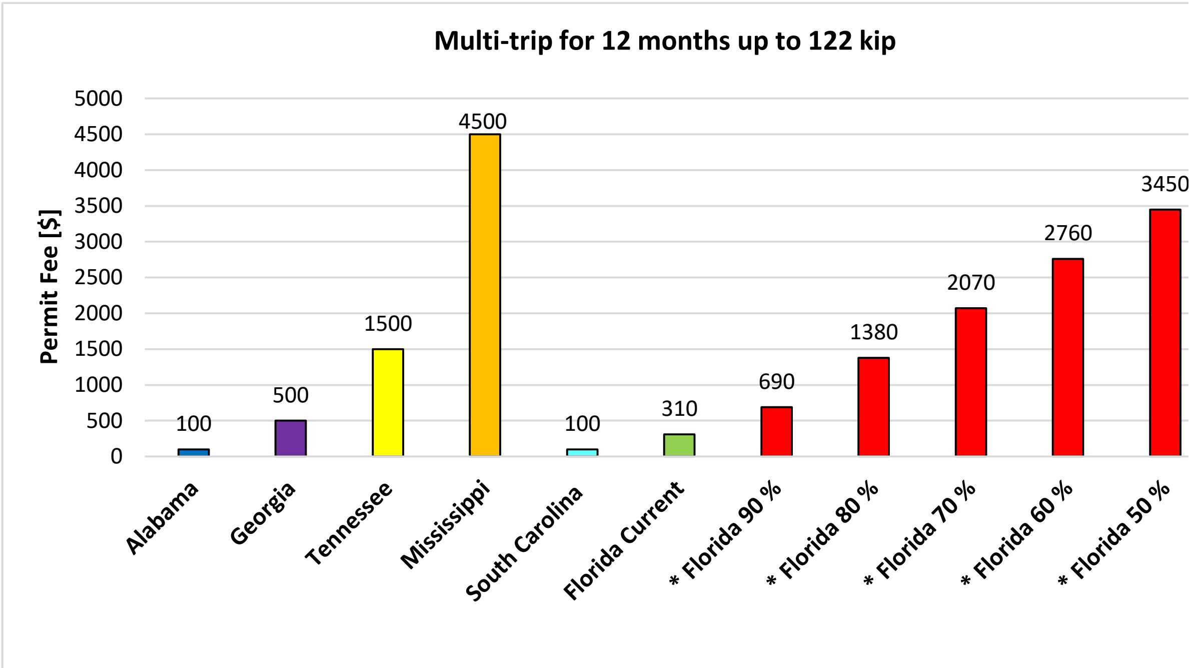


(a)

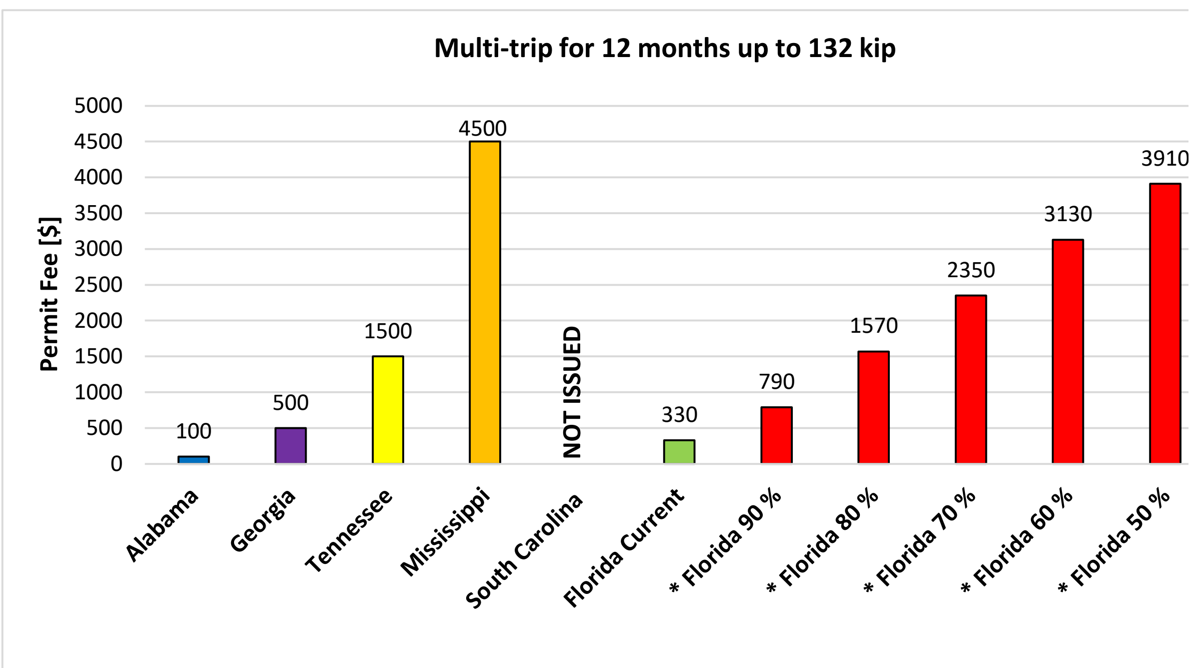


(b)

Figure 18-2. Comparison of annual multi-trip permits fees (a) up to 95 kip, (b) up to 112 kip.

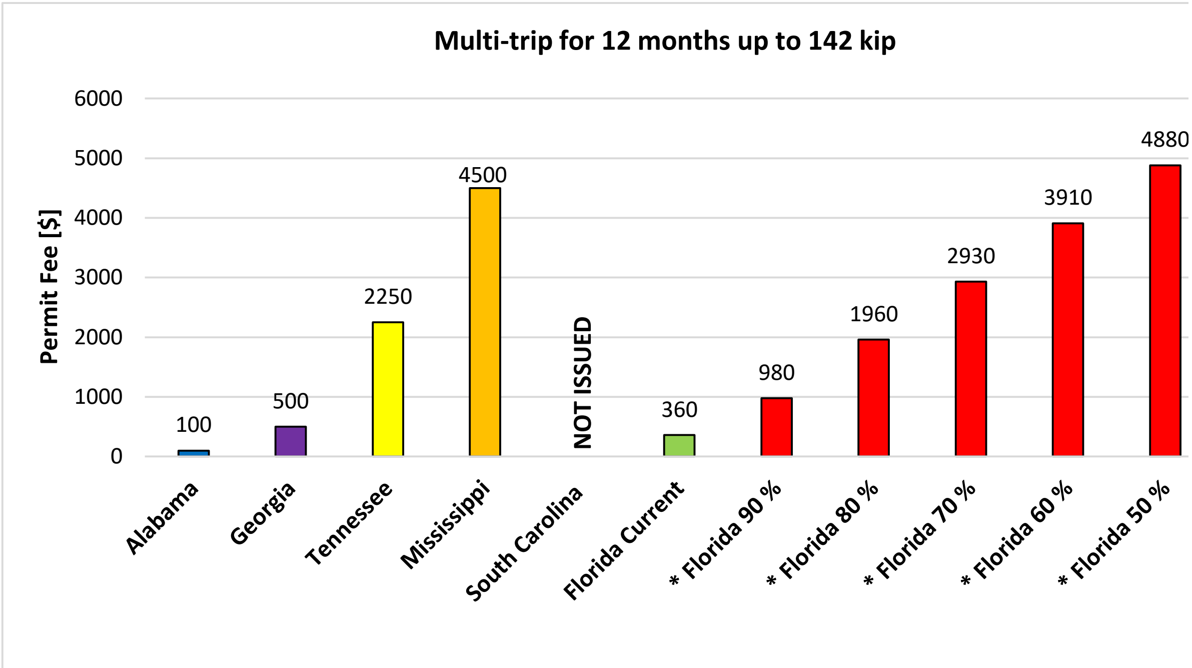


(c)

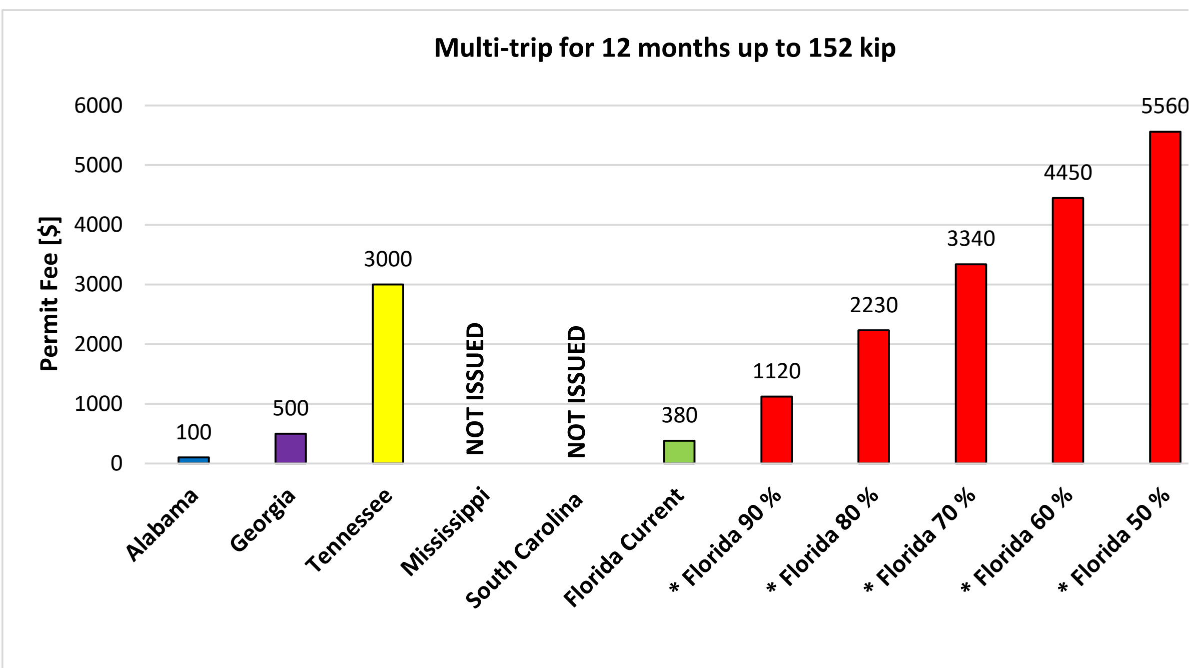


(d)

Figure 18-2. Comparison of annual multi-trip permits fees (c) up to 122 kip, (d) up to 132 kip (continued).

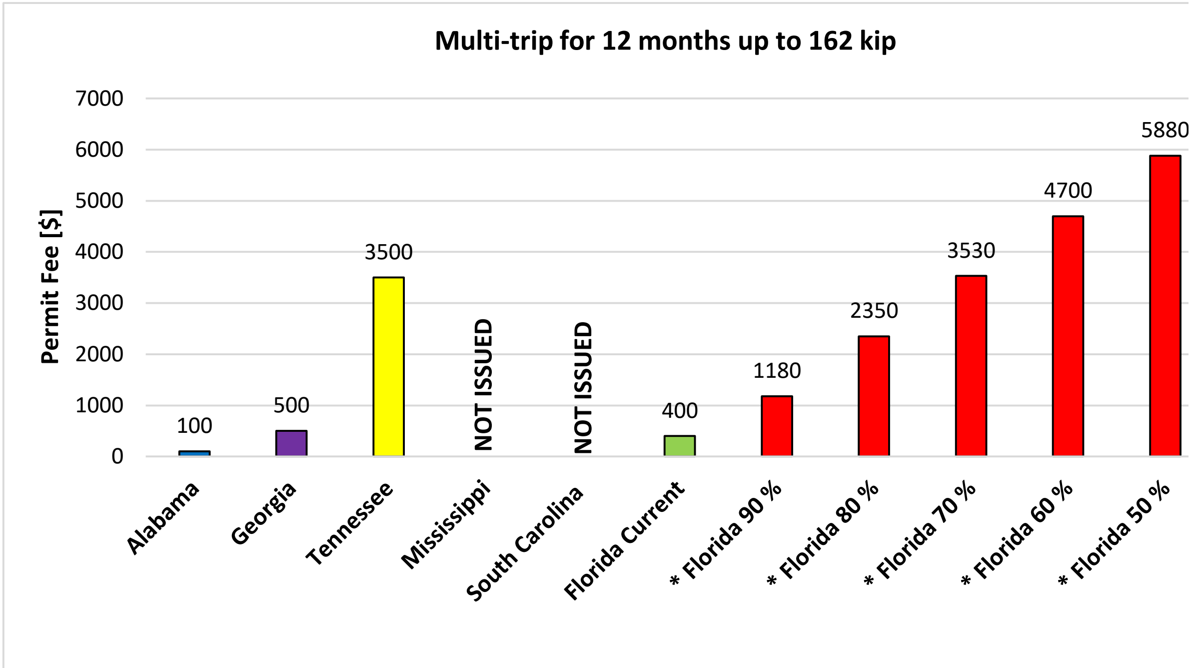


(e)

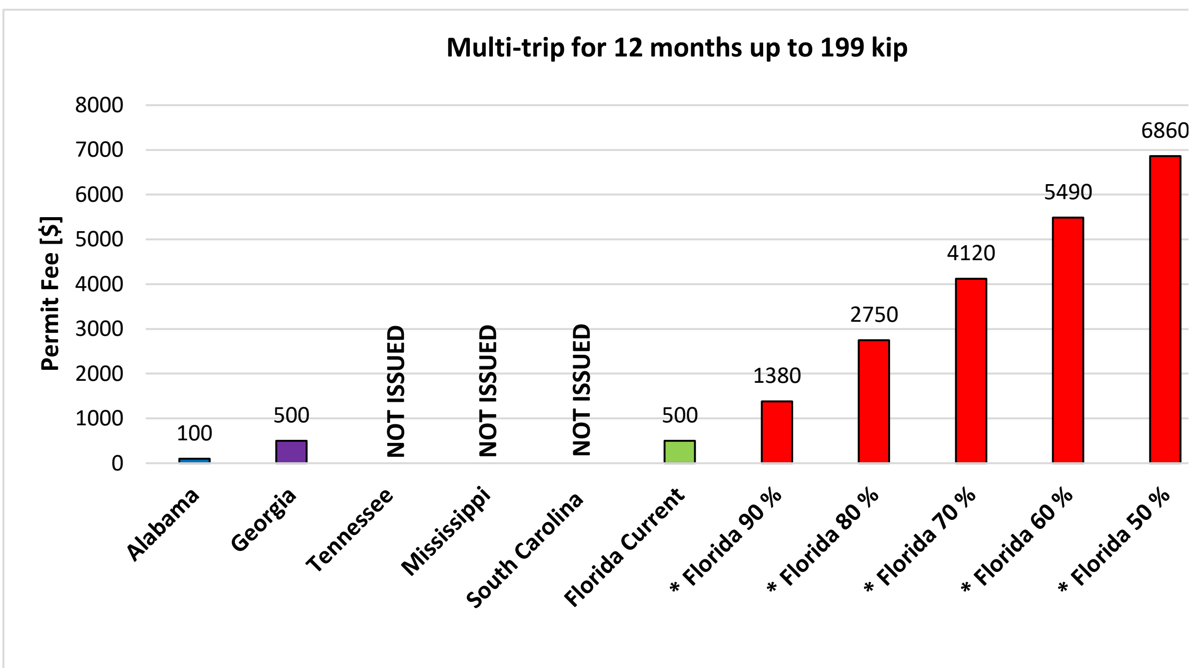


(f)

Figure 18-2. Comparison of annual multi-trip permits fees (e) up to 142 kip, (f) up to 152 kip (continued).



(g)



(h)

Figure 18-2. Comparison of annual multi-trip permits fees (g) up to 162 kip, (h) up to 199 kip (continued).

As Figure 18-2 illustrates, several discounts on the proposed permit fees for Florida are considered. Alabama has the lowest cost of $100 for an annual permit, which is a fixed price that does not depend on the weight of the vehicle. Similarly, Georgia has only one price for all annual permits, which is $500. South Carolina issues annual permits only up to 130 kip. All vehicles that are above that limit need to purchase a single trip permit. Tennessee issues annual permits that are at the lowest $750. The maximum weight for the annual permit is 165 kip, and the cost of that permit is $3,500. In Mississippi, special heavy haul blanket permits are allowed for vehicles up to 150 kip, and the cost of that permit is $4,500. Louisiana does not issue annual permits with an unrestricted number of trips. Florida's current annual permit cost is relatively low.

It is evident that other states do not issue 3-month permits. The 3-month permit is not very popular in Florida. Only 0.5% of all permits is assigned as a 3-month permit. It is important to indicate that the vehicles in the last two GVW groups, according to the current permit fee schedule in Florida, caused significant damage, which was expressed in consumption calculations. It was shown in the bridge damage assessment that the moment caused by heavy vehicles were seven times larger than the moment caused by the typical legal vehicles considered in that study. From that analysis, it is evident that an annual permit should not be issued for very heavy vehicles. The specific number of trips, and hence miles traveled for annual permits, are unknown. Those permitted vehicles might cause significant damage.

19. Revenue Analysis

It is important to know about the revenue that can be generated by the proposed permit fee and how it compares with the existing revenue. The issued permit database from 2016 to 2019 is used to estimate the revenues. There are two ways to calculate the permit fee based on the permit database: 1) Use invoices for issued permits (invoice revenue), and 2) Use the number of issued permits and multiply it by the existing permit fee value (current revenue). The total revenue was calculated to be $27.84 million based on the first method and $25.31 based on the second method. The difference between invoice and current revenue could be due to:

- Excluding the oversize vehicle permits when calculating the "current revenue."
- Unclear nomenclature used in the permit fee database. Some vehicles were assigned REFUND or REBILL, which does not follow the regular prices.
- Existence of some fees in the database that are not a multiplication of the amount that is in the current permit fee structure. It is not clear if there are some other fees such as administration fees added to them.

Revenues for a single trip permit were calculated for an average distance of 180 miles per trip, which is estimated by using the GIS system as previously mentioned. In the case of the GVW of 162-199, the average GVW of 182, and the case of GVW more than 199 kip, the average GVW of 267 kip are used to calculate the single permit revenues. These are GVW averages obtained from the permit fee database. To be consistent with the proposed permit fee, the 3-month permit fees issued for trucks with a GVW over 199 are not included in the calculations. Total revenues generated by the proposed permit fee are presented in Table 19-1. The ratio of revenues generated by the proposed and existing permit fees are presented in Table 19-2.

Table 19-1. Total revenue generated by the proposed permit fee considering various discount rates.

Discount Rate	**90%**	**80%**	**70%**	**60%**	**50%**
Total Revenue (×1000)	$ 37,600	$ 63,242	$ 88,780	$114,852	$140,389

Table 19-2. The ratio of revenue generated by the proposed and existing permit fees considering various discount rates.

Discount on Multi-Trip permits	**Single Trip**	**Multi-Trip (12 months)**	**Multi-Trip (3 months)**	**Total Revenue (Existing fee)**	**Total Revenue (Invoice from permit database)**
90%	1.6	1.5	2.7	1.35	1.49
80%	1.6	2.9	5.3	2.5	2.27
70%	1.6	4.3	7.8	3.51	3.19
60%	1.6	5.7	10.5	4.54	4.12
50%	1.6	7.2	13	5.55	5.04

Figure 19-1 shows the number of issued permits in each GVW category. Also, the proposed and the existing permit fees are presented and compared with one another. As shown in Figure 19-1, most of the single trip permits (more than 50%) are issued for trucks with a GVW of 80-95 and 95-100 kip. Based on the proposed fees, trucks are overpaying in these two GVW categories. Whereas, for the trucks with a GVW more than 112 kip, trucks are paying less in comparison to the proposed fees. This is also reflected in the revenues, as illustrated in Figure 19-2. The revenues from the proposed permit fee in the weight categories of 95-112 and 112-122 kip are less than the revenues generated by existing permit fees. However, for all other GVW groups, revenues generated by the proposed fees are more than the current fees and are maximum for the GVW more than 199 kip.

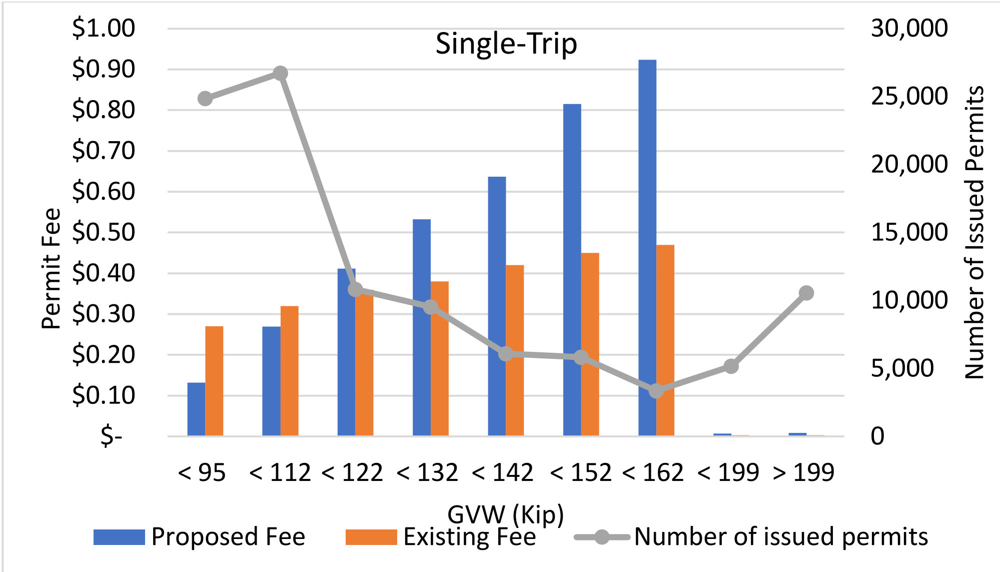


Figure 19-1. Proposed vs. existing single-trip permit fees, number of single-trip issued permits.

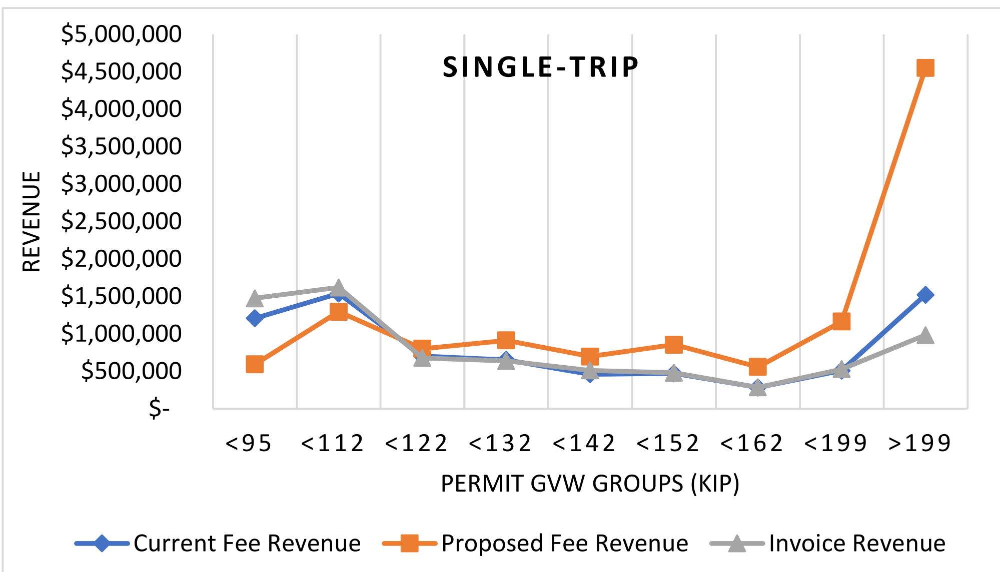


Figure 19-2. Proposed, current, and invoice revenues at each GVW group (single-trip).

In the case of multi-trip permits, the 90% discount rate is used to compare the revenues. Figure 19-3 illustrates the number of issued 12-month permits and each permit fee value for existing and proposed permit fees. Most of the 12-month multi-trip permits fall in the GVW of 80-95 kip. Based on the proposed fees, and considering the 90 percent discount rate, trucks are currently overpaying by 24% in this GVW group. Figure 19-4 shows the revenue generated by 12-month permits. As shown, there is an increase in revenue for all GVW groups, except for 80-95 lbs.

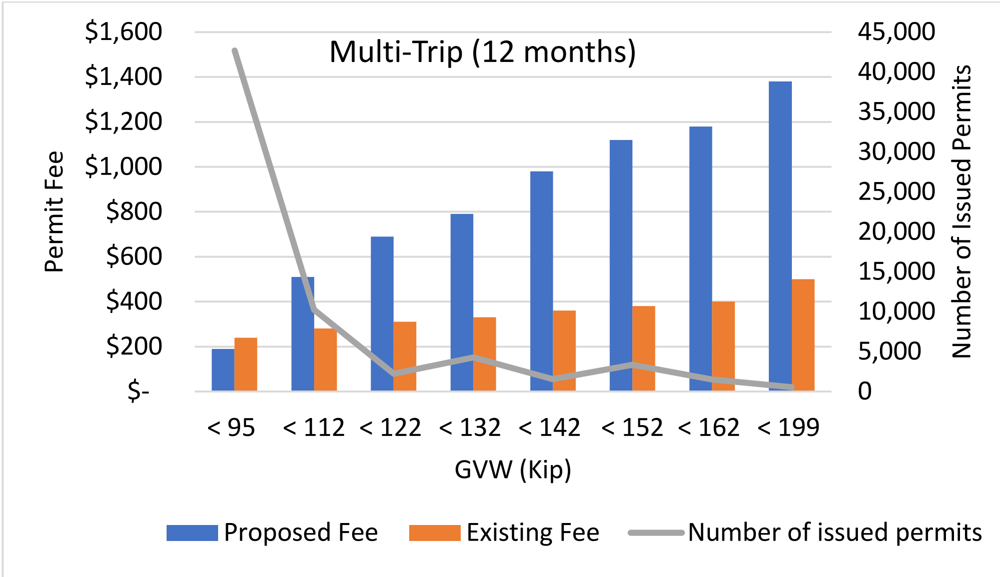


Figure 19-3. Proposed vs. existing multi-trip (12 months) permit fees, number of multi-trip (12 months) issued permits.

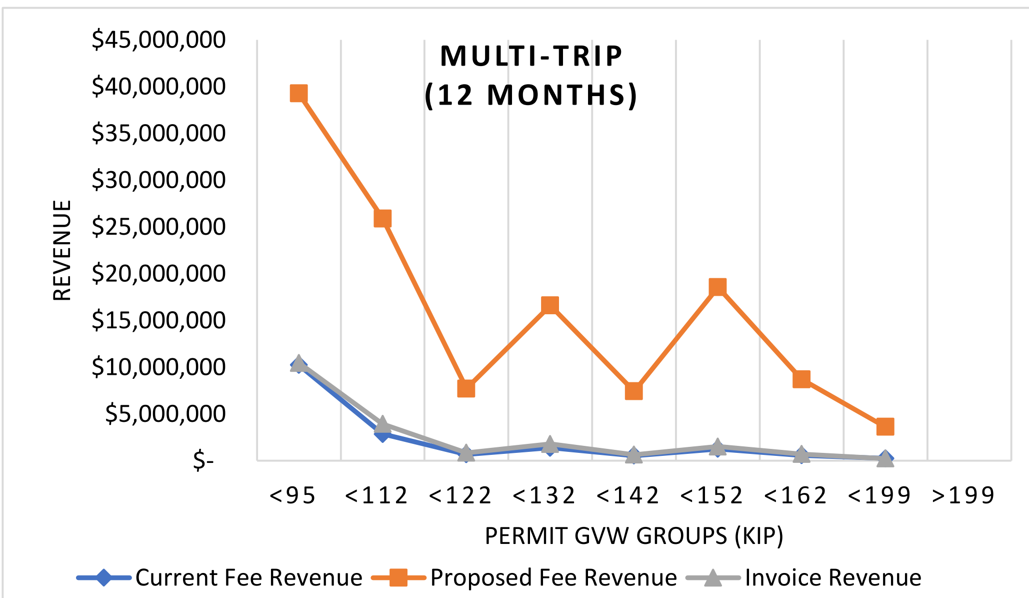


Figure 19-4. Proposed, current, and invoice revenues at each GVW group (12-month multi trips).

As shown in Figure 19-5, in the case of the 3-month permit fees, the maximum number of issued permits falls in the GVW of 162-199 kip. The second highest number of issued permits falls in the GVW of 122-132 kip. Figure 19-6 shows the revenues in each GVW category. There is a considerable difference between “invoice revenue” and the “current revenue” generated by 3-month permit fees. Using the latter should be considered for comparing the existing and proposed revenues.

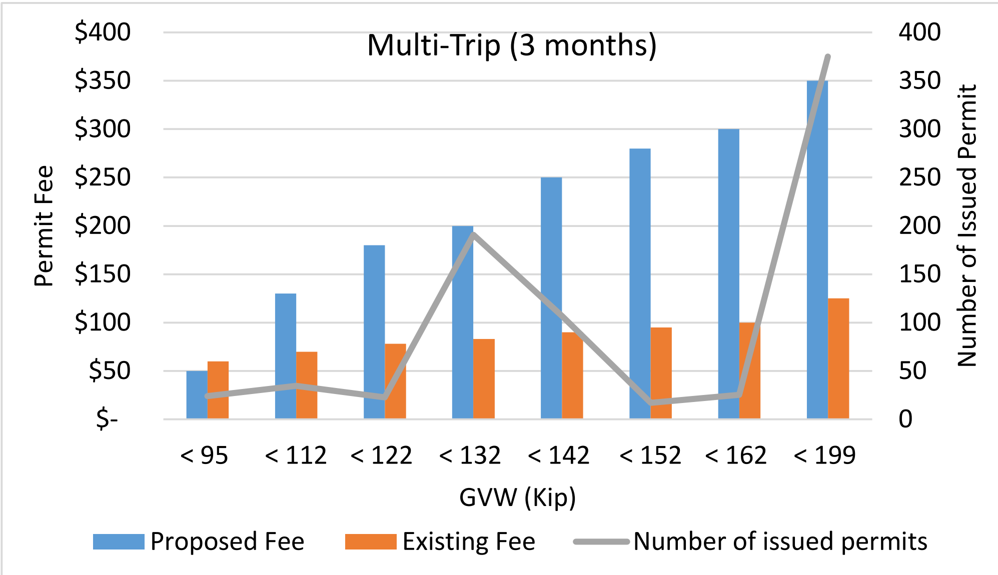


Figure 19-5. Proposed vs. existing multi-trip (3-month) permit fees.

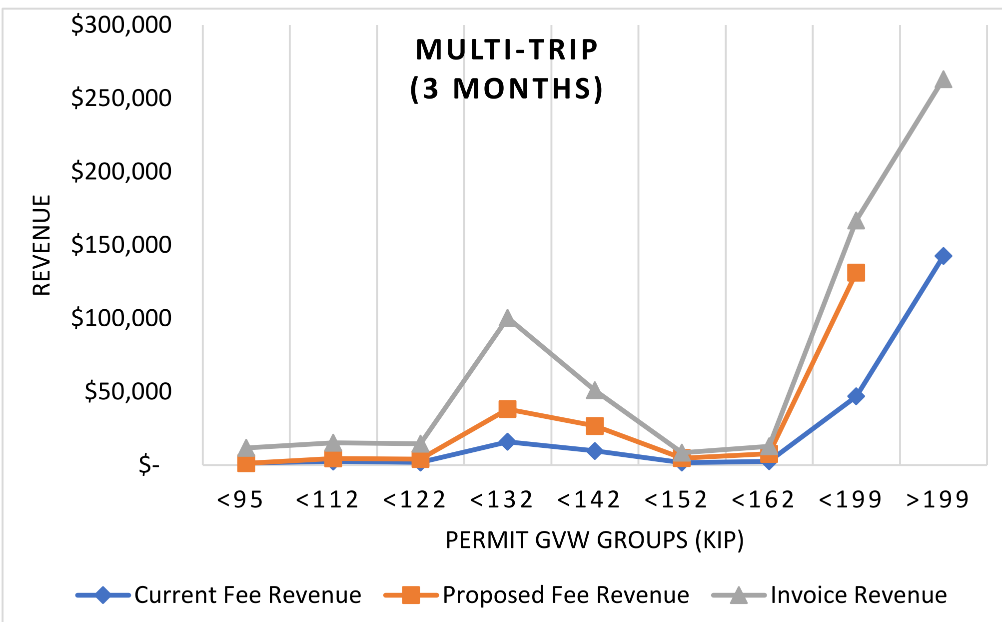


Figure 19-6. Proposed, current, and invoice revenues at each GVW group (3-month multi-trip).

20. Summary

The revenues from the proposed permit fees were compared with those of other states and to current Florida fees. The comparison showed that the proposed fees will increase the revenues of single-trip permits by a factor of 1.6, multi-trip 12-month permits by a factor of 1.5, and multi-trip 3-month permits by a factor of 2.7. This is based on a 90% discount for multi-trip permits. With respect to multi-trip permits, the damage cost is significantly higher than the current imposed fees. The department can choose an appropriate discount rate based on economic considerations.

While the proposed fees are higher than the existing ones, they reflect the current actual cost of damage to Florida's roads and bridges. Furthermore, the proposed fees are in-line with the permit fees imposed by other states.

PART E: SUMMARY AND CONCLUSION

21. Summary

Overweight and/or oversize trucks not only can cause tremendous damage to road infrastructures, but they can also adversely affect traffic flow and safety. To fairly defray the agency and user costs of the roads, it is essential to charge OW/OS trucks with a reasonable permit fee that corresponds to the intensity of the damage that they cause. The vehicle registration fee in Florida is based on vehicle weight. The state of Florida collects the highest initial registration fee per vehicle in the U.S. The issued permit data by FDOT for years 2016 to 2019 indicates that on average, 44% of the issued permits are either OW or a combination of OS and OW permits. Around 400 - 450 permits are issued every day. Most of the issued permits (75% of overall issued permit) by FDOT for years 2016 to 2019 are for single trip permits.

The focus of this study is to find the unit damage cost of road infrastructures (pavement and bridge). There are two major aspects in calculating the unit damage cost: life cycle cost analysis and the damage assessment of the structure. The synthesis of these two elements results in cost per usage. Using the unit damage cost helps to calculate the permit fee based on the OW load damage (consumption). The unit damage cost is calculated for pavement and bridge separately and then combined and reformed to the existing OW permit fee structure. The single trip permit in Florida is weight and distance dependent.

To be consistent with the existing permit fee structure, multi-trip permits (12 and 3 months) were calculated by multiplying the single trip permits to the average length and number of trips. With respect to multi-trip permits, the damage cost is significantly higher than the current imposed fees. Thus, a discount rate is applied to the multi-trip permits fees.

The revenues from the proposed permit fees were compared with other states and with the current Florida fees. In this analysis, six neighboring states (Alabama, Mississippi, Georgia, Louisiana, South Carolina, Tennessee) were compared with Florida. While the proposed fees are higher than existing fees, they reflect the current actual cost of damage to Florida's roads and bridges. Furthermore, the proposed fees are in-line with the permit fees imposed by other states. Also, the revenue generated from the current permit fees are compared with the revenue generated by proposed fees. The comparison showed that the proposed fees will increase the revenues of single-trip permits by a factor of 1.6, multi-trip 12-month permits by a factor of 1.5 and multi-trip 3-month permits by a factor of 2.7. This is based on a 90% discount for multi-trip permits. The department can choose an appropriate discount rate based on economic considerations.

21.1. Bridge Damage Cost Assessment

The consumption for bridges is calculated for the representative bridge in Florida. The representative bridge parameters were established based on the sample bridge database, the FDOT new bridge construction cost data, the National Bridge Inventory database, and the Weigh-in-Motion datasets. An extensive study was conducted to find parameters such as bridge cost, ADTT, span length, and material and structural type. The permit database was used to determine the total damage on bridges. Existing permit vehicles operating on the roads and bridges in Florida are utilized to determine the damage. Monetary consumption caused by permitted overweight vehicles was calculated according to the current permit fee schedule in Florida.

21.2. Pavement Damage Cost Assessment

To estimate the pavement damage cost, roads are categorized based on their structure and their traffic level. Thirty-seven different scenarios (different road functional classes, traffic levels, construction costs, and M&R practices) were selected to estimate the average pavement damage cost. The results showed that the average pavement damage cost is higher for the minor roads compared to the interstates and principal arterials. In this study, the type of roads that a truck will use from the starting point to the destination and its number of axles are the determining factors in the calculation of the permit fee associated with each truck. Compared to the proposed permit fees (Appendix D), some trucks are currently paying more than the damage that they cause, and some pay less.

The proposed permit fee may have some enforcement complications due to the consideration of three types of road (IS, PA, and MR) and a different number of axles for each GVW group. To enhance the convenience of monitoring and enforcement, two levels of merging are proposed to simplify the proposed structure. First, the estimated length of the trip that a truck may travel on each road category is used to merge the fees associated with each of road type (Table 15-1). Second, in addition to merging level one, the fees associated with the axel groups at each GVW category are merged (Table 15-2). Both levels of merging decrease the accuracy of the issued permit fee, but merging level two offers the least accuracy. The level two merging yields a permit fee structure identical to the current fee structure used in Florida.

22. Potential Disadvantages of Multi-trip Permits

It is reported that although the highway agencies that switched from single-trip permits to multi-trip permits saved costs related to the monitoring efforts, they lost significant revenue overall [115]. It could be due to the fact that heavy vehicles will not limit their number of trips during the blanket permit. There are also some truck companies that dedicate trucks for freighting as many overweight movements as possible to maximize their profits under a multiple-trip permit system, whereas they would purchase a single-trip overweight permit from time to time for many trucks [116]. Regarding the aforementioned issues associated with multi-trip permits, it is not recommended by this study. However, obtaining a single-permit for clients who have a large number of overweight trips could be arduous and troublesome to their business. In such cases, FDOT can determine and issue multi-trip permits proportional to the intensity of their overweight operations.

23. Recommendation for Future Overweight Permit Fee Studies for Florida

The research team conducted the damage assessment analysis for bridges and pavement in Florida for the purpose of updating the permit fees to fund repairs for damages caused by permitted vehicles. A project requirement was to maintain the current permit fee structure. The presented study was conducted in accordance with that expectation, but the Research Team conceived a new approach to analyze the impact of permit vehicles based on use of the GIS system.

The new idea is to compile different databases with a GIS system. A big database system can be used to compute the consumption of a permitted overweight and oversize vehicle for a selected route. The fee will be calculated depending on the GVW, number of axles, oversize provisions and most importantly, the condition of the bridges and pavement on the selected routes. This is an innovative approach that can help FDOT control the operation of permit vehicles, prevent the acceleration of damage and improve maintenance procedures. The proposed approach has many advantages, not only from the permit vehicle’s point of view, but also from a maintenance, budgeting, and infrastructure supervision point of view.

A proposal for a new fee schedule is offered, in which the cost of the permit will depend on bridge and pavement conditions on the selected route, GVW and geometry of the vehicle. The new fee schedule may be a supplement to the fee schedule proposed in Phase 1, or it may be a completely new system.

The proposed new permit fee schedule allows more flexibility in choosing a specific route based on different options. A client can apply for a permit depending on preferences with an option for "Routing", which will show possible routes, permit fees, and an estimated time of the trip. The route will be verified by a special procedure (to be developed) to determine bridge structure and pavement types on the route selected by the applicant. The fee will be calculated for the specific vehicle’s parameters. The applications will also offer alternative routes (if available), along with the permit fees. The system may also offer cheaper alternative route(s), and thus reduce the damage created by a permitted vehicle. The consumption assessment for bridges and pavements will consider available discounts and exemptions based on the rules and preferences allowed by FDOT. The other PAS application features remain the same.

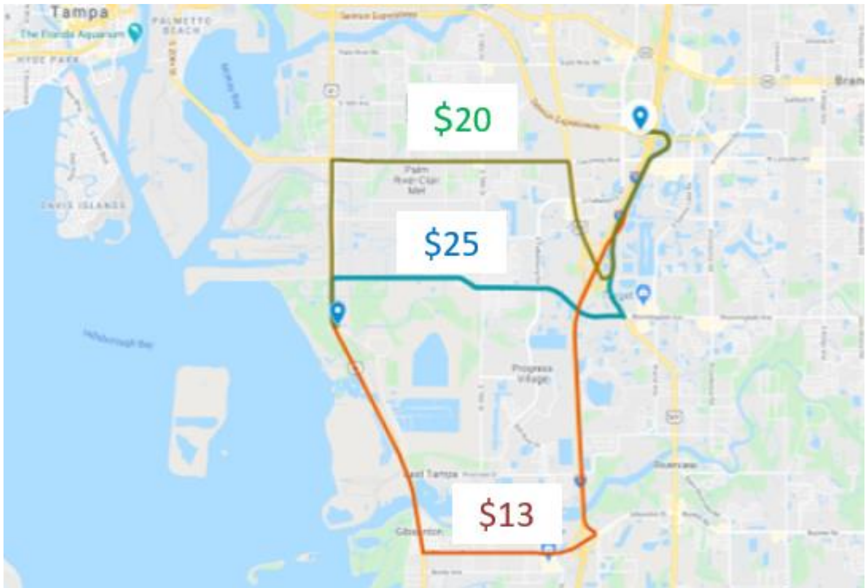


Figure 23-1. GIS alternative route selection.

The advantages of implementing the new permit schedule are as follows:

- Automatic calculation of the actual dollar consumption for a permit vehicle based on GVW, number of axles, geometry, and bridge and pavement conditions on designated routes.
- Assessment of bridge and pavement conditions based on accumulated damage calculations based on issued permits and historical database.
- Forecast of bridge and pavement consumption, with a possibility of predicting the necessity for inspection or any other repair or maintenance activity.
- Quick access to historical data on vehicle transit routes for issued permits.
- An application with a user-friendly interface for preparing statistical summaries based on permit data. Statistics might be generated automatically and saved in Excel or any other preferable format.
- Generation of current valid permits on selected road sections and/or bridges. The maps can be used for planning repairs, shutdowns, detours (knowing the number of permits issued, types of vehicle configurations and GVW, one can plan detour routes for sections covered by the work zone).
- Graphical presentation of the routing system on a map. The routes can be shown in different colors for different types of vehicles, load, distance, time, impact of vehicle passage on pavements and bridge structures, etc.
- Plan the development of the transport network, and changes in the parameters of roads and bridges adapted to current vehicle operations.

- Create a link between permit and WIM databases that can be used for verification of the permit vehicle on designated routes.

The proposed permit system has many advantages that can provide flexibility to the clients to choose the routes based on different criteria. It can also help to protect the infrastructure in Florida. An advanced permit system will allow for the computation of the fees depending on the vehicle and route. It will also help to monitor bridge and pavement conditions. The system may be adjusted to DOT needs. The proposed approach can be evaluated and improved in Phase 2 of the project.

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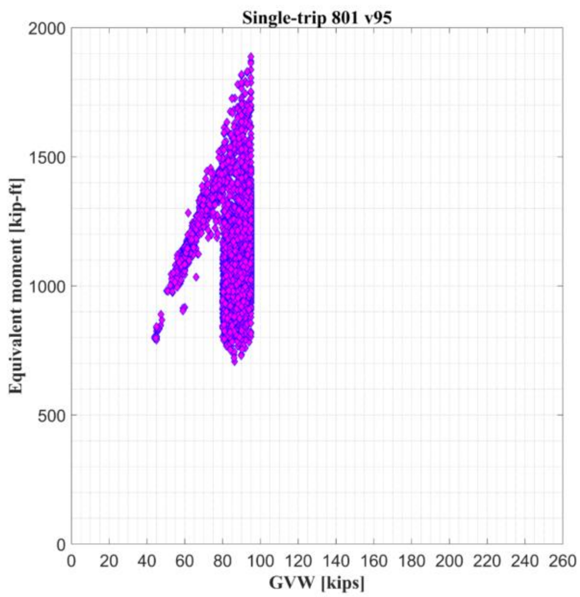
APPENDIX A: Moment Equivalent Relationships

Single trip permits



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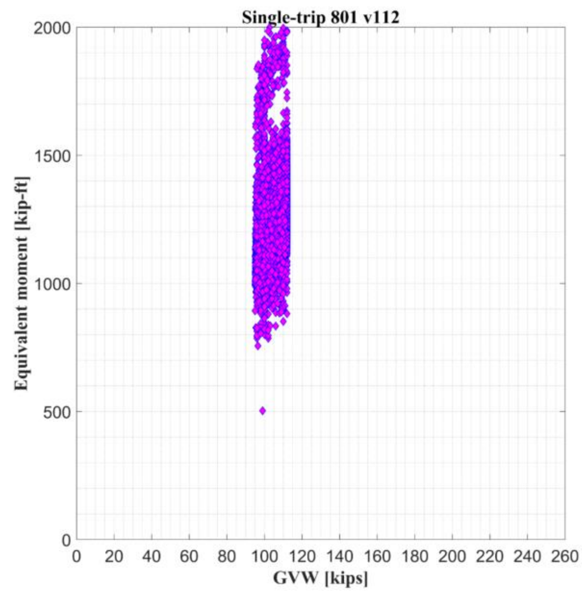

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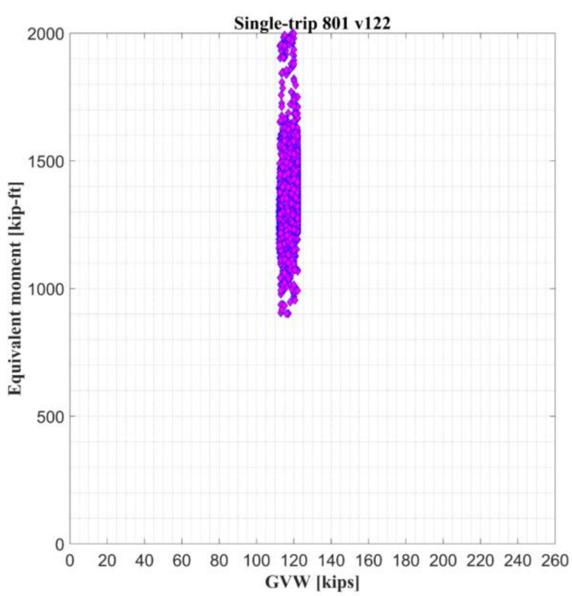

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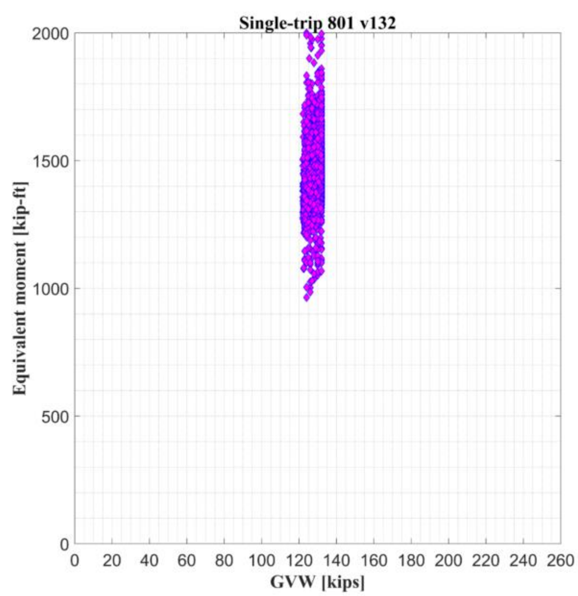
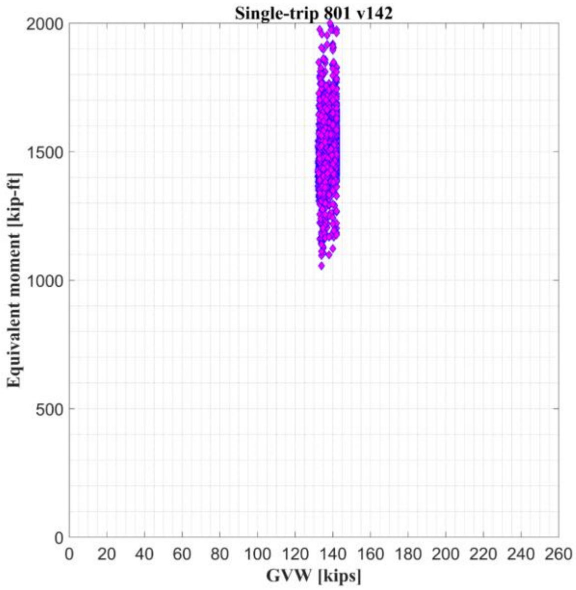
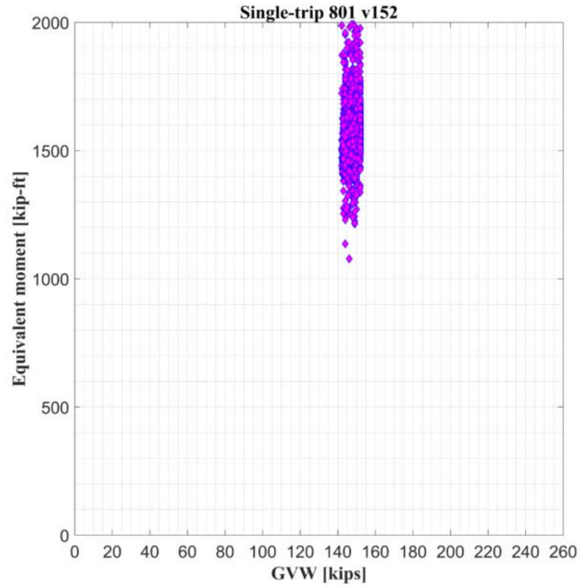


(d)

Figure A-1. Equivalent moment vs. GVW for single trip permits, group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.



(e)



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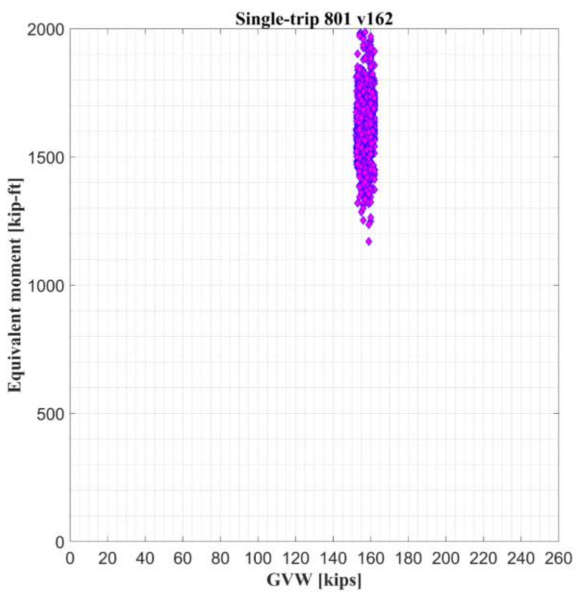

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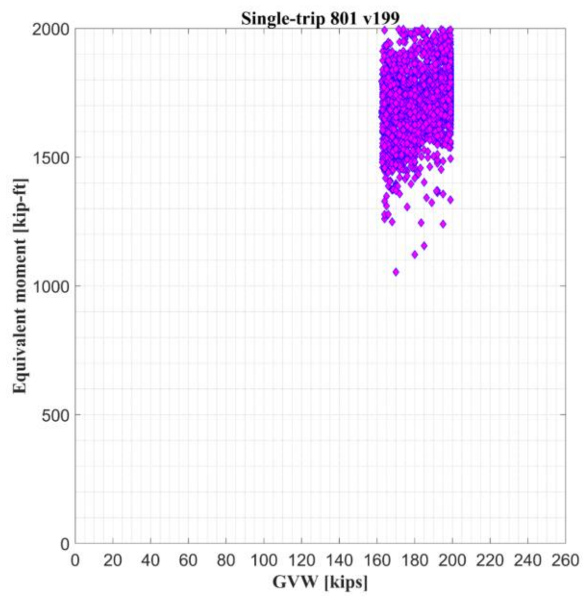
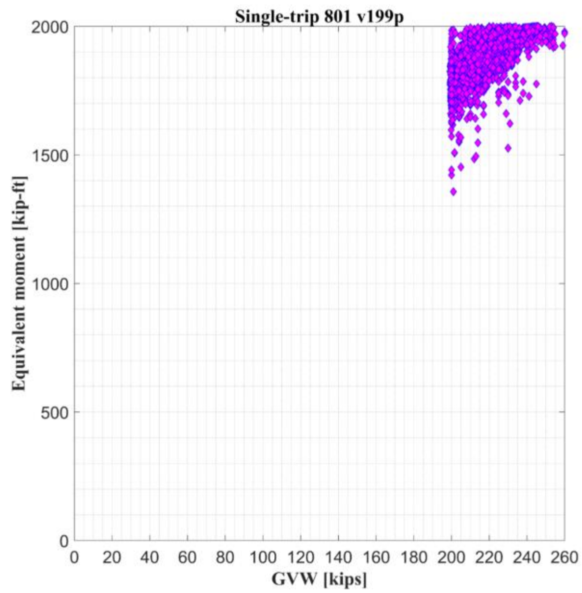


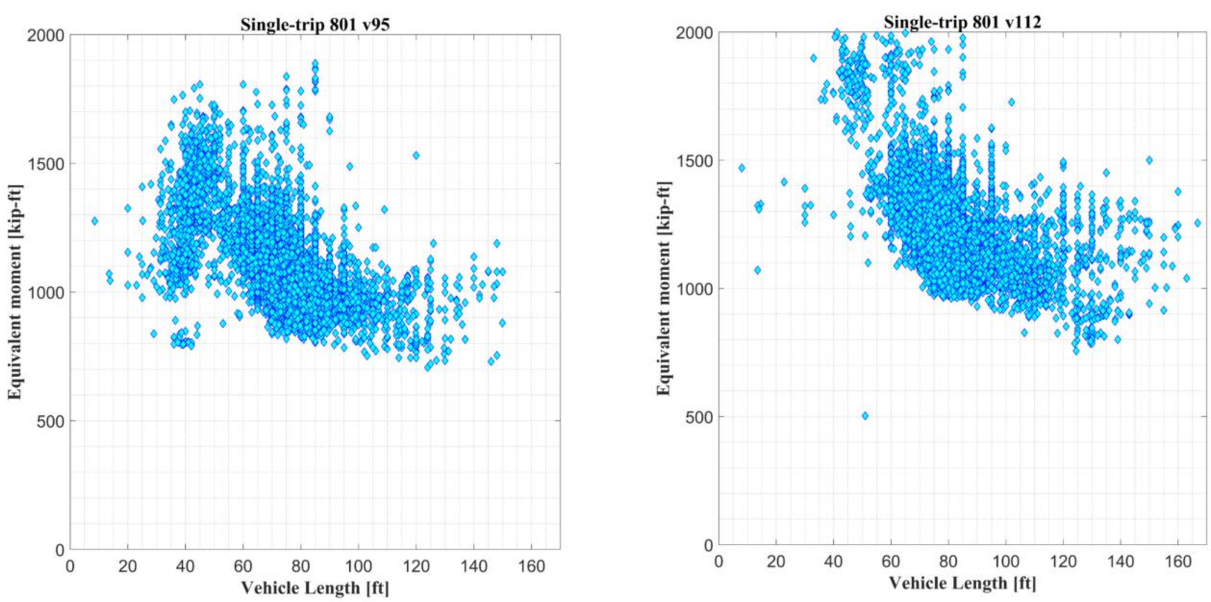
(h)

Figure A-1. Equivalent moment vs. GVW for single trip permits, group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips, (i) above 199 kips (continued).



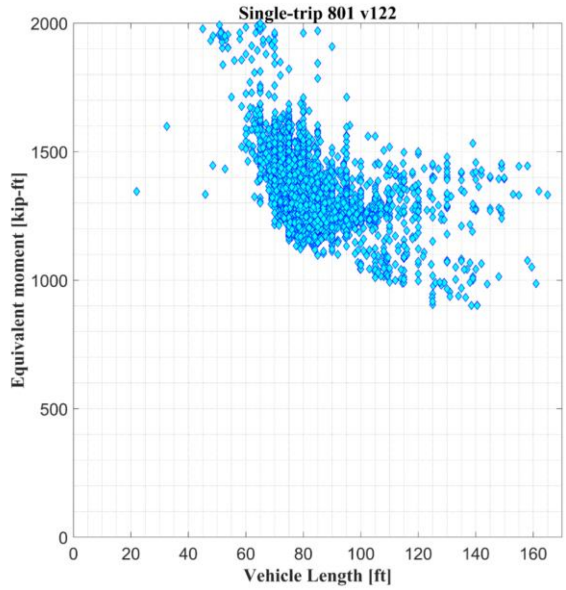
(i)

Figure A-1. Equivalent moment vs. GVW for single trip permits, group (i) above 199 kips (continued).



(a) (b)

Figure A-2. Equivalent moment vs. The total length of the vehicle for single trip permit group (a) up to 95 kips, (b) up to 112 kips.



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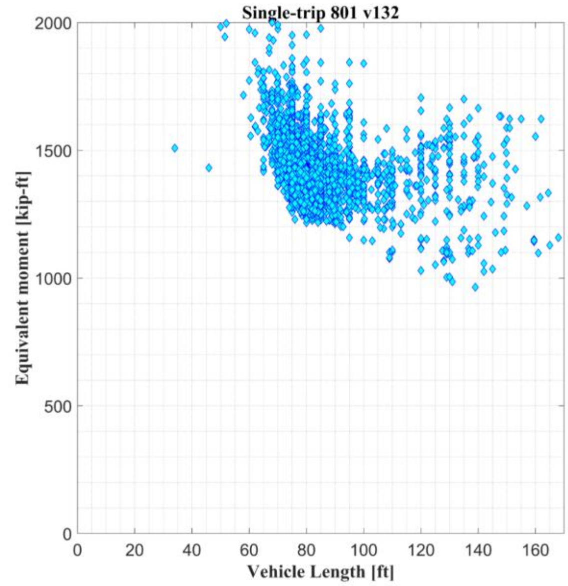

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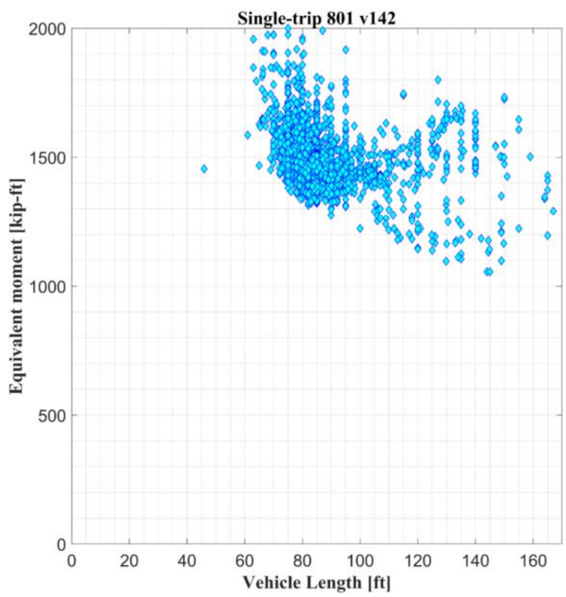

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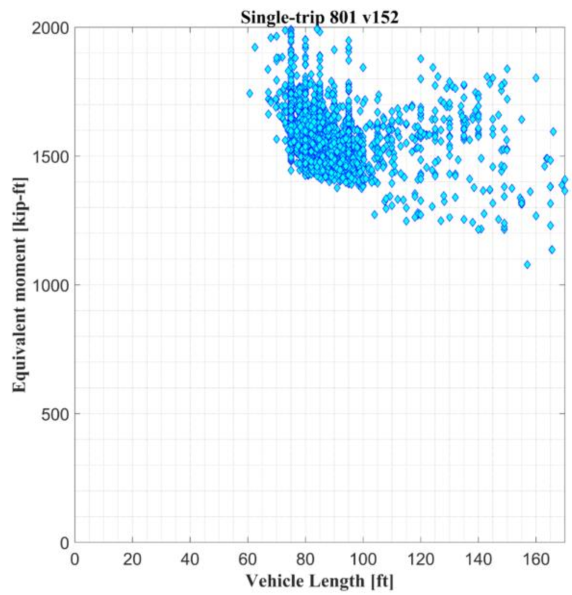
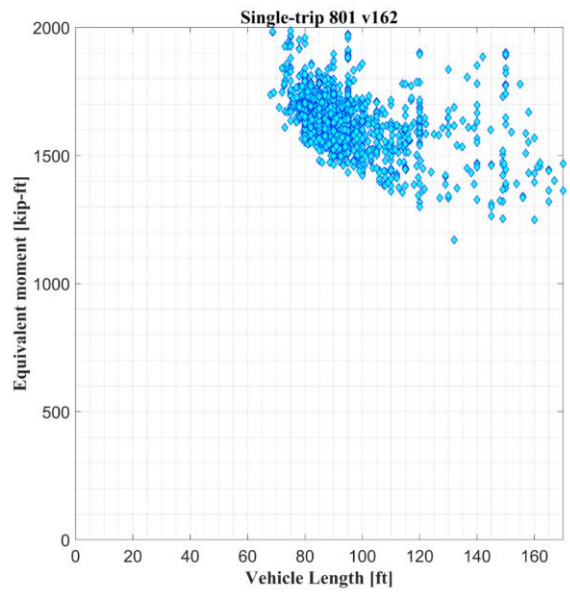


(f)

Figure A-2. Equivalent moment vs. The total length of the vehicle for single trip permit group, (c) up to 122 kips, (d) up to 132 kips, (e) up to 142 kips, (f), up to 152 kips (continued).



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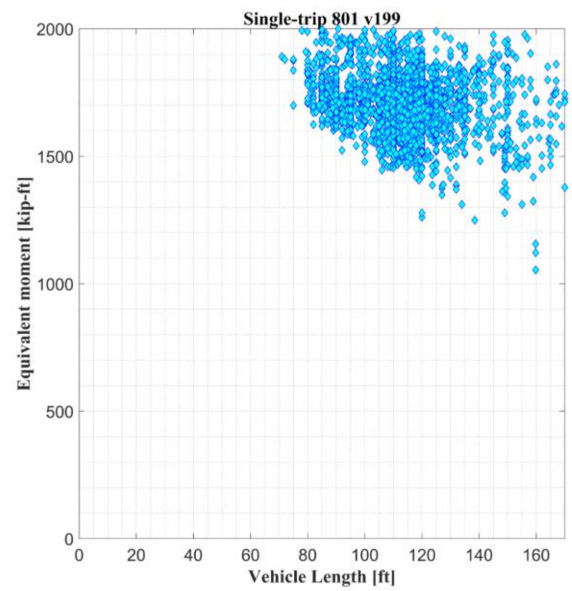

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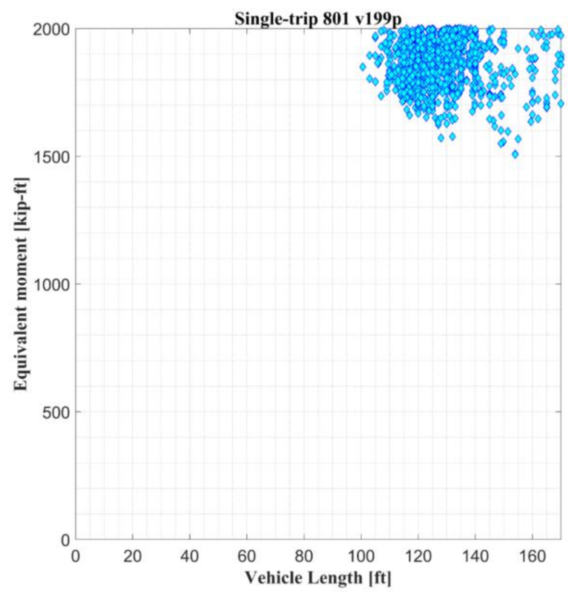
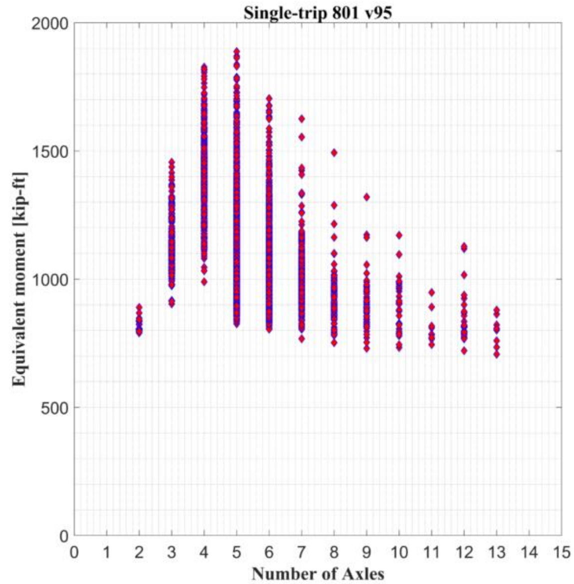


(i)

Figure A-3 Equivalent moment vs. The total length of the vehicle for single trip permit group (g), up to 162 kips, (h) up to 199 kips, (i) above 199 kips (continued).



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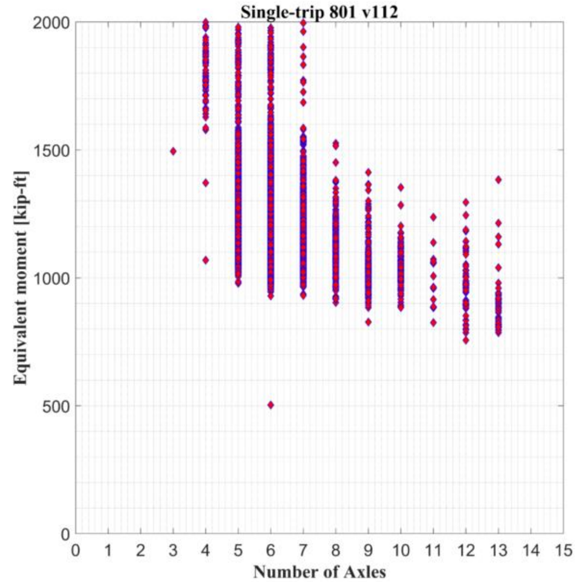

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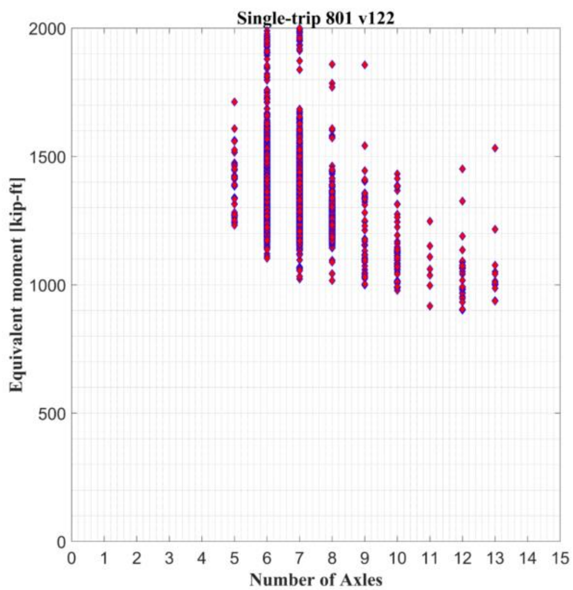

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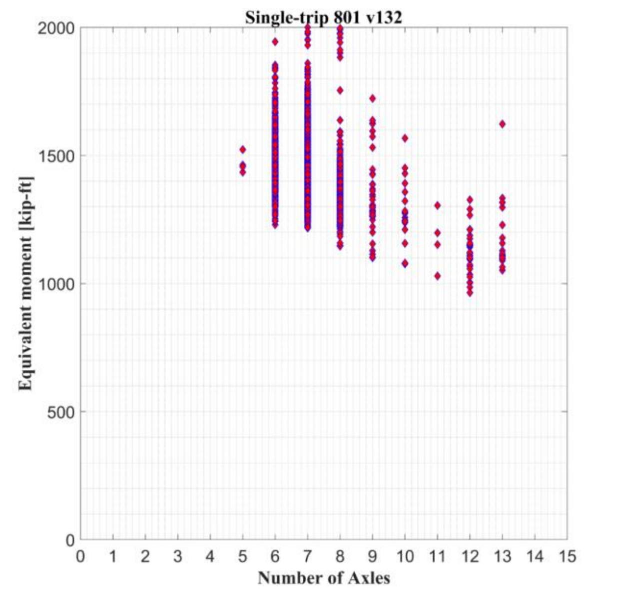
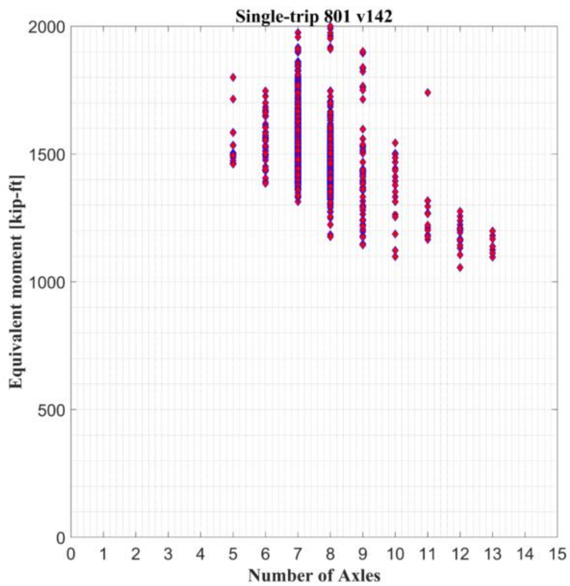


(d)

Figure A-3. Equivalent moment vs. Number of Axles for single trip permits group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.



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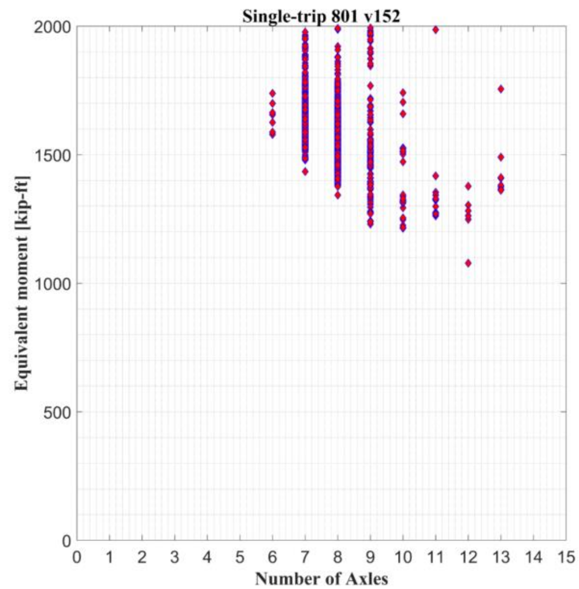

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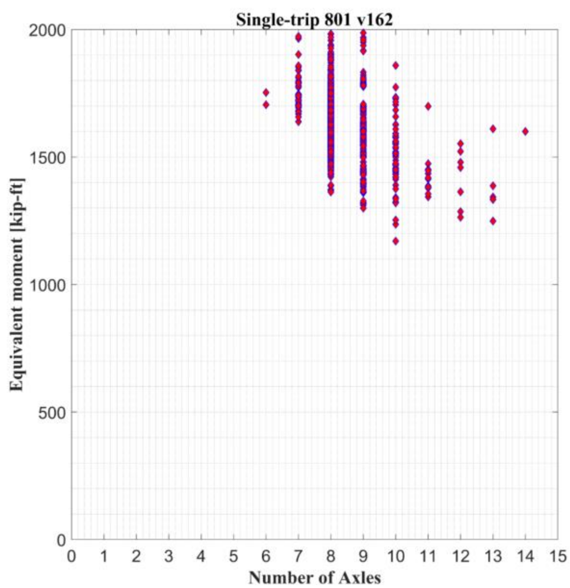

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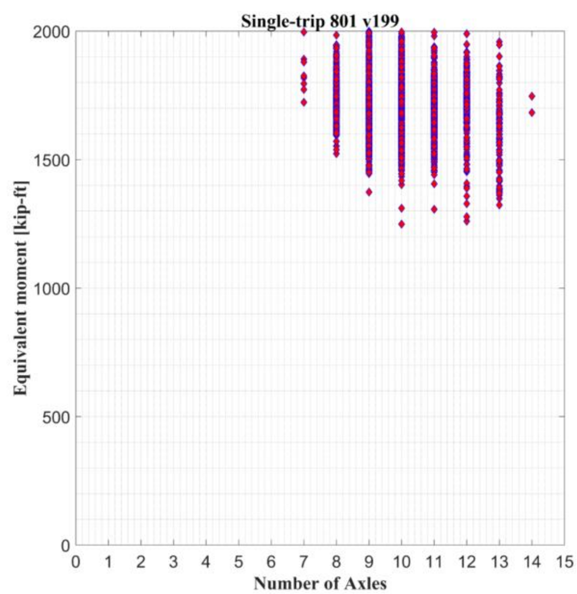
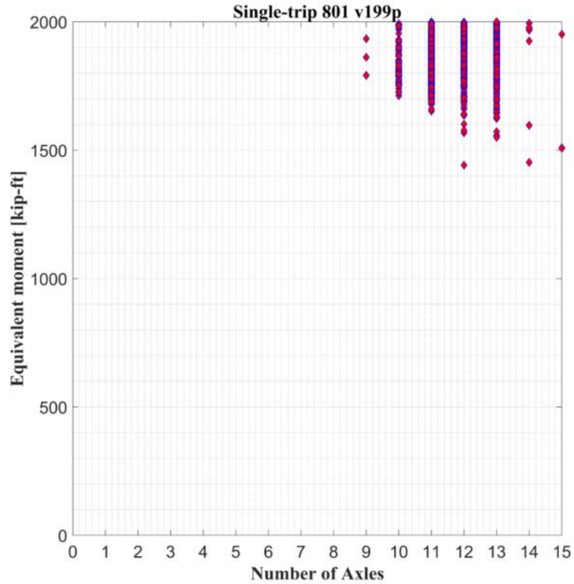


(h)

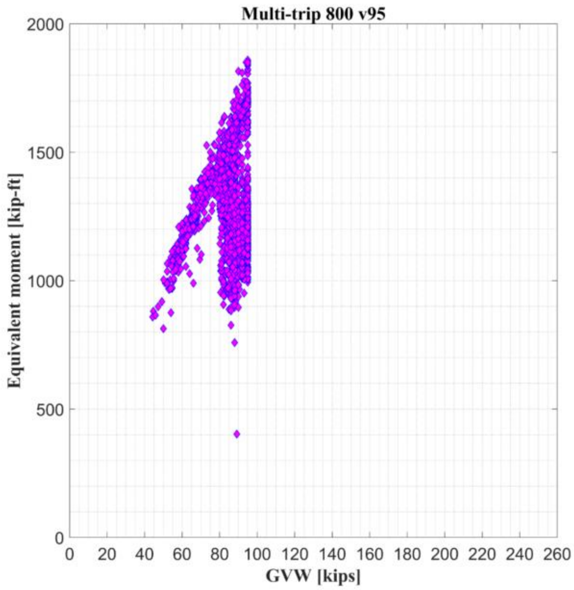
Figure A-3. Equivalent moment vs. Number of Axles for single trip permits group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).



(i)

Figure A-3. Equivalent moment vs. Number of Axles for single trip permits group (i) above 199 kips (continued).

Multi-trip 12 months permits



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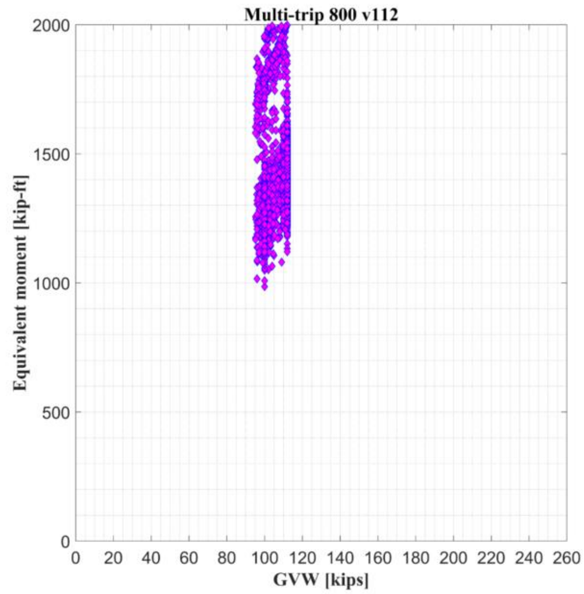

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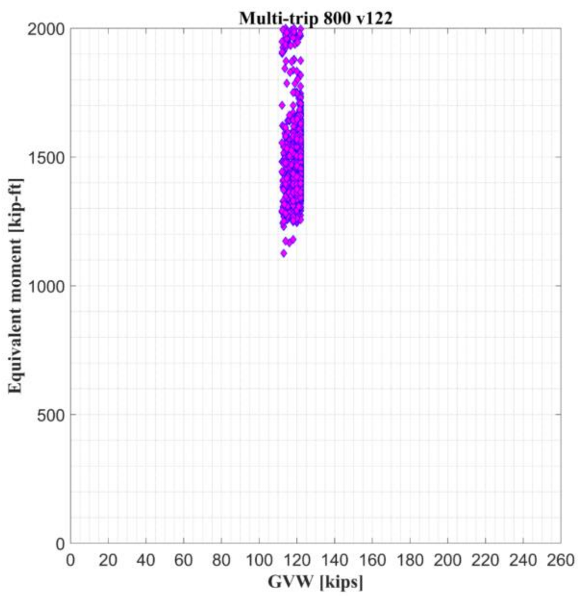

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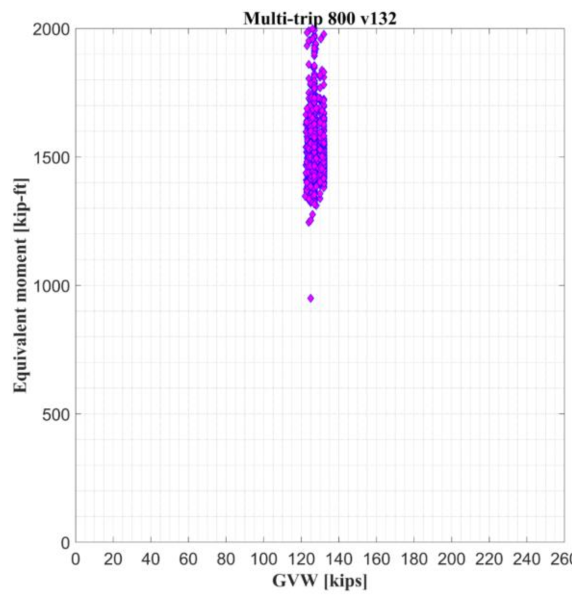
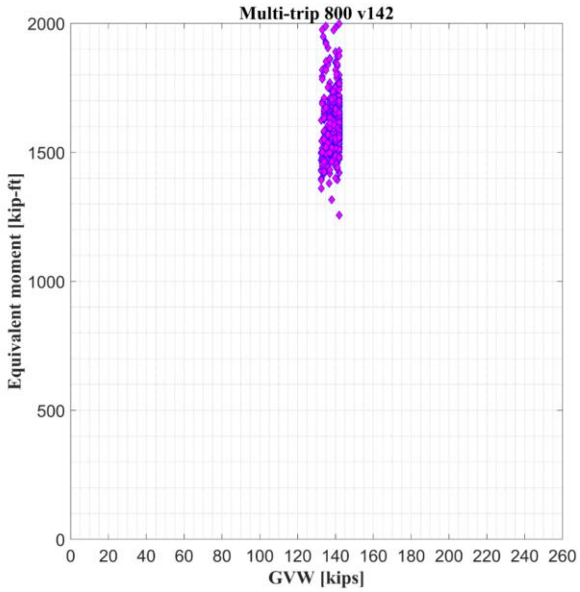


(d)

Figure A-4. Equivalent moment vs. GVW for multi-trip permits for 12 months type 800 (a) up to 95 kips, (b) up to 112 kips,(c) up to 122 kips, (d) up to 132 kips.



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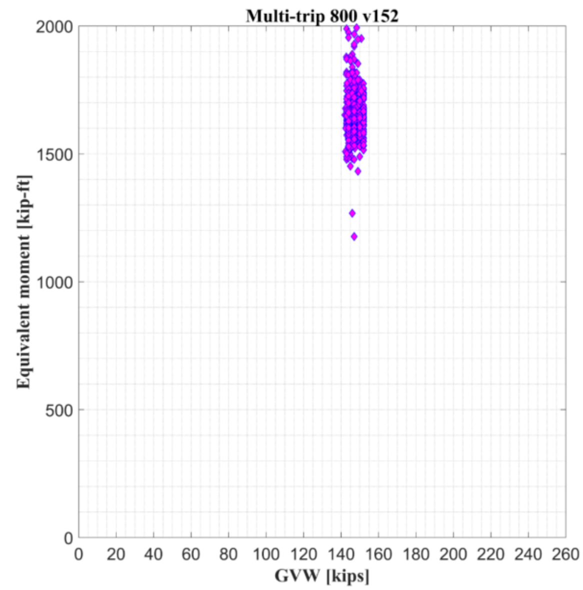

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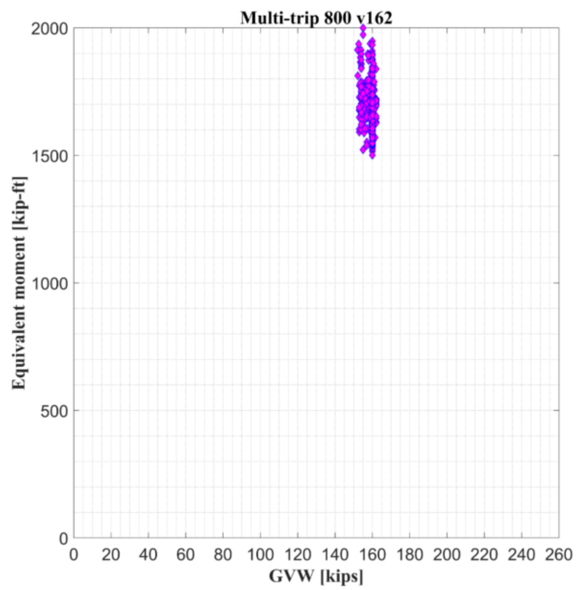

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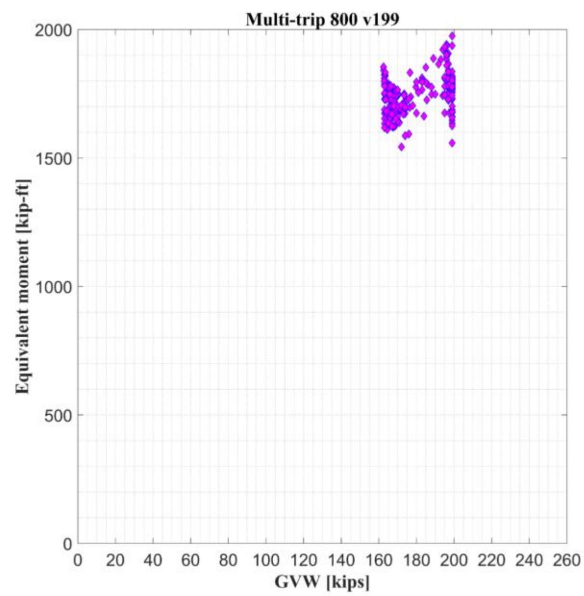
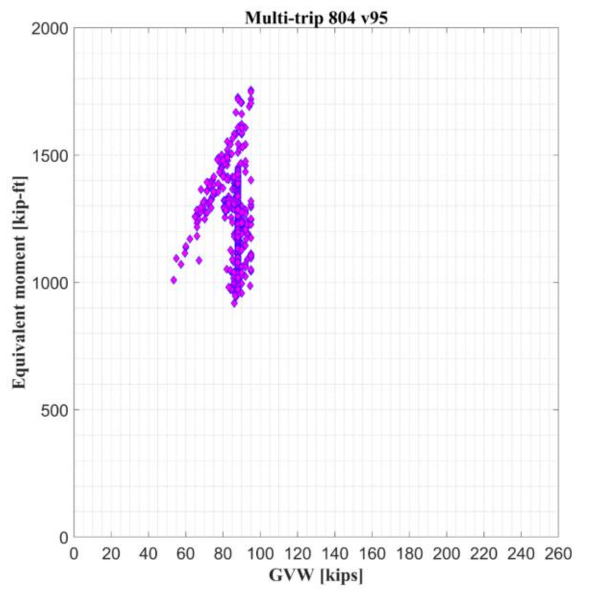


(h)

Figure A-4. Equivalent moment vs. GVW for multi-trip permits for 12 months type 800 (e) up to 142 kips, (f) up to 152 kips, (g) up to 162 kips (continued).



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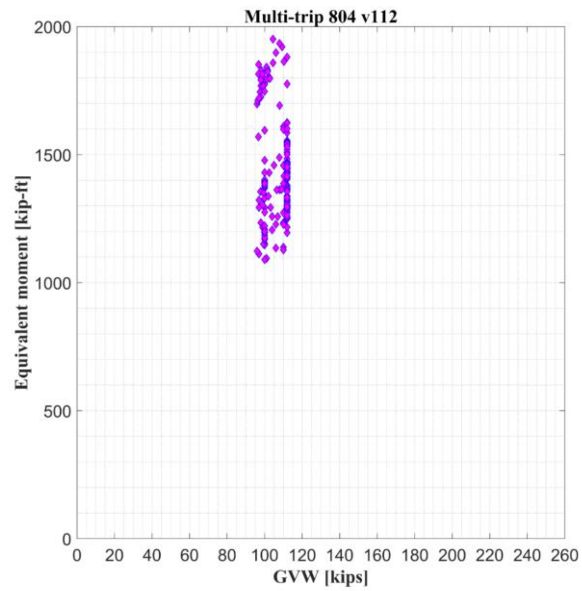

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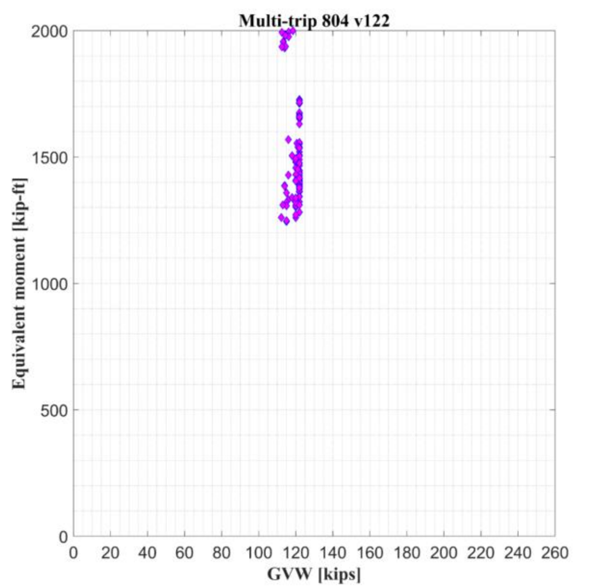

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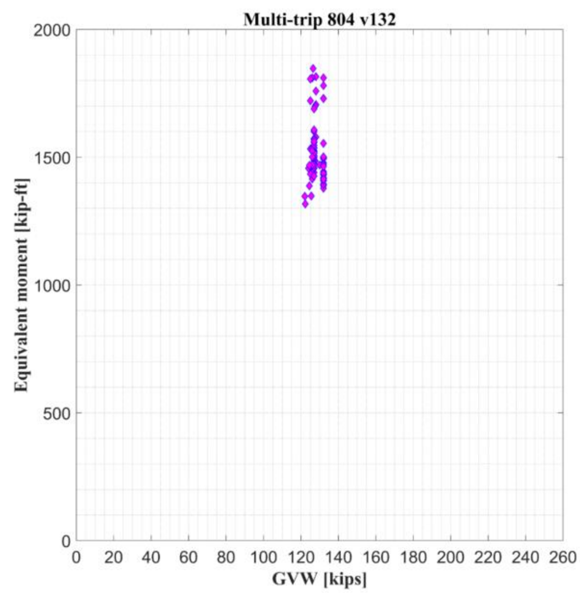
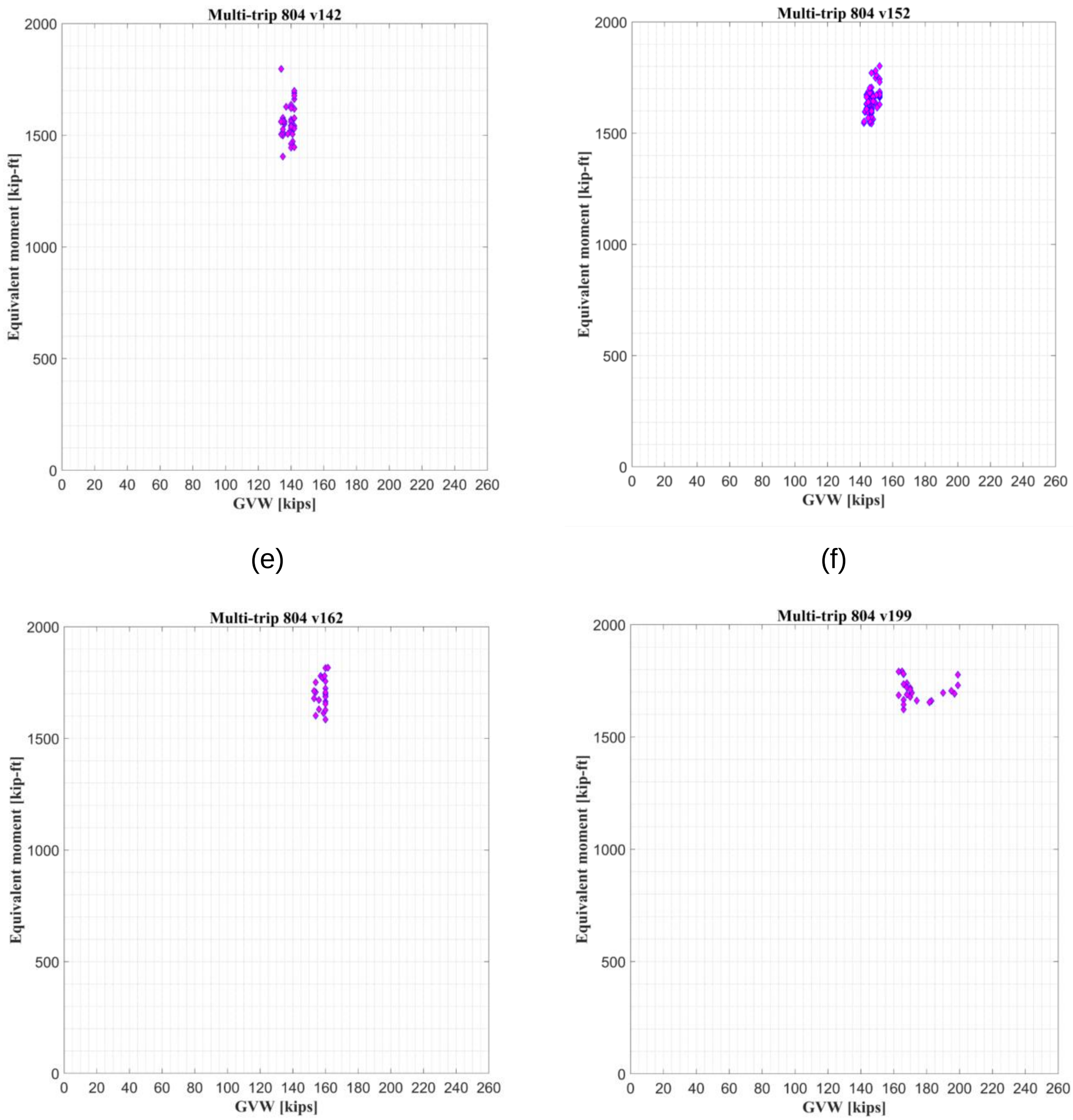


(d)

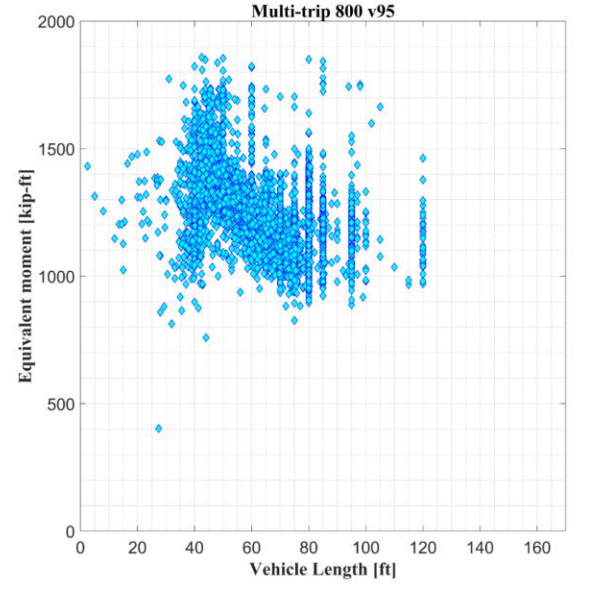
Figure A-4. Equivalent moment vs. GVW for multi-trip permits for 12 months, type 804 group (a) up to 95 kips, (b) up to 112 kips,(c) up to 122 kips, (d) up to 132 kips.



(e) (f)

(g) (h)

Figure A-4. Equivalent moment vs. GVW for multi-trip permits for 12 months, type 804 group (e) up to 142 kips, (f) up to 152 kips, (g) up to 162 kips, (h) up to 199 kips (continued).



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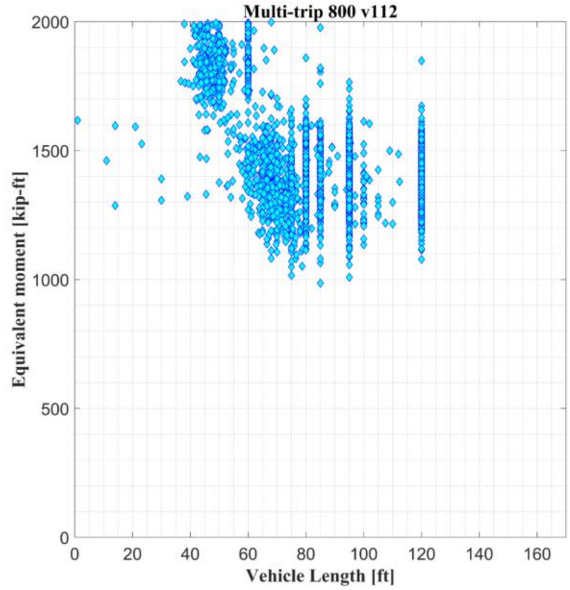

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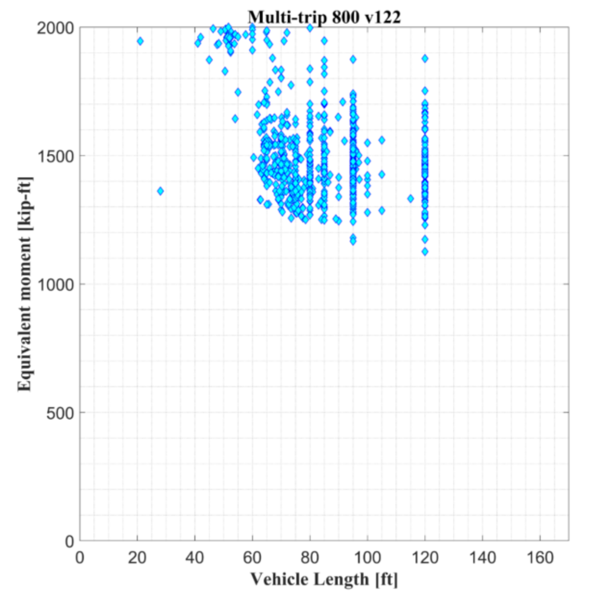

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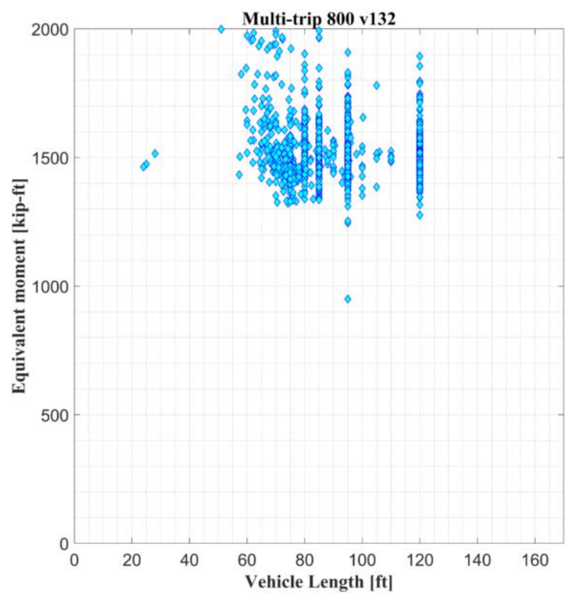
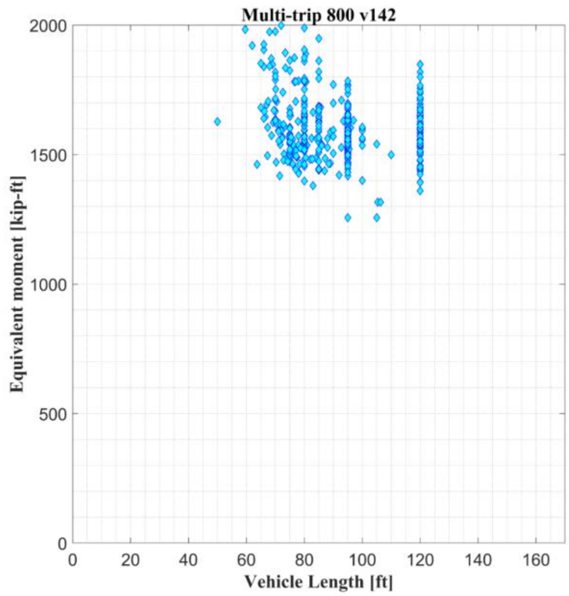


(d)

Figure A-5. Equivalent moment vs. Total length of the vehicle for multi-trip permits for 12 months type 800 group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.



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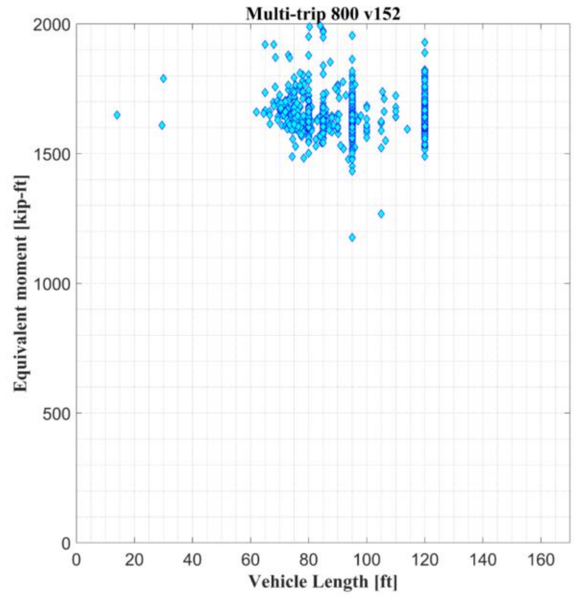

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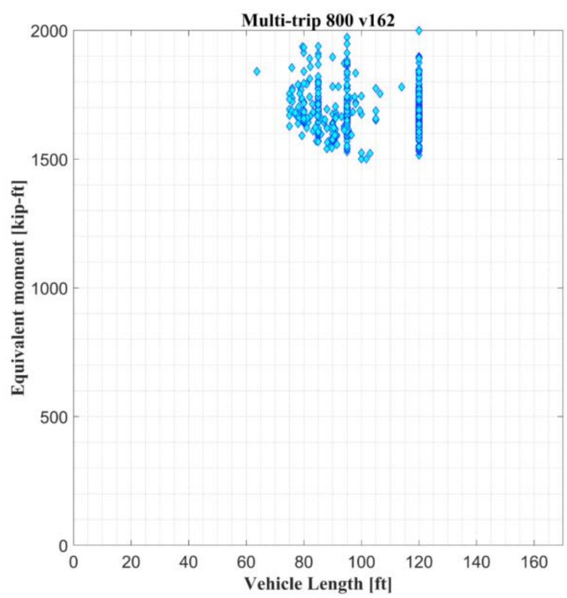

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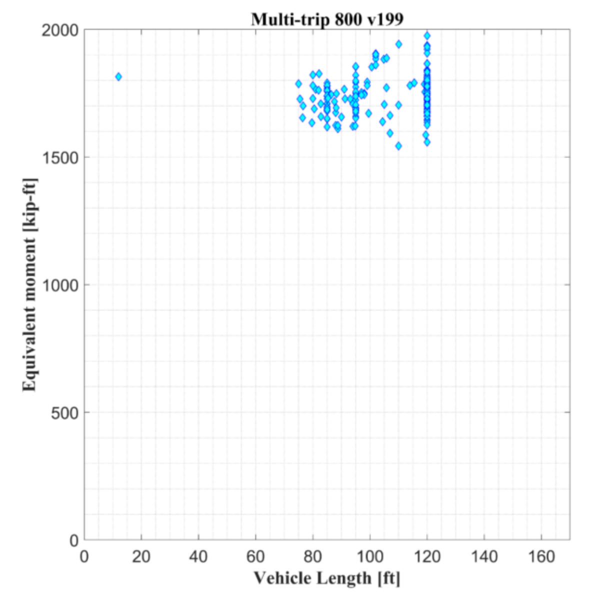
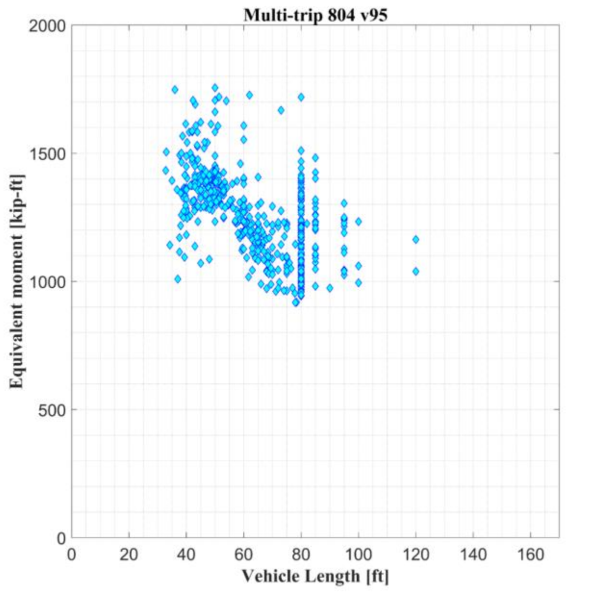


(h)

Figure A-5 Equivalent moment vs. Total length of the vehicle for multi-trip permits for 12 months type 800 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).



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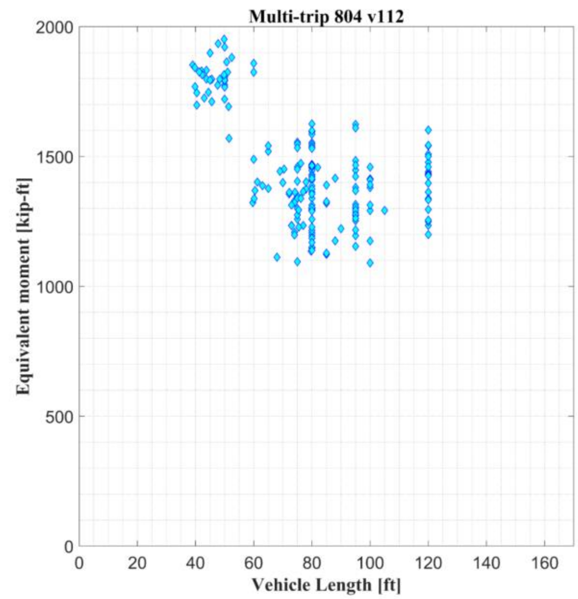

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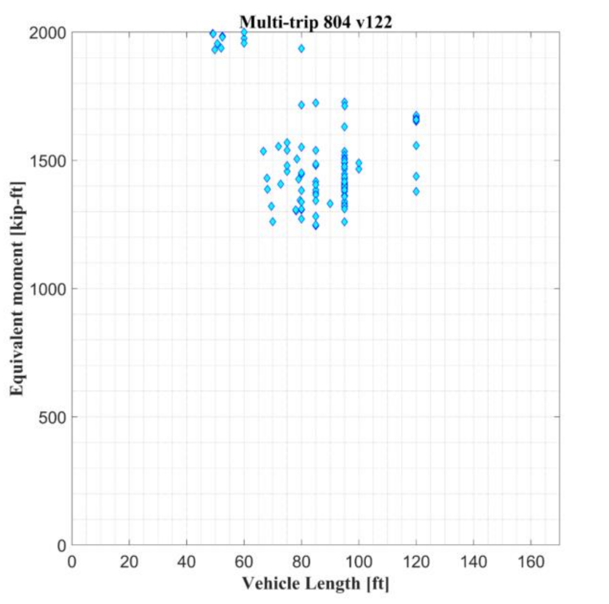

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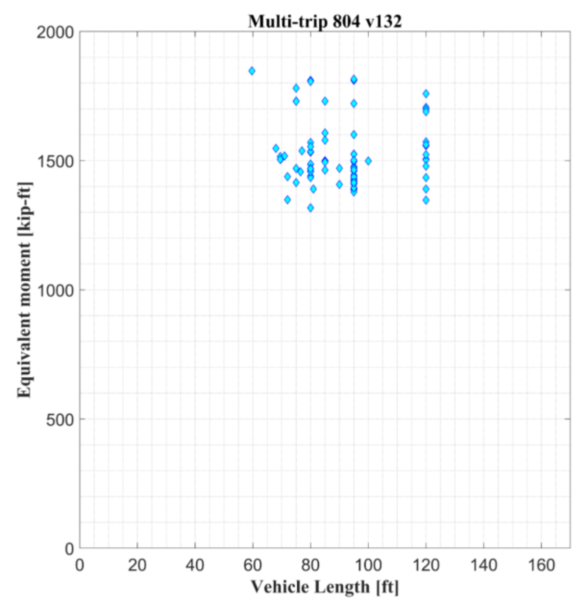
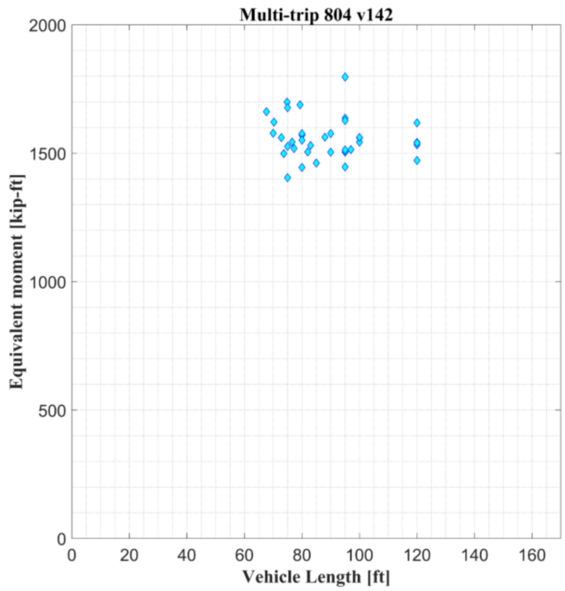


(d)

Figure A-6. Equivalent moment vs. Total length of the vehicle for multi-trip permits for 12 months, type 804 group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.



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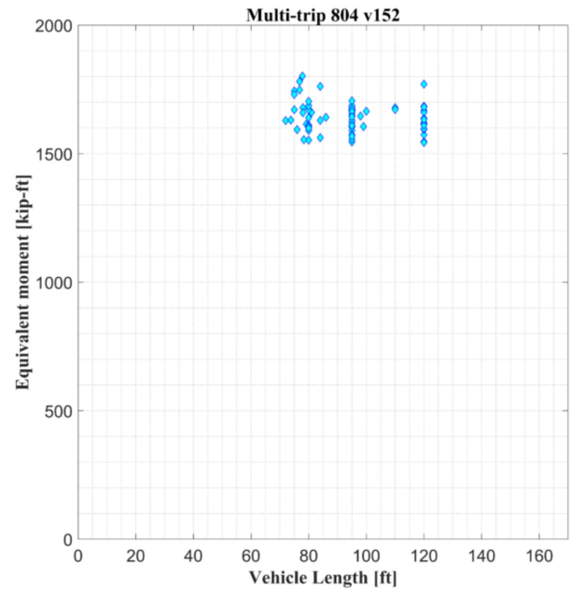

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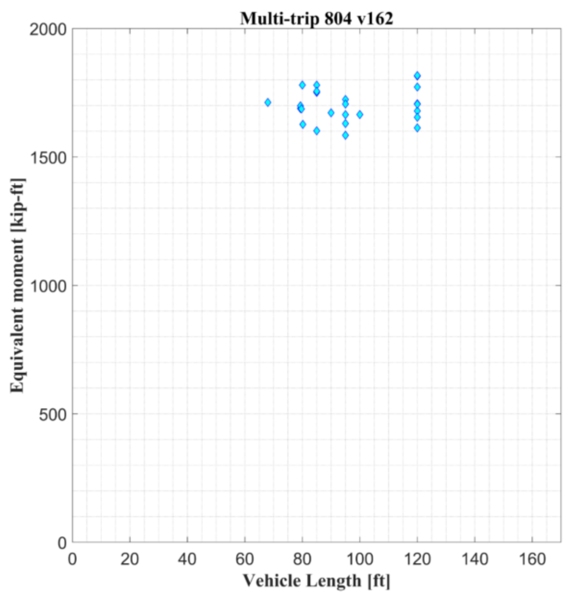

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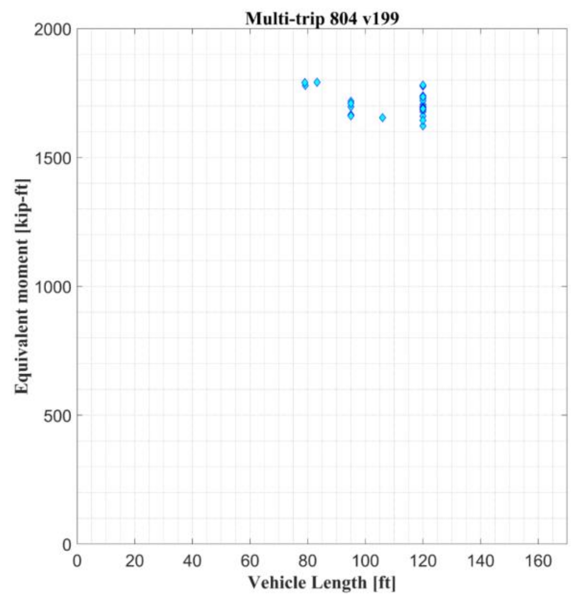
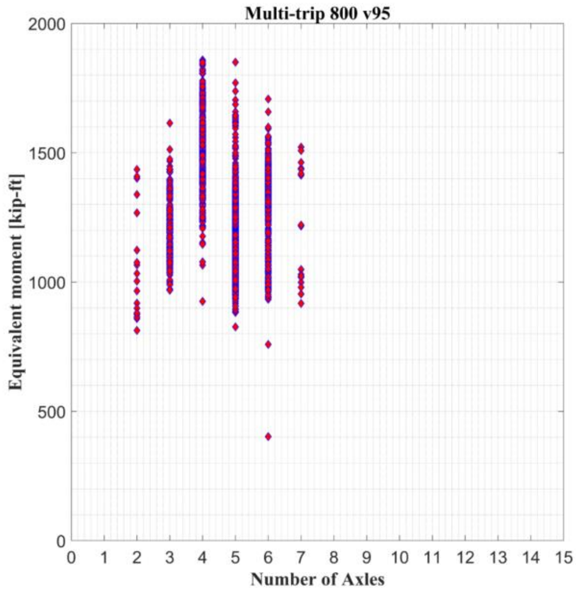
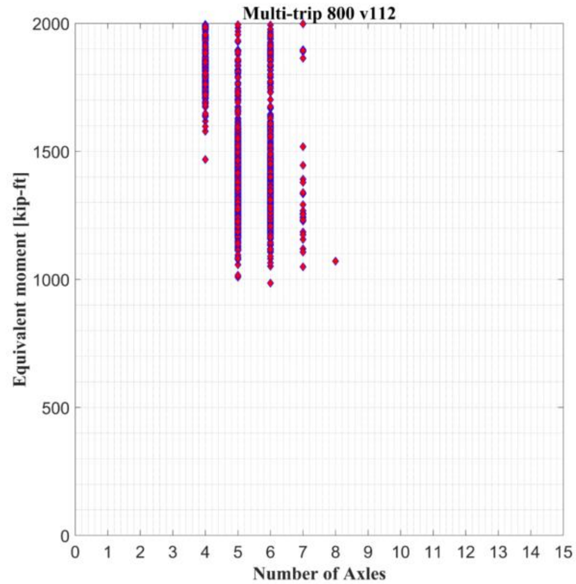


(h)

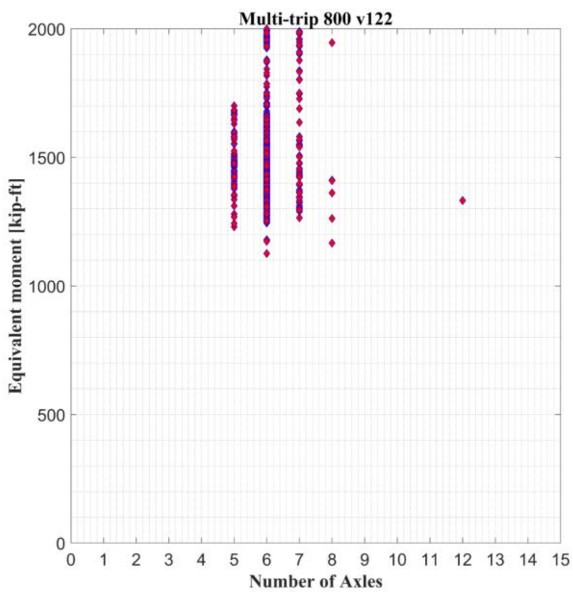
Figure A-6. Equivalent moment vs. Total length of the vehicle for multi-trip permits for 12 months, type 804 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).



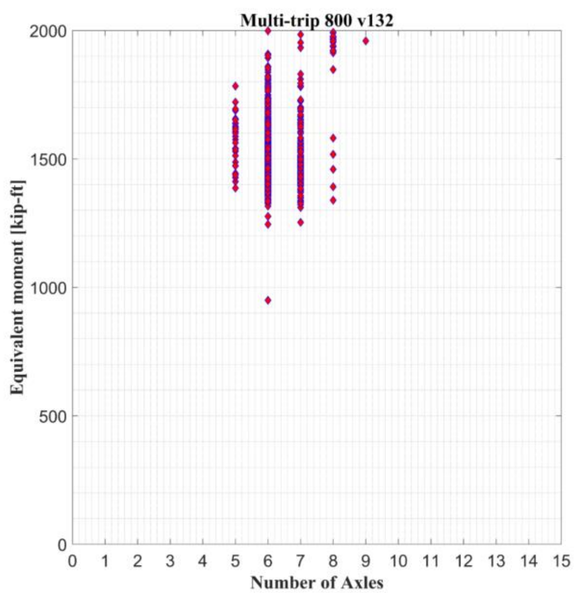
(a)



(b)

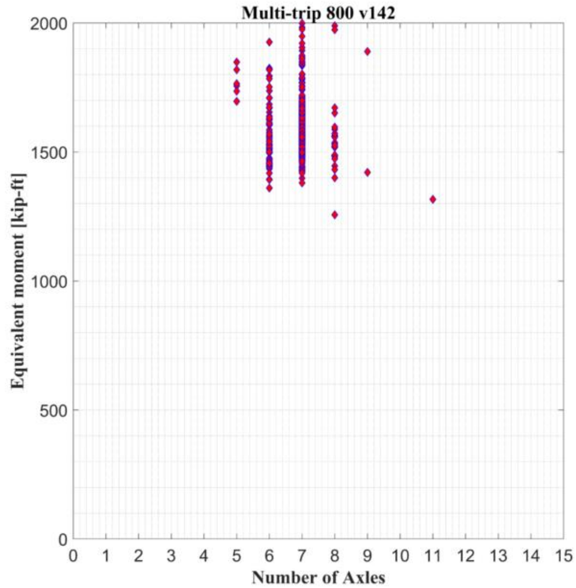


(c)

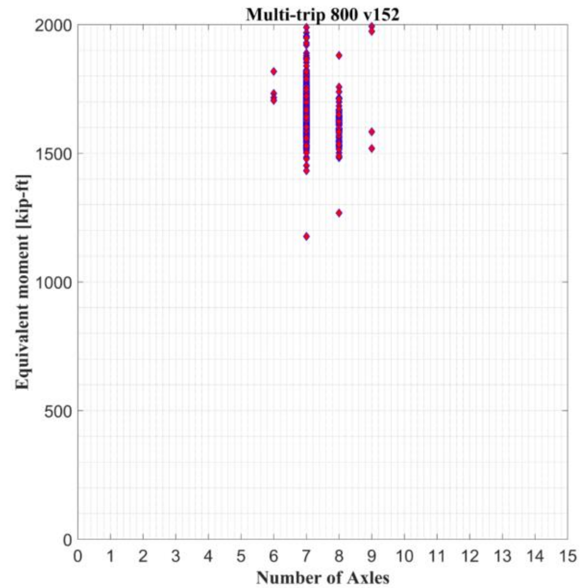


(d)

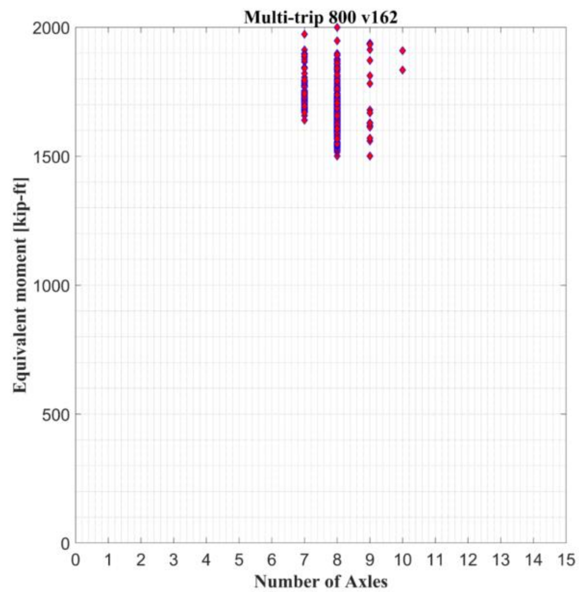
Figure A-7. Equivalent moment vs. Number of Axles for multi-trip permits for 12 months, type 800 group(a) up to 95 kips, (b) up to 112 kips,(c) up to 122 kips, (d) up to 132 kips.



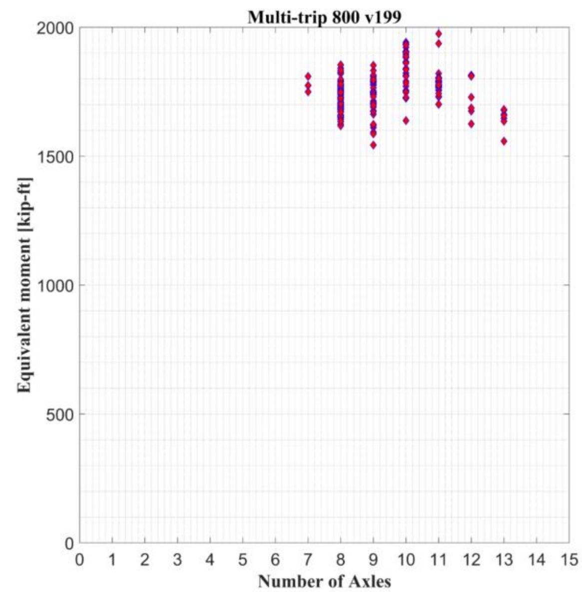
(e)



(f)



(g)



(h)

Figure A-7. Equivalent moment vs. Number of Axles for multi-trip permits for 12 months, type 800 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued)

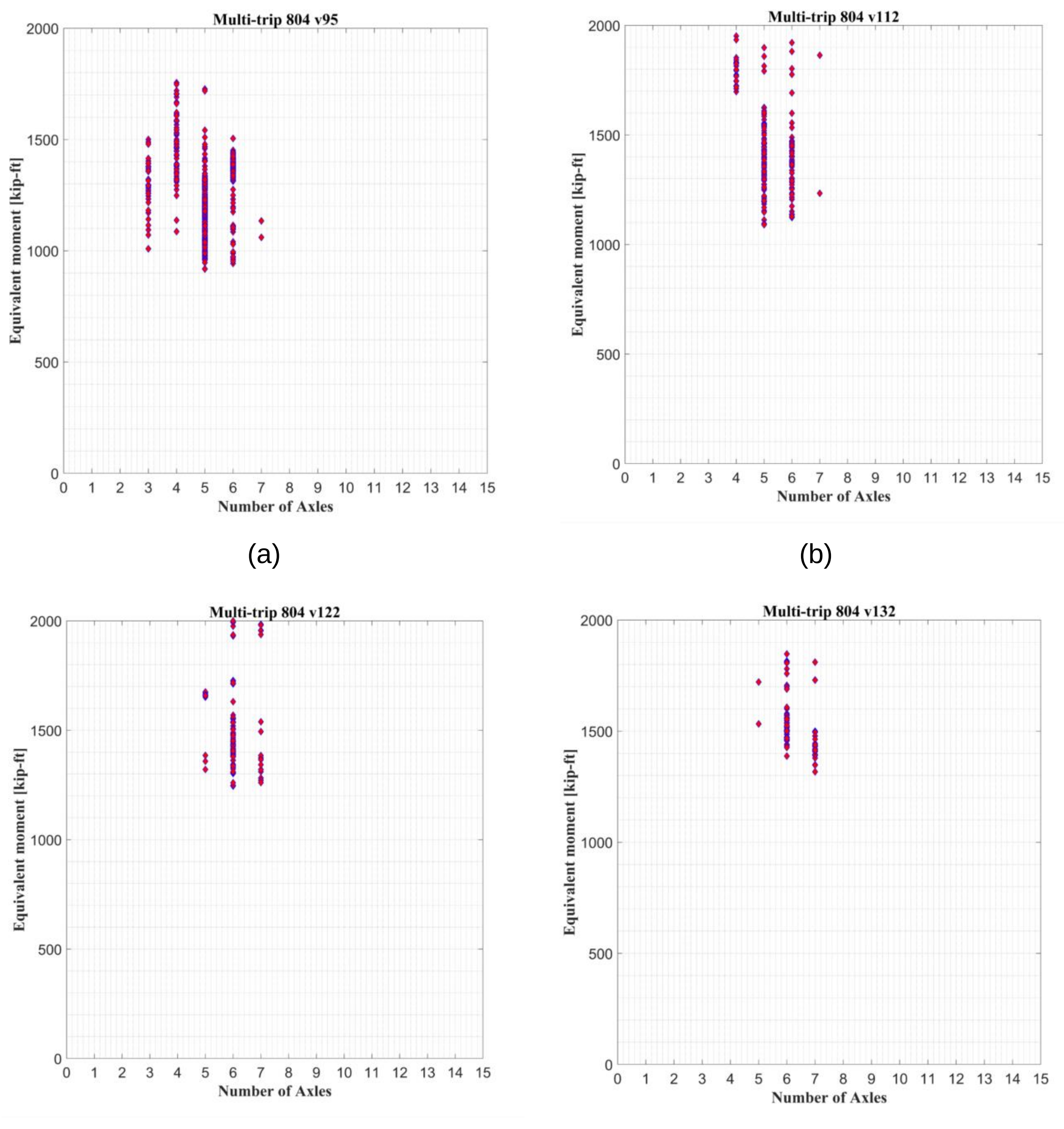


Figure A-8. Equivalent moment vs. Number of Axles for multi-trip permits for 12 months, type 804 group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.

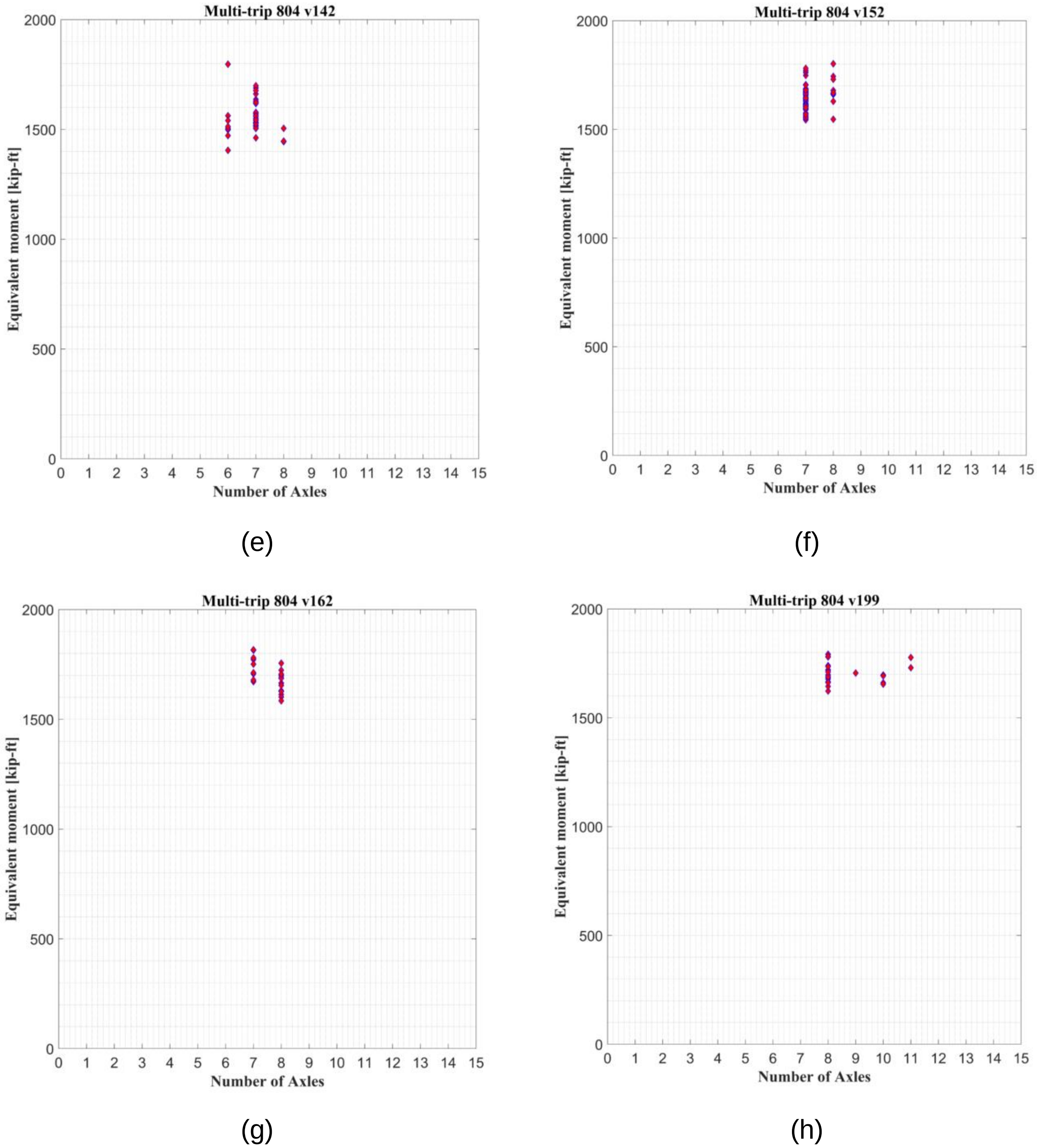


Figure A-8 Equivalent moment vs. Number of Axles for multi-trip permits for 12 months, type 804 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).

Multi-trip 3-month permits

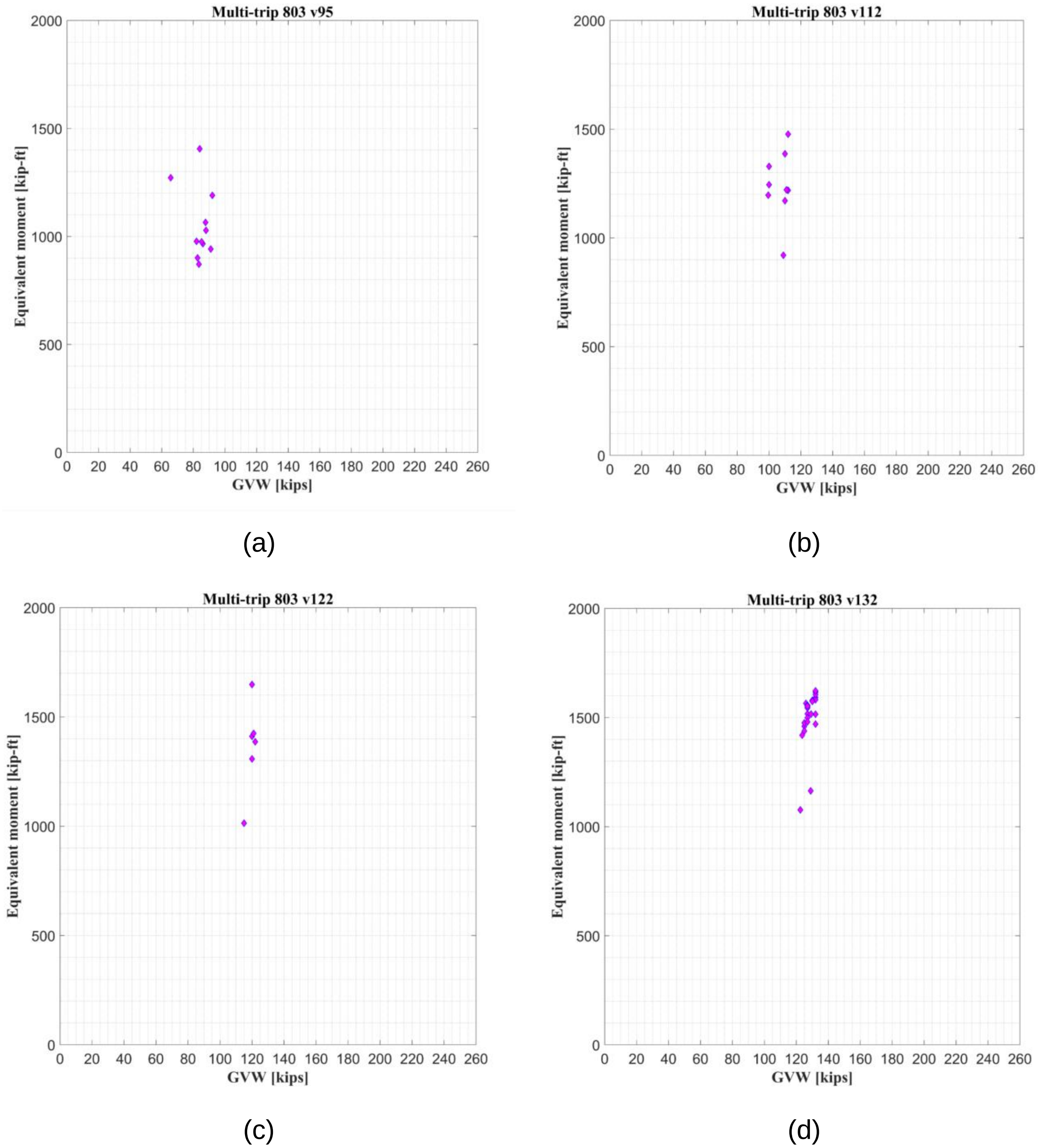


Figure A-9. Equivalent moment vs. GVW for multi-trip permits for 3 months, type 803 group (a) up to 95 kips, (b) up to 112 kips,(c) up to 122 kips, (d) up to 132 kips.

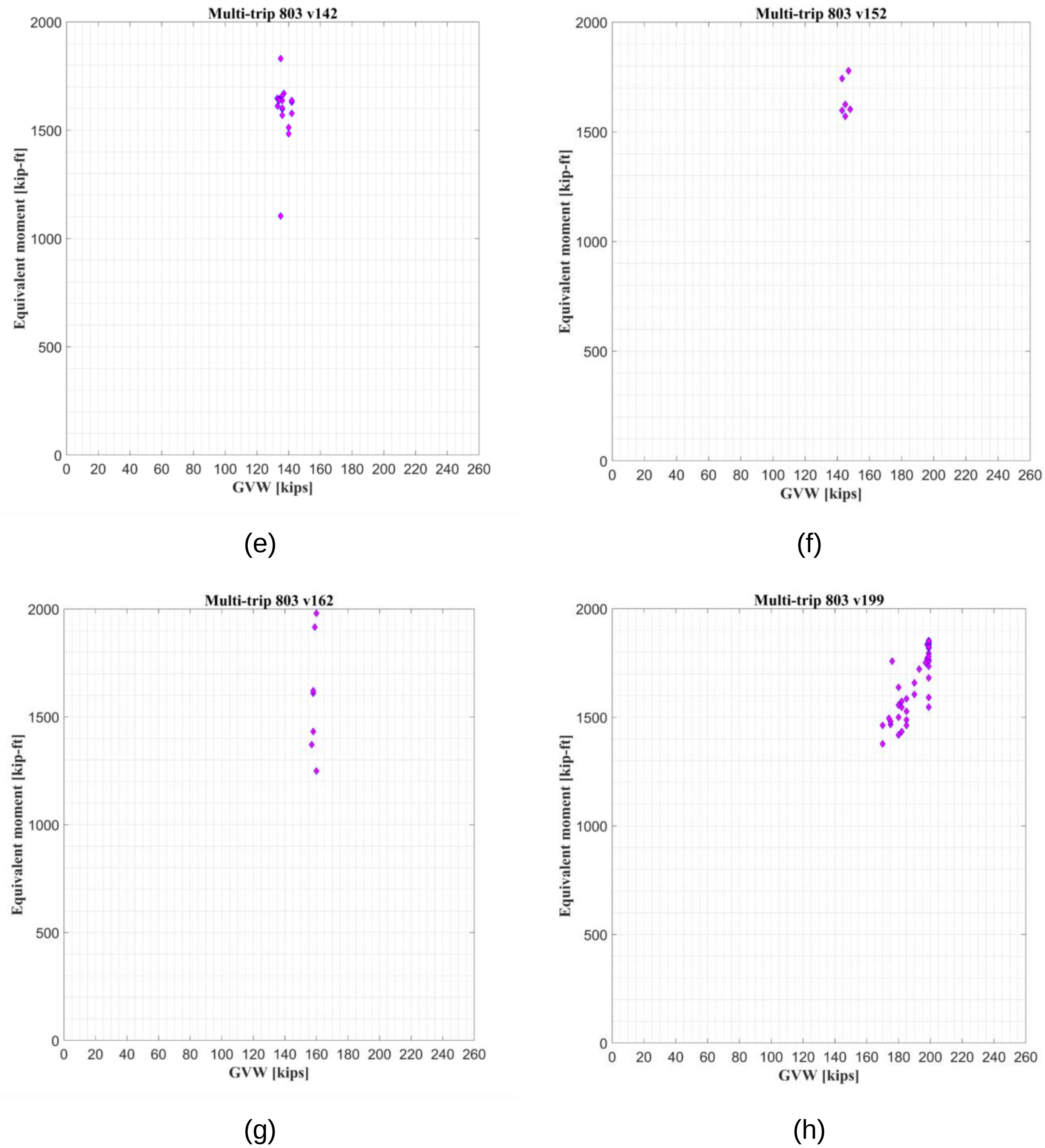
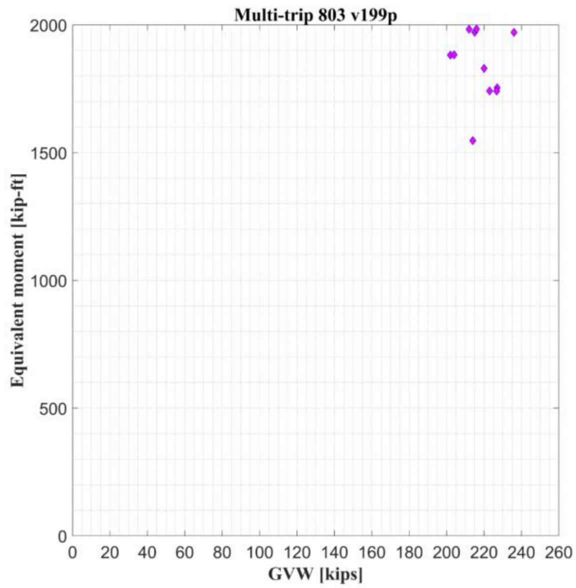
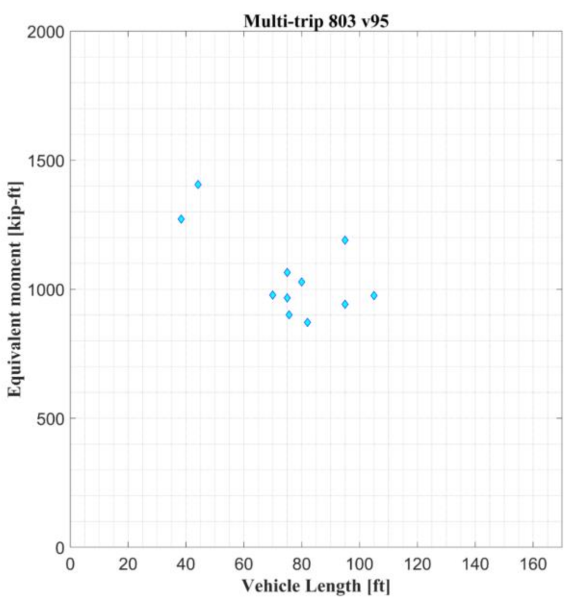


Figure A-9. Equivalent moment vs. GVW for multi-trip permits for 3 months, type 803 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).

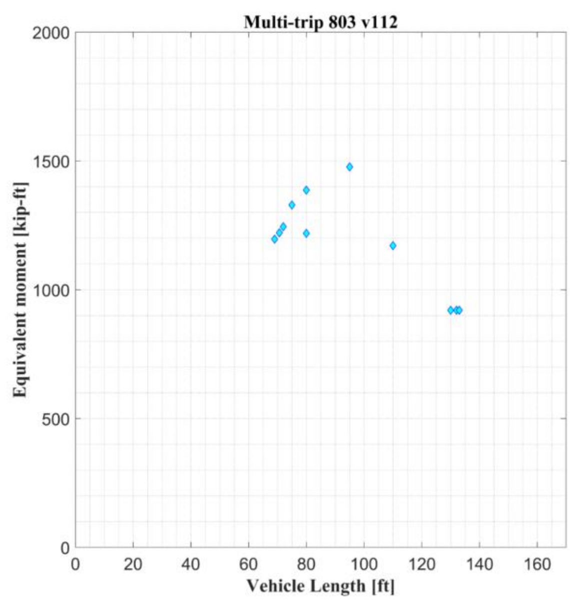


(i)

Figure A-9. Equivalent moment vs. GVW for multi-trip permits for 3 months, type 803 group (i) above 199 kips (continued).



(a)



(b)

Figure A-10. Equivalent moment vs. Total length of vehicle for multi-trip permits for 3 months, type 803 group (a) up to 95 kips, (b) up to 112 kips.

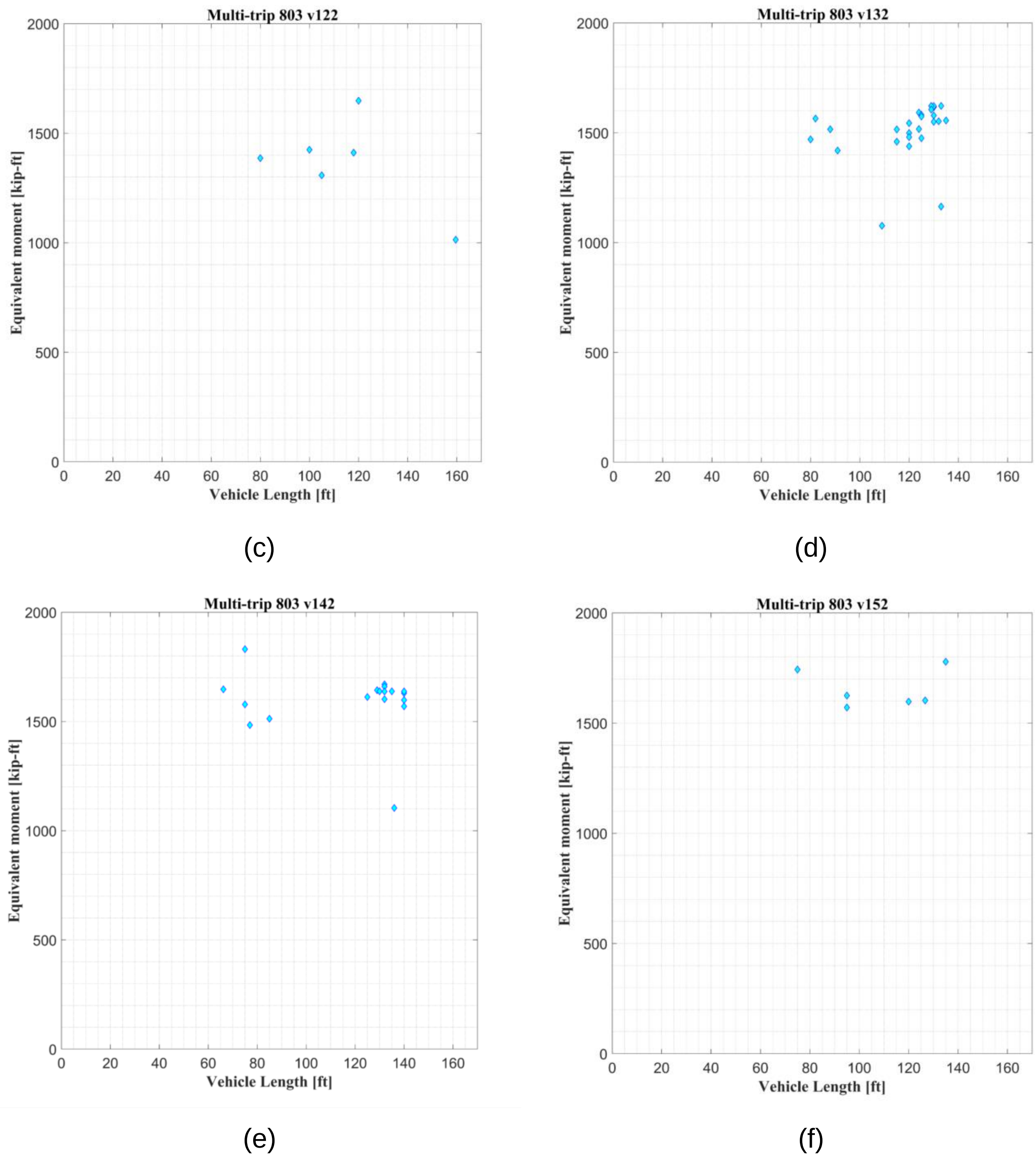
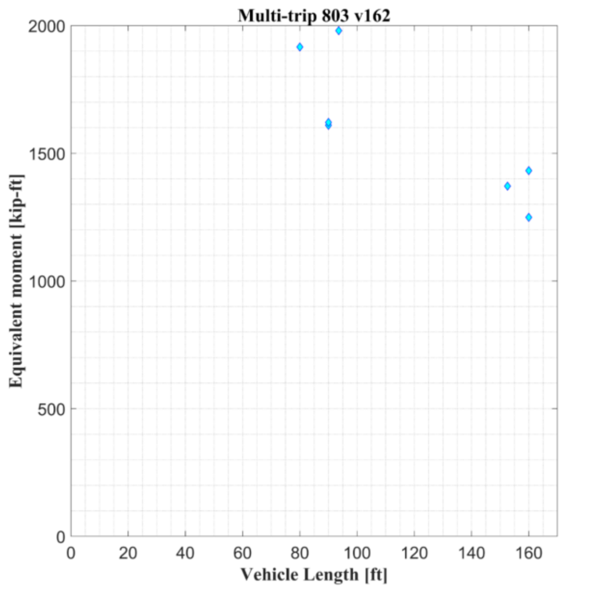
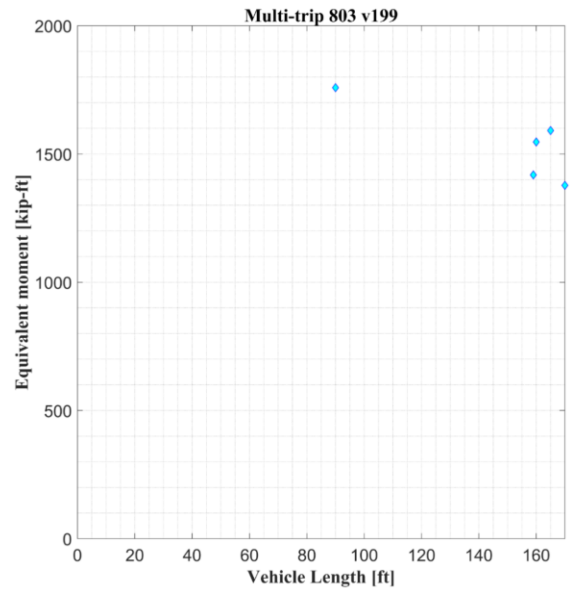


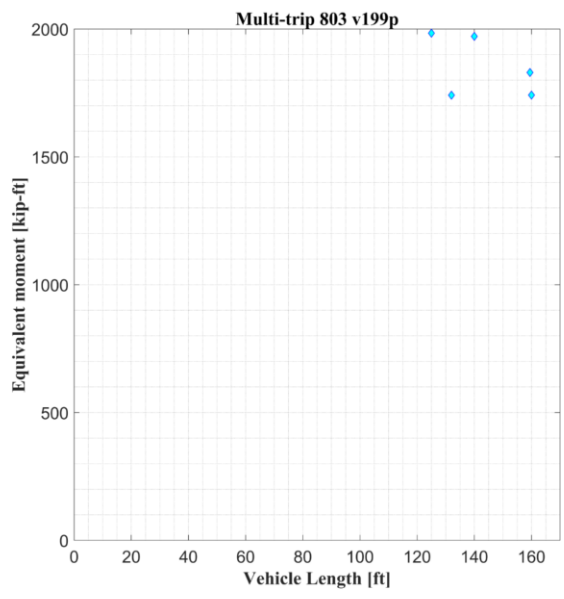
Figure A-10. Equivalent moment vs. Total length of vehicle for multi-trip permits for 3 months, type 803 group (c) up to 122 kips, (d) up to 132 kips, (e) up to 142 kips, (f), up to 152 kips (continued).



(g)



(h)



(i)

Figure A-10. Equivalent moment vs. Total length of vehicle for multi-trip permits for 3 months, type 803 group (g), up to 162 kips, (h) up to 199 kips, (i) above 199 kips (continued).

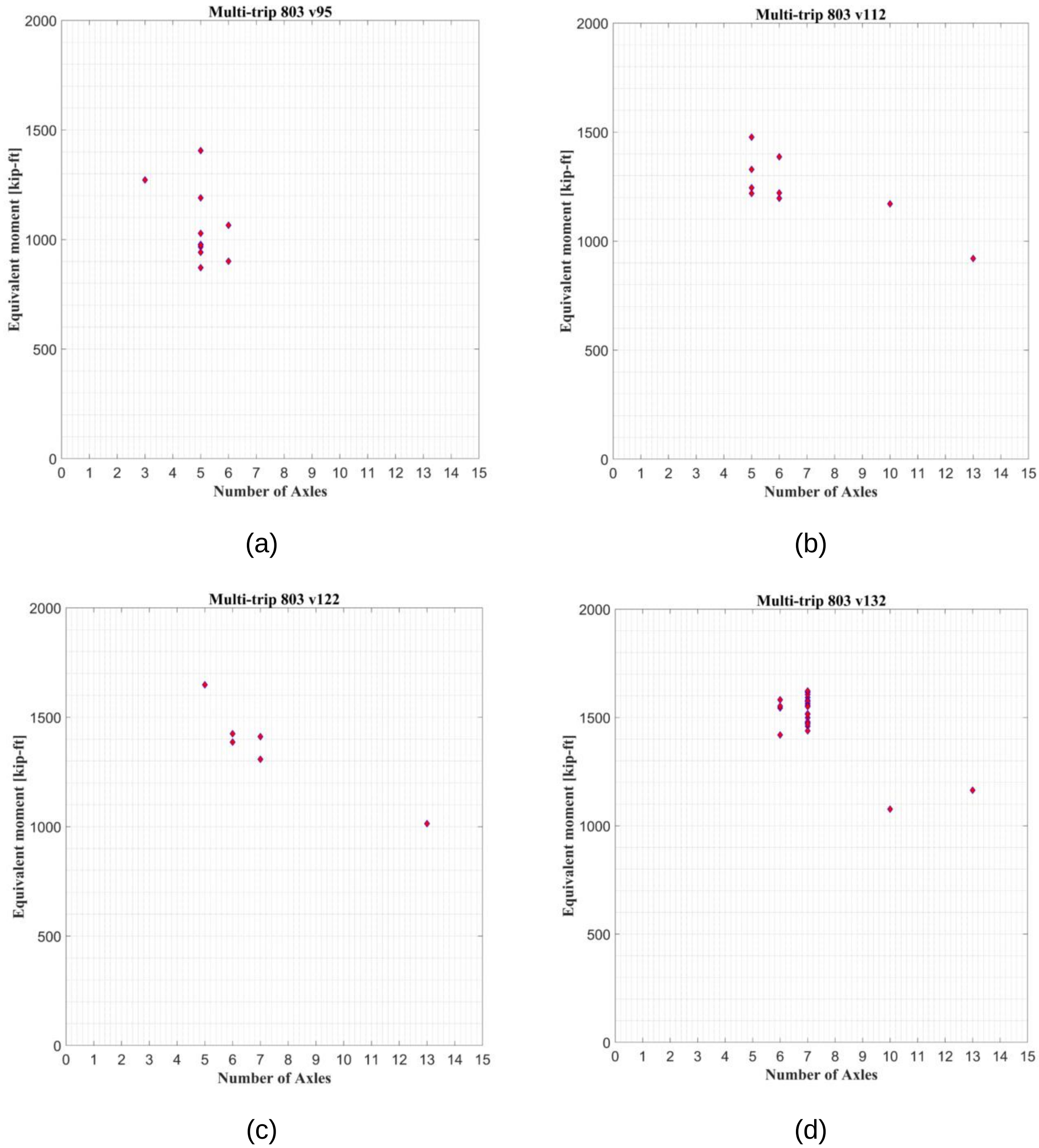
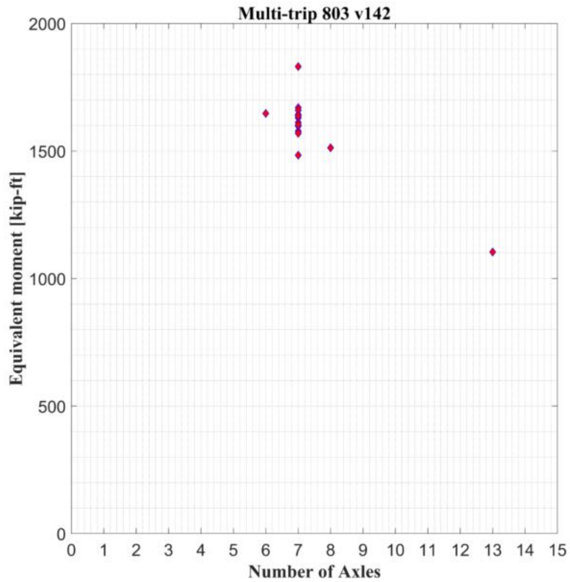
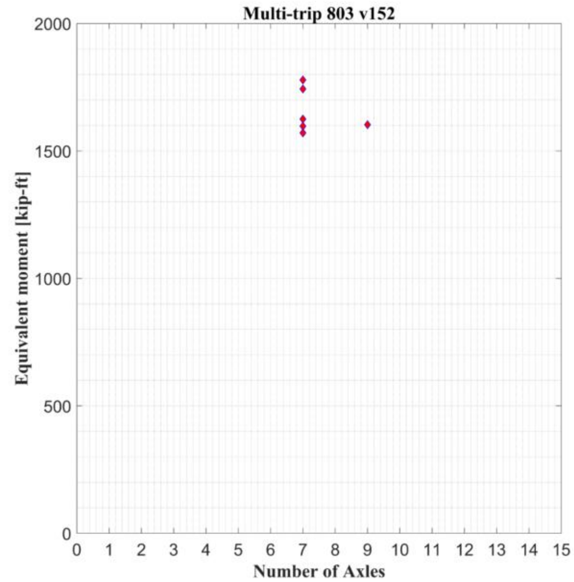


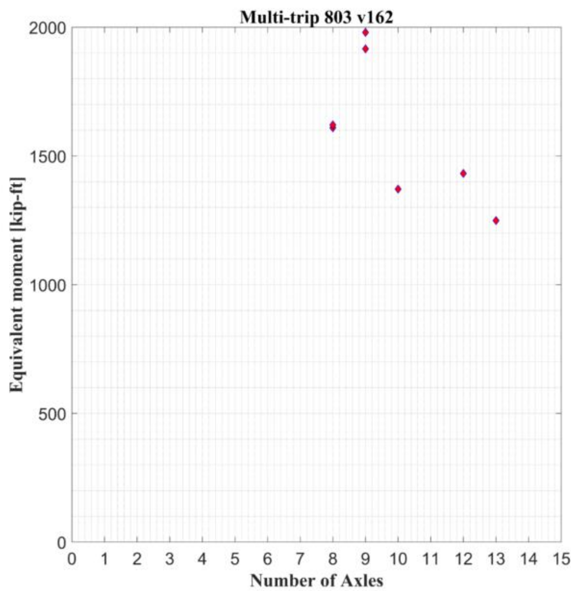
Figure A-11. Equivalent moment vs. Number of Axles for multi-trip permits for 3 months, type 803 group (a) up to 95 kips, (b) up to 112 kips (c) up to 122 kips, (d) up to 132 kips.



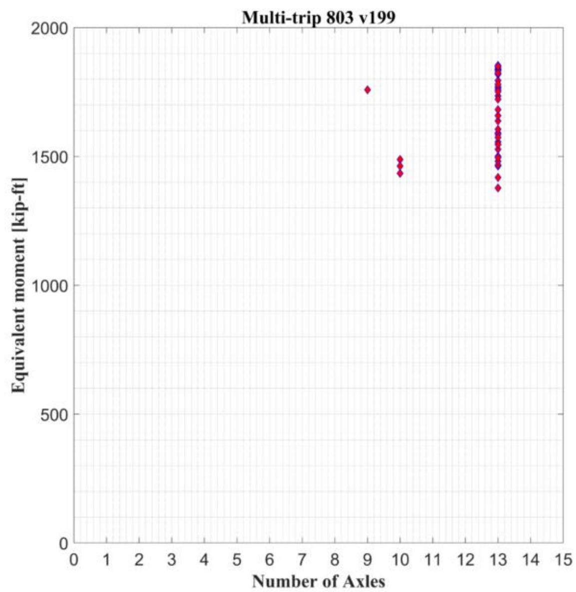
(e)



(f)

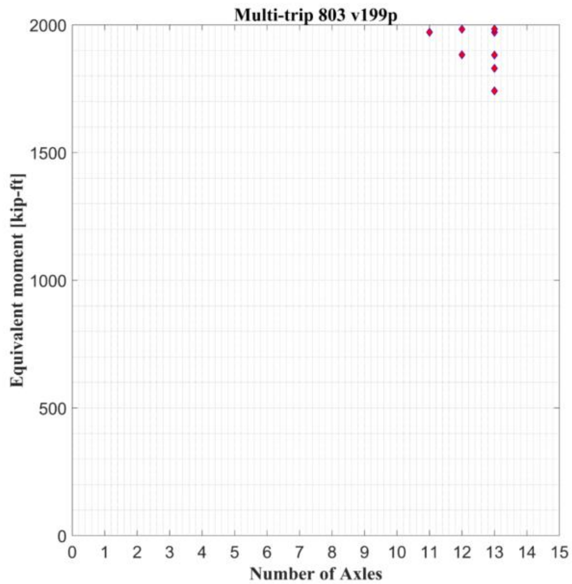


(g)



(h)

Figure A-11. Equivalent moment vs. Number of Axles for multi-trip permits for 3 months, type 803 group (e) up to 142 kips, (f), up to 152 kips, (g), up to 162 kips, (h) up to 199 kips (continued).



(i)

Figure A-11. Equivalent moment vs. number of axles for multi-trip permits for 3 months, type 803 group (i) above 199 kips (continued).

-trip permits for 12 months type 800 group: (e) up to 142 kip; (f), up to 152 kip; (g), up to 162 kip; (h) up to 199 kip (continued).

APPENDIX B: FHWA Vehicle Classifications (Hallenbeck et al., 2014).

Class	Description	Class includes:	Number of Axles
1	Motorcycles		2
2	Passenger Cars	All cars, Cars with one-axle trailers, Cars with two-axle trailers	2, 3, or 4
3	Other Two-Axle Four-Tire Single-Unit Vehicles	Pick-ups and vans, Pick-ups and vans with one- and two-axle trailers	2, 3, or 4
4	Buses	Two- and three-axle buses	2 or 3
5	Two-Axle, Six-Tire, Single-Unit Trucks	Two-axle trucks	2
6	Three-Axle Single-Unit Trucks	Three-axle trucks Three-axle tractors without trailers	3
7	Four or More Axle Single-Unit Trucks	Four-, five-, six- and seven-axle single-unit trucks	4 or more
8	Four or Fewer Axle Single-Trailer Trucks	Two-axle trucks pulling one- and two-axle trailers / Two-axle tractors pulling one- and two-axle trailers / Three-axle tractors pulling one-axle trailers	3 or 4
9	Five-Axle Single-Trailer Trucks	Two-axle tractors pulling three-axle trailers Three-axle tractors pulling two-axle trailers Three-axle trucks pulling two-axle trailers	5
10	Six or More Axle Single-Trailer Trucks	Multiple configurations	6 or more
11	Five or Fewer Axle Multi-Trailer Trucks	Multiple configurations	4 or 5
12	Six-Axle Multi-Trailer Trucks	Multiple configurations	6
13	Seven or More Axle Multi-Trailer Trucks	Multiple configurations	7 or more

APPENDIX C: NPV at Year 2020 and ESALs for 40 Years Starting from 2020

#	Routes number and name	NPV(×1000) $	ESALs (×1000)
1	State Road (SR) 71,	2,489	14,203
2	SR 123, North of Tom's Creek to Turkey Creek	1,664	10,192
3	County Road (CR) 578	4,565	6,134
4	SR 123, North of SR 85 to North of Tom's Creek	1,310	10,938
5	SR 76	4,501	9,209
6	US 90	2,898	8,814
7	SR 968	3,698	16,552
8	SR 390	4,037	10,222
9	Jacksonville national cemetery access road (Urban Section)	1,200	1,907
10	Jacksonville national cemetery access road (Rural Section)	1,394	1,855
11	SR 123, Turkey Creek to SR 85	2,561	10,938
12	SR 390, 23rd Street to Baldwin	3,880	6,836
13	US 90A	2,751	8,701
14	SR 21, Blanding Boulevard	3,730	13,832
15	SR 41, US 301/Gall Blvd	3,382	23,679
16	SR 823, NW 57th Ave	4,488	16,552
17	SR 80	5,108	29,248
18	SR 77, Clayton Road to I-10	2,506	6,188
19	SR 77, North of Wausau to the south of CR 276	2,671	3,537
20	SR 80, from Indiana hills drive to CR 833	1,289	26,887
21	SR 710, SW Warfield Blvd	4,715	26,273
22	SR 713, From North of I-95 to North of Commercial Circle	2,226	16,248
23	SR 50, From east of SR 35 to Hernando county line	3,029	19,412
24	SR 710, From Northlake Blvd to SR-708/Blue Heron Blvd	4,078	7,636
25	SR 20, NW 56th Avenue to CR 315 in Interlachen	2,642	7,429
26	US 98, Okaloosa county line to Tang-o-mar drive Walton	4,474	13,653
27	US 98, Airport road to Walton Co. line Okaloosa	4,266	9,676
28	US 331, Edgewood Circle to I-10	2,922	40,770
29	SR 400 (I4), Segment 2	8,189	43,731
30	SR 400 (I4), Segment 3	7,476	70,102
31	SR 400(I4), Segment 4	8,113	56,968
32	SR 400 (I4), Segment 5	10,227	87,643
33	SR 9 (I95)	8,763	66,670
34	SR 32	4,235	56,116
35	SR 93 (I275)	2,893	77,211
36	SR 93A (I75)	3,400	73,316
37	SR 93 (I75), SR 56 to CR 54	3,870	119,113

APPENDIX D: Complete Proposed Permit Fees to Cover Pavement Damage Only

(A) Number of Truck axles	(B) Avg ESAL	(C) Max Allowable ESAL	(D) Additional ESALs	(E) IS	(F) PA	(G) MR
				$ Per Mile Per Truck		
				0.018	0.049	0.147
80-95 kip (Current permit fee= $0.27/mile)						
4	7.6	4.8	2.8	0.05	0.14	0.42
5	4.7	3.0	1.7	0.03	0.08	0.25
6	2.9	1.9	1.0	0.02	0.05	0.14
7	1.9	1.2	0.6	0.01	0.03	0.09
8+	1.1	0.9	0.3	0.00	0.01	0.04
95-112 kip (Current permit fee= $0.32/mile)						
4	19.6	4.8	14.8	0.27	0.73	2.17
5	7.5	3.0	4.5	0.08	0.22	0.66
6	5.0	1.9	3.1	0.06	0.15	0.45
7	3.3	1.2	2.1	0.04	0.10	0.31
8+	2.4	0.9	1.6	0.03	0.08	0.23
112-122 kip (Current permit fee= $0.36/mile)						
5	12.0	3.0	9.0	0.16	0.44	1.32
6	7.9	1.9	5.9	0.11	0.29	0.87
7	5.3	1.2	4.1	0.07	0.20	0.60
8	3.7	0.9	2.8	0.05	0.14	0.41
9+	3.4	0.8	2.6	0.05	0.13	0.38
122-132 kip (Current permit fee= $0.38/mile)						
5	18.0	3.0	15.0	0.27	0.74	2.20
6	10.6	1.9	8.7	0.16	0.43	1.28
7	7.5	1.2	6.3	0.11	0.31	0.92
8	5.1	0.9	4.2	0.08	0.21	0.62
9+	3.4	0.8	2.6	0.05	0.13	0.38
132-142 kip (Current permit fee= $0.42/mile)						
5 axles	23.9	3.0	20.9	0.38	1.03	3.07
6 axles	16.0	1.9	14.1	0.26	0.69	2.07
7 axles	9.0	1.2	7.8	0.14	0.39	1.15
8 axles	6.7	0.9	5.9	0.11	0.29	0.86
9+ axles	6.6	0.8	5.8	0.11	0.29	0.85

Complete Proposed Permit Fees to Cover Pavement Damage Only (continued)

(A) Number of Truck axles	(B) Avg ESAL	(C) Max Allowable ESAL	(D) Additional ESALs	(E) IS	(F) PA	(G) MR
				$ Per Mile Per Truck		
				0.018	*0.049*	*0.147*
142-152 kip (Current permit fee= $0.45/mile)						
6	20.0	1.9	18.1	0.33	0.89	2.65
7	12.2	1.2	11.0	0.20	0.54	1.62
8	8.9	0.9	8.0	0.15	0.39	1.17
9	9.6	0.8	8.8	0.16	0.43	1.29
10	4.7	0.7	4.0	0.07	0.20	0.58
11+	3.6	0.4	3.2	0.06	0.16	0.46
152-162 kip (Current permit fee= $0.47/mile)						
7	16.4	1.2	15.2	0.28	0.75	2.23
8	11.1	0.9	10.2	0.19	0.51	1.50
9	12.8	0.8	12.0	0.22	0.59	1.76
10	5.9	0.7	5.2	0.09	0.25	0.76
11	4.2	0.4	3.7	0.07	0.18	0.55
12+	3.5	0.3	3.2	0.06	0.16	0.46
162-199 kip (0.003 Per 1000 pounds per mile) (Average $0.54)						
7	21.6	1.2	20.4	0.37	1.01	2.99
8	15.0	0.9	14.1	0.26	0.70	2.07
9	19.7	0.8	18.9	0.34	0.93	2.78
10	10.4	0.7	9.7	0.18	0.48	1.42
11	9.4	0.4	8.9	0.16	0.44	1.31
12	7.7	0.3	7.4	0.13	0.36	1.08
13+	4.4	0.3	4.1	0.07	0.20	0.60
200- 240 kip (0.003 Per 1000 pounds per mile) (Average $0.66)						
8	27.8	0.9	26.9	0.49	1.33	3.95
9	39.6	0.8	38.9	0.71	1.92	5.70
10	18.0	0.7	17.3	0.31	0.85	2.53
11	14.0	0.4	13.6	0.25	0.67	1.99
12	13.5	0.3	13.2	0.24	0.65	1.93
13+	11.2	0.3	10.9	0.20	0.54	1.60
240- 260 kip (0.003 Per 1000 pounds per mile) (Average $0.75)						
11	26.4	0.4	25.9	0.47	1.28	3.81
12	18.3	0.3	18.0	0.33	0.89	2.64
13+	16.5	0.3	16.2	0.30	0.80	2.38
260- 280 kip (0.003 Per 1000 pounds per mile) (Average $0.81)						
11	34.0	0.4	33.6	0.61	1.65	4.92
12	25.0	0.3	24.7	0.45	1.22	3.62
13+	20.7	0.3	20.4	0.37	1.01	3.00