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Quantify Bridge and Pavement Consumption Due to Permitted Overweight Vehicles

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16. Abstract

Overweight (OW) vehicles contribute to pavement and bridge deterioration, creating additional maintenance needs that may exceed the revenues generated through existing permit fees. This study developed a methodology for periodically updating Texas OW permit fees to reflect evolving traffic patterns, vehicle configurations, and infrastructure costs. The methodology also considers opportunities to enhance vehicle-miles-traveled (VMT) estimates and account for unrouted permit activity and off-system infrastructure impacts. Researchers analyzed more than two million permitted vehicle records from the Texas Permitting and Routing Optimization System (TxPROS) from 2018 to 2023. Annual on- and off-system VMT was estimated by permit and industry type, and infrastructure consumption was benchmarked against reference vehicles. The effect of OW vehicles on pavements was quantified using the so-called Equivalent Consumption Factors (ECF); while the effect on bridges was evaluated relative to inventory-vehicle rating. Estimated structural consumption costs and revenues were compared with permit fee structures in peer states to derive a cost-recovery rate per mile tailored to Texas conditions. The study concluded by proposing a mileage-based approach as one potential strategy for supporting equitable cost recovery while accounting for differences vehicle configuration, permit type, and roadway use.

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THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Comprehensive Research Report

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From: Danilo Inoue, Jorge Prozzi, Jose Weissmann, Angela Weissmann, and Brianne Glover

Subject: TxDOT Project 0-7195 – **R1**

Date: January 31, 2026

Quantify Bridge and Pavement Consumption Due to Permitted Overweight Vehicles

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1. INTRODUCTION

The Texas Department of Transportation (TxDOT), like many other state Department of Transportations (DOT), faces many challenges in securing adequate funding through traditional federal and state fuel taxes, permit fees, and various other ad-hoc fees used for maintaining their surface transportation network. These conventional funding sources have failed to keep pace with inflation, and considerably increasing maintenance and construction costs. Coupled with the prevalence of fuel-efficient vehicles, they have proven to be insufficient. In response to this challenge, the Texas Legislature has undertaken extensive studies to explore avenues for revenue enhancement and budget allocation to ensure the continued maintenance and serviceability of the state's road and bridge infrastructure. State personnel, researchers and transportation engineers have advocated for a pragmatic solution to address this deficit by adjusting the permitting fee structure for oversize and overweight (OS/OW) vehicles, since those vehicles consume the service life of the network infrastructure at a faster rate relative to regular commercial vehicles. Furthermore, they impose direct costs on highway appurtenances (such as signs, traffic signals, and light poles), while also generating financial burdens for local jurisdictions through enforcement and management.

In 2012, the 82nd Texas Legislature mandated that TxDOT conduct a study to assess the increased wear and tear on pavements and bridges caused by OS/OW vehicles. This study, known as Rider 36, proposed adjusting the permitting fee, as recommended to the Governor and the Legislative Budget Board (Prozzi et al., 2012). At that time, the costs related to OS/OW vehicles damaging bridges and pavements exceeded the revenue from permit fees by about $200 million annually. In 2021, the 87th Texas Legislature enacted House Bill 2223, commonly referred to as HB 2223, to conduct another study on the effects of OS/OW vehicles on the infrastructure system (Prozzi et al., 2022c). The results of HB 2223 aligned with those of Rider 36, indicating an annual revenue shortfall of approximately $168 million. However, these two studies focused solely on the state maintained highways system (so called on-system). Although there was significant traffic demand on off-system roads (e.g., local and county roads), neither study evaluated the impact of OS/OW fleets on the off-system infrastructure. Another limitation of the most recent study was the absence of a detailed assessment of non-routed permits (issued for more than a single trip), since they normally lack of both vehicle configuration and tracked mileage.

1.1 Objectives of the Research Project 0-7195

Given the shortcomings above-mentioned and the need to continuously adjust the OS-/OW permit fee structure to compensate the infrastructure consumption cost, the TxDOT decided to address the following shortcomings:

- Lack of a methodology for periodically adjusting permit fees to account for changes in traffic patterns and vehicle-axle configurations, considering higher inflation rates;
- Lack of accurate data and process for calculating annual vehicle miles traveled (VMT) for each permit type using both on- and off-system highways;
- Uncertainty on identifying the VMT for multi-trips permits; and
- Absence of a methodology to assess the damage caused by OW vehicles on infrastructure assets located on the off-system network.

This study aimed at developing, proposing, and delivering a robust and up-to-date approach for evaluating the costs related to pavement and bridges caused by OW vehicles. The study covers the assessment on both on- and off-system network, and recommends permit fee adjustments to break even the structural consumption caused by OW vehicles.

1.2 Scope of the Comprehensive Report

This report is organized as follows. Section 2 provides a comprehensive overview of the regulatory landscape of truck permitting, including methodologies used to estimate the marginal structural damage (or consumption) of bridges and pavements attributable to OS/OW vehicles. This section also reviews relevant studies conducted in Texas and peer states. Section 3 examines the current permitting framework in Texas, as defined by the Transportation Code and implemented by the Texas Department of Motor Vehicles (TxDMV). Section 4 focuses on the Texas Permitting and Routing Optimization System (TxPROS), the primary platform used by TxDMV to issue OS/OW permits, detailing the permit types available in Texas and the corresponding reports generated by the system. Section 6 analyzes available databases used to track mileage for OW fleets, disaggregated by permit type and industry. The mileage estimates developed in this section are critical inputs for the bridge and pavement analyses, as costs are evaluated on a per-mile basis. Sections 7 and 8 present the bridge and pavement analyses, respectively, including the adopted methodologies and the estimation of unit consumption costs per mile for each OW permit type. Finally, Section 9 revisits the current permit fee framework and, based on the findings from previous sections, conducts a revenue–cost analysis to estimate recovery rates (dollars per mile) required to offset the infrastructure costs associated with OW vehicle operations in Texas.

2. REGULATORY LANDSCAPE ON TRUCK PERMITTING

Efficient and safe truck freighting is essential for any society to facilitate its economic growth, social welfare, national defense, domestic security, and quality of life goals. For user safety and system preservation purposes, trucking operation characteristics (e.g., speed, weights, widths, heights, etc.) are regulated by federal and state legislation. However, the inherent characteristics of certain commodities (or services) can make it impractical to divide their loads into multiple commercial truck units. This necessity prompts motor carriers to seek state permissions, commonly referred to as Oversize and Overweight Permits, which grant them the authority to exceed both national and state-imposed size and weight limits. Despite this, it is incumbent upon TxDOT to safeguard the taxpayers' investment in the state highway network system. This is achieved through the implementation of its own size and weight restriction policies, strategically designed to attract heavy industry without compromising its infrastructure condition.

The size and weight policies developed at national level by the United States Department of Transportation (USDOT) are adopted by most state DOTs, and have subsequently evolved over the years to accommodate local industry needs and their specialized hauling vehicles. For more than 60 years that transportation engineers are aware that axle load governs pavement performance, while most bridge performance functions are concern with momentum, which considers the combination of axle load and spacing (Prozzi et al., 2022c).

DOTs generally consider uniform federal thresholds for vehicle size and weight to determine if an OS/OW permit needs to be issued. In accordance with federal legislation, the Interstate Highway system imposes a maximum Gross Vehicle Weight (GVW) of 80,000 lbs. This includes a cap of 20,000 lbs. for a single axle and a limit of 34,000 lbs. for a tandem axle group (FHWA, 2023). However, off-system roadways lack the rigorous oversight and law enforcement which is more common on interstate and state highway systems. Also, municipal and county roads are usually design to standards that are comparatively lower in terms of strength and geometry than those applied to the federal/state highways, due to their expected traffic volumes and characteristics.

There is a variety of industries and commodities that are required to issue a truck permit in Texas. Some of them are seasonal (e.g., implements for husbandry and agriculture, machinery, and equipment for highway construction or maintenance, timber), while others depend on specific industries (e.g., portable houses, milk, oil, and petroleum derivates, ready-mixed concrete etc.). OS/OW permits can be single-trip based, time- or multi-trip based (e.g., monthly, or annual permits), and distance-based (i.e., charged per mile traveled). It is expected that permits maintain revenue neutrality, meaning that the amount generated by its fee is enough to cover the additional cost imposed to the whole infrastructure system. Hence, in essence, permit fees should only recover costs and not make any profit.

The following subsections presents a literature review on methodologies to assess both pavement and bridge associated costs with OS/OW vehicles, and specifics data mining processes used on permit bases to assess vehicle's configurations for infrastructure performance evaluation. A more detailed review of permit fee frameworks implemented by other DOTs is presented in Section 9.

2.1 A Synthesis of Overweight Truck Permitting (Bilal et al., 2010)

A systematic literature review was carried out by Purdue University in cooperation with the Indiana Department of Transportation (InDOT) and the Federal Highway Administration (FHWA) with the purpose of documenting the state of practice of OW truck permitting in the state of Indiana vis-à-vis those of its neighboring states based on fee amounts and structure (Bilal et al., 2010). The objective of the study was to help InDOT to synthesize existing information on various issues related to the permitting process, including the pavement costs due to excess loading, as well as the level and past trends of permit revenue generation in Indiana, which would allow the state agency to assess the impacts of OW vehicles on highways and update their permit fee structure.

The report focused only on the effect of OW vehicles, excluding OS. Due to the lack of studies conducted at the time in the Midwestern states, the authors relied on federal reports, including one state report done in Texas (Texas Transportation Institute, 1988). They found that most reports were based on a pavement cost per mile using the concept of Equivalent Single Axle Load (ESAL). The results from their literature review are summarized in Table 1. The main findings from this research were:

- Pavement damage cost decreases drastically with increase in number of axles for a given traveled distance in a non-linear fashion;
- Agencies that switched from a single-trip permit system to an annual permit system report that they benefited from cost savings due to reduced monitoring efforts but lost significant revenue overall, indicating that the adoption of an annual blanket fee may be unfavorable from the perspective of revenue generation, although favorable to truck operators; and
- Some states were found most favorable to truck permitting because of their rela-

tively high or nonexistent maximum-weight thresholds for defining what a super-load[1] is, and relatively lower fees for OW vehicles.

Some important remarks and suggestions from the authors included:

- Investment on "constant monitoring and direct survey" to maintain an updated database of vehicle configurations, fee levels and structure, and road conditions;
- Thresholds could be changed over time since the impact of OW trucks on new pavements (or bridges) differ due to aged and less resilient infrastructure, and this should also reflect how the routing system for OW permits operates;
- Permit fees should be tied to the infrastructure condition in some sort of dynamic pricing, which is also associated to the previous point, meaning that the fees could follow the non-linear behavior of pavement deterioration (i.e., lower fees for newer facilities and higher fees for older [or more vulnerable] ones); and
- Fund a division to check for compliance and assess increases in agency cost through OW permitting, that could translate into purchase of equipment and establishing a bureau to specific monitor OS/OW fleet.

[1] Super-load (or super-heavy) is a special freight load beyond both federal and state limits that requires specific engineering analysis during their routing procedures.

Table 1: Summary of pavement cost of past studies (Bilal et al., 2010)

Reference[1]	**Study Scope**	**Assumptions**	**Cost Range**	**Units**
Small et al. (1989)	Evaluated the relationship between pavement life and ESAL through survival analysis using AASHO Road Test data, and assigned pavement damage cost.	At the existing investments levels in 1985 and different road classes.	1.48 - 125.45	cents per ESAL-mile (1985 dollars)
		Under optimal investments levels and different road classes.	0.33 - 101.30	cents per ESAL-mile (1985 dollars)
Vitaliano and Held (1990)	Estimated the cost of pavement damage by heavy vehicles (5-axles and GVW of 80,000 lbs.) using data from New York.	Assume 50% of pavement deterioration by traffic and 50% by climate, and different road classes.	0.03 - 14.8	cents per ESAL-mile (1990 dollars)
Nix et al. (1992)	Estimated pavement damage cost based on typical construction costs in southern Ontario.	Low- and high-volume roads.	0.40 - 0.50	cents per ESAL-mile (1990 dollars)
Hajek et al. (1998)	Used marginal cost method to assess the impact of changing truck weight and dimensions regulations in Ontario.	Modeled for new and in-service pavements for urban road and highway classes.	0.25 - 89.50	cents per ESAL (1998 dollars)
Hiroshon (2002)	Compared Nix et al. (1992) estimates a decade later.	Based on Canadian government road infrastructure expenditures.	$\sim$ 27.0 - 33.0	cents per ESAL-mile (1989 dollars)
FHWA (2000)	Used marginal pavement cost to assess the damage by OW vehicles ranging from 4-axle with GVW of 40,000 lbs. to 5-axle with GVW of 80,000.	Cost-based on Interstate rural and urban roads.	0.25 - 8.18	cents per ESAL-mile (2000 dollars)

[1]Note: all citations in this table are referenced in (Bilal et al., 2010)

2.2 Accommodating Oversize and Overweight Loads (Middleton et al., 2012)

In 2012, the Texas Transportation Institute (TTI) in cooperation with TxDOT and FHWA developed methods to identify the most common OS/OW dimension and weight groups in Texas (Middleton et al., 2012). A detailed analysis was performed to identify OS/OW routes by considering factors such as load characteristics, permit type, and highway type.

During the study, the former TxDOT's Motor Carrier Division (MCD) experienced approximately 500,000 OS/OW permits applications per year that generated an annual revenue of over $100 million (in 2012 dollars). Around the same time, the renewable energy sector increased the number of wind farms in Texas, representing over half of the US wind industry growth, which pushed the demand for OS/OW permits. Out of the 25 different types of truck permits, defined according to the Transportation Code Chapter 623, the so-called "Super-heavy permit" was the most frequent permit issued by the MCD, representing 65 to 70 percent of the total number of permits issued.

The permitting process at the MCD was through the Central Permitting System (CPS), an internet-based program that allowed motor carriers to apply for a permit. That was the only system available at the time and routing permits was a manual process by using customized paper maps containing all route restrictions, which depended on daily updates from district officials. In parallel with this study, a new automated mapping/routing system called Texas Permit Routing Optimization System (TxPROS) was under development under another project, which is now currently used by the TxDMV for routing and issuing OS/OW permits.

Middleton et al. (2012) study was primarily motivated by concerns about the structural capacity and safety of bridges. As mentioned before, at that time Texas lacked an automated system for routing OS/OW permits, highlighting a pressing need to accurately assess bridge structural capacity to withstand those heavy loads. Such analysis was crucial because it would consider the existing condition of the bridges and the additional damage potentially caused by these vehicles. It was previously understood that for longer spans, bridges needed to accommodate the entire vehicle length, making the bridge's load-carrying capacity a significant limitation for permit issuance. Also, accurately determining the live loads that existing bridges might encounter was (and still is) a challenging task.

The TTI team found that the over 75 percent of the permitted trucks surpassed the legal vehicle width of 8.5 ft. Lastly, in terms of GVW, approximately one third of the permits were loaded with more than 80,000 lbs., with around half of those falling below

120,000 lbs.

The team also tracked and summarized the various types of commodities and industries associated with truck permits. Significant routing issues were identified, including limited connectivity and inefficiencies between interstate permitted corridors (e.g., a load traveling on a designated permitted route in one state may enter a non-permitted corridor upon crossing into another state). At the time, the motor carriers suggested that DOTs should develop an "envelope vehicle" with high-wide-heavy requirements at a national level, so that each state could establish their own OS/OW routes, resulting in a more efficient and interconnect inter-state routed system. Another important input from motor carriers was that the reliability within this freight sector could lie on specific categories of operation, such as permits carrying loads over the legal limits but below the upper threshold of 254,300 lbs. This conclusion proved to be reasonable because loads below those limits represented low risk, and those above 254,300 lbs. are required a detailed mile-by-mile analysis. Also, extreme loads (and sizes) usually require movement under direct traffic control with escorts, mitigating any possible safety risk.

Furthemore, Middleton et al. (2012) leveraged the use of GIS data and OS/OW vehicle information to analyze the distribution of overweight vehicle trips on Texas' Farm-to-Market (FM) roads, highlighting that the Atlanta and Pharr districts bore the highest volumes of overweight permitted loads. Additionally, significant trips with GVWs between 120,000 and 150,000 lbs. were noted in the Odessa, Atlanta, and Pharr districts, while Abilene's FM roads predominantly carried loads over 200,000 lbs., linked to local wind farm development. Major origin-destination analysis pinpointed Houston, Dallas, Fort Worth, and El Paso as key hubs for OS/OW load traffic, with Houston experiencing notable traffic due to the Port of Houston activities. Traffic flow between Oklahoma and New Mexico via the Texas Panhandle was also significant. The study suggested reviewing district's *One-Year Plans* to assess the impact of the OS/OW fleet on off-system roads, aiming to align infrastructure planning with anticipated construction and/or maintenance projects.

2.3 Rider 36: Oversize and Overweight Permit Fee Study (Prozzi et al., 2012)

The 82nd Texas Legislature required TxDOT to conduct a study to evaluate the pavement and bridge consumption by OS/OW vehicles, including those exempt vehicles at the time (i.e., vehicles carrying agricultural products, solid waste or recycled materials, ready-mix concrete, and milk) (Prozzi et al., 2012). This study, also referred to as Rider 36 Study, was one of the most comprehensive analyses carried to date involving quantifying and pricing pavement and bridge associated costs due to permitted trucks. Some of the challenges of this analysis included the development of a methodology to assess the non-routed vehicles, and propose a fee adjustment to equalize the revenue from OS/OW permits and the expenditures on infrastructure maintenance. The proposed fee adjustment also had to account for costs associated with non-compliant vehicle dimensions, most associated with damage to bridges and other highway appurtenances.

The bridge analysis employed fatigue concepts with different methodologies to obtain VMT for routed and non-routed permits. For the assessment of routed permits, bridge data was integrated into a GIS platform. This facilitated the selection of representative OW vehicle configurations, which were then mapped onto specific routes to calculate the VMT. Conversely, for non-routed permits, a Monte Carlo simulation approach was adopted. This method involved the stochastic assignment of routes to representative permitted vehicles, based on annual mileage estimations[2]. The methodology for bridge consumption was based on live load bending moments relative to the existing inventory rating load for each given bridge.

The pavement analysis was done in terms of equivalent consumption factor (ECF), a mechanistic-empirical modular approach based on the additional deterioration caused by OW vehicles. The ECFs were developed for different pavement structures, varying between surface treatment pavements (STP), asphalt concrete pavements (ACP), jointed concrete pavement (JCP), and continuous reinforced concrete pavements (CRCP). Also, each ECF model was tailored to different failure criteria, such as fatigue cracking, rutting, transverse cracking, faulting, number of punchouts and roughness[3].

The calculation of pavement consumption costs was based on the concept that permit fees should cover the costs associated with increasing the structural capacity of the pavement network to support the OW fleet. The recommended average permit fee was 3.7 cents per ESAL per mile for rigid pavements and 2.9 cents per ESAL per mile

[2]Estimates were obtained through meetings with practitioners from both TxDOT and TxDMV.

[3]Roughness is not a distress mechanism, but rather a measure of riding quality for a given highway facility as perceived by drivers. However, it is directly connected to the operational cost of the roadway.

for flexible pavements.

The Rider 36 contained a comprehensive examination of rate/VMT fees tailored for over-width, over-height, and over-length vehicles, incorporating case studies to illustrate the calculation of consumption and impact costs, which led to the proposal of a new permit fee structure. The analysis of permit fee calculations revealed potential additional costs, identifying an estimated $60.1 million (in 2012 dollars) that could be integrated into permit fees. Furthermore, extra costs were identified amounting to $10.5 million (in 2012 dollars), directly related to OS/OW vehicle operations, yet these costs were deemed non-assignable to permit fees. The study also explored costs linked to OS/OW permit fee administration, enforcement, and legal proceedings, assessing their potential inclusion in permit fees. The primary outcomes and recommendations derived from the Rider 36 Study are summarized as follows:

- Streamline the permit fee structure by consolidating the various existing permit types and eliminating industry-specific permits. This approach would not only simplify the system but also minimize the introduction of new permit types for vehicles exempt from such fees;

- Implement a Pavement and Bridge Consumption fee system based on VMT for all permits;

- Implement an Operations and Safety fee system based on VMT for assessing permit fees for OS vehicles;

- Apply the Consumption and Operations and Safety fee schedule to all permits. If the existing permit system and permit types are continued, infrastructure operations and safety impact rates would need to be determined to calculate fees for all permit types, as applicable;

- Apply a $10 administration fee to each permit sold;

- Include a $40 TxDOT base fee for each permit sold to help recover additional costs associated with OS/OW operations;

- Create an OS/OW and Heavy Vehicle Training, Education, and Study Center, funded by a portion of the new permit administration fee;

- Exclude certain exemptions from consideration for a permit fee; and

- Identify the counties in which OS/OW permitted vehicles are intended to operate on every permit.

Additionally, the Rider 36 study identified eight other elements that require further consideration, analysis, or research and that could be addressed by the proposed "OS/OW Study Center":

- Gather additional information from the trucking industry on issues and needs related to OS/OW vehicle operations, including an assessment of the economic advantages of these vehicles to integrate these benefits into the permit system framework;
- Continue evaluating methods for incorporating legally loaded heavy vehicles and OS/OW permitted vehicles into the Safety Improvement Index contained in TxDOT's Highway Safety Improvement Program Manual, particularly in cases where rural roads are frequently used for permitted loads;
- Evaluate vehicle configurations and loads that may result from the combination of a temporary registration permit and the agricultural 12 percent over-axle tolerance exemption;
- Develop methods to evaluate and quantify increased pavement and bridge consumption due to super-heavy loads that may not be visually evident from a distress survey of the permit route;
- Conduct further research to evaluate the current OS/OW fine structure and identify policies and processes that improve the effectiveness of fine administration in discouraging illegal overweight truck operations on Texas roads and bridges; and
- Perform analyses to determine the types of information that should accompany each permit purchase to support the development of improved pavement and bridge consumption models, thereby enhancing infrastructure operations and safety.

2.4 Effects of Overweight Vehicles on New York State Infrastructure (Ghosn et al., 2015)

In 2015, the New York State Department of Transportation (NYSDOT) conducted a study to assess the effect of OW vehicles on the state's infrastructure, specifically focusing on pavement and bridges (Ghosn et al., 2015). The study involved an in-depth data mining procedure utilizing weight-in-motion (WIM) data.

A decision tree was developed to distinguish between a Dual Vehicle (DV) and a Single Haul (SH) by analyzing axle weight and axle spacing. Vehicles that did not fit into these specified categories were then identified as illegal (IL). During the study, it was observed that a truck identified as *illegal* was indeed illegal. However, there was no guarantee that a truck labeled *potentially with a permit* actually had a permit. Additionally, if a truck met the criteria for both DV and SH classifications simultaneously, it could be categorized as either DV, SH, or potentially IL. The pattern recognition algorithm alone could not determine which trucks labeled as having permits were truly permitted and which ones were illegal but resembled permitted trucks. Therefore, a statistical Bayesian updating procedure was employed to estimate the percentage of illegal trucks using the WIM data.

Because many illegal trucks had weights and configurations like those of permitted trucks, it was expected that the final algorithm would misclassify many illegal trucks into permit truck categories. In order to estimate the percentage of illegal trucks that could be wrongly categorized as permitted trucks, a database of illegal trucks provided by NYSDOT was assembled, and a pattern recognition algorithm was utilized. It was found that the 95.2 percent was classified as unknown permits (UP), 1.1 percent of the trucks were classified as DV, and 0.7 percent as SH. The remaining 3.0 percent were properly identified as IL.

A sensitivity analysis was also performed to assess the effect of WIM errors in axle spacing and axle weight. It was determined that WIM systems produced a standard error less than 10 percent on both the axle spacing and the axle weights, leading to reasonably accurate estimation of the percentages of illegal and permitted trucks.

For the bridge analysis, the study evaluated the effect of OW vehicles over a representative sample of 55 bridges. This sample was taken from a population of about 14,500 simple span bridges and 495 continuous bridges. Special bridges types such as culverts, trusses, arches, movable, suspension and long span bridges were excluded from the analysis because, according to the authors, those were less prone to be damaged by individual OW trucks. The damage on bridges is usually associated with the cost to increase the structural design to carry those heavier vehicles. However, because of the inherent presence of reserve strength capacity in bridge design standards, most OW vehicles do not lead to bridge collapse, but they increase the risk of failure by reducing the built-in safety margin. Thus, the cost allocation approach in the study was based on safety margin utilization (SMU) cost. Two failure mechanism for bridges were considered: *overstress*, which is the damage caused by a single application of a heavy load that exceeds the live-load design limits; and *fatigue life*, which regards the cumulative damage caused by low levels live-load, but with a high number of loading cycles.

The AASHTO HS-20 truck was used as the baseline for comparison because most existing New York State bridges were designed to meet the AASHTO standard design. Also, the HS-20 load is the base line for the determination of the truck legal load limits from the Federal Bridge Formula (FBF). Thus, the overstress and the fatigue effects of each OW truck were calculated and compared to the effects from the HS-20 load. The fatigue analysis was performed for the main structural longitudinal member of the bridge and for the deck. A flowchart for the bridge analysis is depicted in Figure 1.

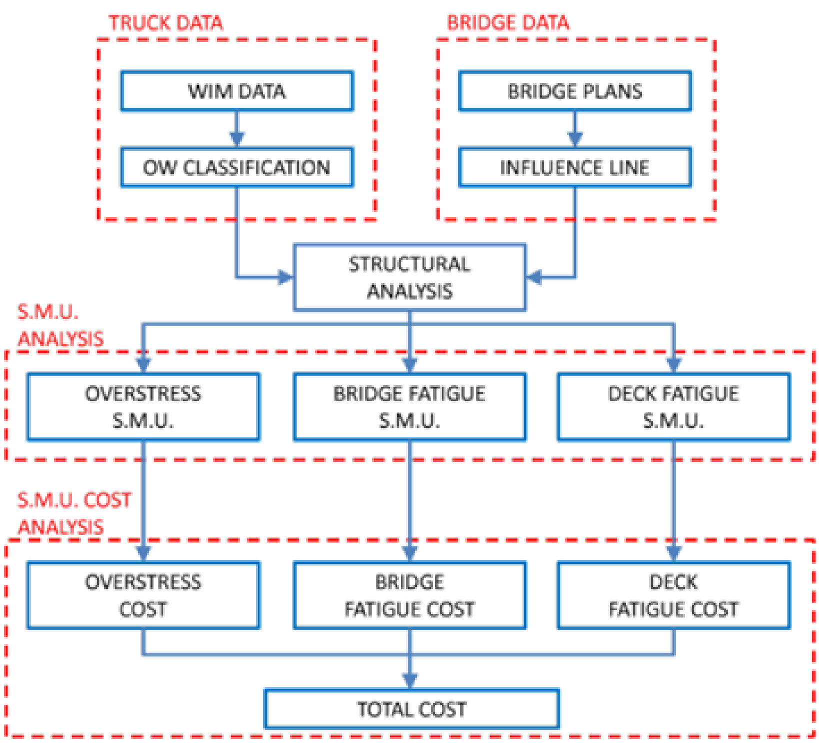

Figure 1: Procedure to analyze the effect of OW vehicles on bridges (Ghosn et al., 2015)

The bridge fatigue analysis specifically targeted steel bridges, where the predominant damage exhibits a third-power relationship between stress and damage. The resistance to fatigue relies on both the stress range and the frequency of loading. Therefore, design provisions incorporate a factored "fatigue design truck" with calibrated axle spacing and factored axle weights to induce equivalent fatigue damage as seen from typical truck spectra on standard bridge configurations. The stress range derived from the analysis under the influence of the design truck, combined with the anticipated number of trucks crossing the bridge throughout its service life, was utilized to estimate cumulative fatigue damage and ensure it remained below one, adhering to Miner's rule[4].

The bridge associated cost models were developed for each material type, considering the two failure criteria: overstress and fatigue (on the deck and on the beam). One important assumption during this analysis was that the labor cost was equal to the material cost. Furthermore, it was necessary to divide the state into upstate and downstate counties, because the types of permits allowed in each region were different. The total cost due to OW vehicles for upstate counties' bridges was estimated to be $58.5M per year, including DV ($9M per year), SH ($1.5M per year), and IL ($48M per year). In downstate counties, the total cost was equal to $36.5M per year, including DV ($2.0M per year), SH ($0.5M per year), and IL ($34.0M per year). The total cost for the entire state of New York bridge network was equal to $95M per year. The average cost was $5.29 per truck crossing of a typical upstate bridge and $3.15 per truck crossing of a downstate bridge.

For the pavement analysis, the traffic load was also obtained from WIM data, using the same algorithm to differentiate between permit categories. The method proposed by NYDOT to compare the effects of OW trucks was based on two scenarios. The first scenario considered all the mixed traffic including the OW trucks, while the second scenario considered an *ideal scenario* where all the cargo currently transported by OW trucks were re-distributed to non-overweight trucks[5]. The pavement analysis procedure consisted of the following steps:

1. Identify the pavement section to be analyzed and its characteristics, including Average Daily Truck Traffic (ADTT), number of lanes, section length, and width;

2. Design a pavement section for current truck weights using the ESAL method;

3. Determine the required number of maintenance cycles under current truck traffic using the MEPDG method:

    (a) Determine truck configurations based on WIM data;

[4]Miner's rule assumes that the damage done by each stress repetition at a given stress level is equal, meaning the first stress cycle at a uniform stress level is as damaging as the last. Thus, when the sum of damage fractions is equal to 1.0, it means that it reached failure

[5]It is important to note that this is a strong assumption, since the damage done to pavement is exponentially related to the axle load, as presented by the Forth Power Law during the AASHO Road Test (HRB, 1962). This assumption could underestimate the overall effect of OW trucks

(b) Determine MEPDG input parameters; and

(c) Perform MEPDG analysis to determine the time at which corrective maintenance is required.

4. Repeat Step 2 for an "idealized scenario" with no OW trucks.

5. Repeat Step 3 for the "idealized" traffic scenario traveling over the pavement designed in Step 4.

6. Calculate incremental costs:

   (a) Define material costs for design;

   (b) Define maintenance costs; and

   (c) Determine the difference between the costs associated with Steps 2 and 3 and those associated with Steps 4 and 5.

For the purposes of the NYDOT study, both flexible and rigid pavements were considered. In New York, flexible pavements are typically surfaced with hot-mix asphalt, while rigid pavements are typically jointed plain concrete pavements. At the time this study was conducted, the state's pavement design procedures were based on an adapted version of the AASHTO 1993 Pavement Design Guide (AASHTO, 1993). Average truck equivalency factors of 1.35 and 1.85 were used for flexible and rigid pavements, respectively. The redistribution of weights from overweight trucks to legal trucks was performed only for vehicles with ESAL values exceeding the maximum ESAL of a typical legal truck.

For the costs associated with pavements, a life cycle analysis using MEPDG[6] was performed to estimate the costs of maintenance and rehabilitation. Due to the highly computationally demanding nature of the MEPDG, it was impractical to conduct analyses on every truck traversing each segment of the NYDOT highway network. To overcome this issue, a sampling method was adopted. The approach involved categorizing trucks based on the FHWA Class type and their weight classifications into four distinct groups: non-overweight trucks (NO), trucks authorized with permits for divisible loads (DV), trucks granted special hauling permits (SH), and those operating illegally (IL).

The cost analysis considered the incremental approach, which estimates the cost to adjust the pavement thickness that would be required to accommodate OW trucks while

[6] Coefficients and parameters usually calibrated with laboratory tests and used on performance models from the MEPDG were determined from available sources, such as reports, technical standards, and books.

keeping the design life constant. The implementation on the entire NYDOT pavement network showed that the cost due to OW trucks was on the order of $145M per year, with $78M per year allocated to DV permits, $7M per year allocated to SH permits, and the remaining $60M per year to illegal OW vehicles.

2.5 Pavement, Bridge, and Safety Cost Evaluation Tool for Overweight Truck Corridors Serving Coastal Port Regions and Border Ports of Entry (Walton et al., 2017a)

In 2017, the Center for Transportation Research (CTR) of The University of Texas at Austin conducted a study to develop a logical approach for assessing costs and formulating a permit fee structure for OS/OW freight corridors servicing Texas' coastal port areas and border regions (Walton et al., 2017a). This research analysis covered pavement and bridge wear and tear, as well as safety-related expenditures. Given the significant variation in truck sizes and weight limits among the three North American Free Trade Agreement (NAFTA) signatories (where Texas allows over 20 distinct types of truck permits surpassing U.S. Federal Interstate limits) it was imperative to employ an engineering model capable of accurately estimating infrastructure consumption rates. This model needed to effectively reflect the toll charges applied to each truck by considering both axle weight and spacing to ensure fairness and precision in the fee structure.

The objective of the bridge analysis was to provide an estimate of the bridge consumptions costs per one-way trip per mile, at a policy level. The cost of any specific one-way route could be estimated by multiplying the unit cost by the respective route mileage. The methodology used was the one developed during the Rider 36 Study (please refer to Section 2.3). A detailed data mining was performed on Texas's bridge inventory to eliminate all parallel bridges, because this could artificially increase the cost since the truck consumes only one of the bridges in each pass.

The pavement analysis was also based on the methodology developed during the Rider 36 Study. A mechanistic-empirical analysis was performed, based on the concept of ECF, where each pavement section was assessed using the respective pavement type distresses. Since failure criteria do not happen at the same time, a weighing mechanism was required to proper address the fundamental engineering principles of pavement materials. For instance, rutting is more critical in warm climatic regions, while cracking is a dominant distress mechanism in colder regions. Besides climate conditions, geology also affects the type of subgrade support which in turn have a bearing on the pavement structural response and performance. For these reasons, it was important to design an experiment that accounted for the different pavement structures, traffic levels and environmental regions. OS/OW vehicle have atypical axle configuration due to the nature of its payload, which required the analysis to account for a broad range of different axle loads (with different configuration).

The permit fee structure, suggested as part of this study, was based on consumption of the infrastructure service life by OW truck traffic. No attempts were made to account for the economic benefits of increasing freight axle loads. The authors adopted an improved version of the proportional method for cost allocation, since it was understood that the most appropriate allocator would be related to the concept of equivalent consumption as it considers the weight characteristics of individual axles (which determines the consumption of service lives of highway facilities).

A key component of this entire procedure was obtaining reliable estimates for construction costs, which was addressed by referring to TxDOT's average low bid price portal. The calculated costs were determined at a dollar per ESAL per mile basis. The study team realized that there was no relationship between the calculated fees and the functional classification for the highway facilities, which encouraged them to obtain an average fee.

2.6 The Impact of Specialized Hauling Vehicles on Pavement and Bridge Deterioration (Walton et al., 2017b)

This study was performed to ensure that Texas complied with a FHWA requirement that each state had to certify either the non-permission operation of specialized hauling vehicles (SHV), or if permitted, the completion of bridge load rating analyses (Walton et al., 2017b).

A single-unit truck (SU) is designed with steering and drive axles on the same chassis. An SHV is essentially a modified SU with one to four extra liftable axles, either positioned ahead or behind the drive axles or mounted on a hydraulic system that extends the chassis length when loaded. These liftable axles are raised when the vehicle is empty or when entering a construction or storage site to unload. However, many liftable axles are caster-steered and tend to follow the track of the steering axle, potentially leading to tire scrubbing during turns, which can impact truck steering and stability. For this reason, drivers might lift part or all the liftable axles during a turn, which significantly increases the steer and drive axle tire loads on the pavement. Adding lift axles increases the allowable load by distributing the load across the axle groups. Also, various SHV configurations, most notably the SU7, adds a booster axle to extend the chassis length to meet the limits of the Federal Bridge Formula.

The study team developed and implemented a comprehensive data collection effort to characterize SHV operation in Texas. More than 53,500 trucks were visually identified and recorded in spreadsheet databases, sorted by type, configuration, number of axles (liftable axles, if any), route, and date of sighting. Based on the collected information, weight enforcement data from the Texas Department of Public Safety (DPS) was combined with TxDOT WIM data, and the average and standard deviation GVW were determined. Then, a representative SHV configuration was developed to quantify SHV deterioration effects on pavements, while comparing the damage done by standard truck configurations with legal axle load limits.

The study compared SHV configurations with HS20 and HL93 load configurations for bridges. It also included several analyses of SHVs, covering safety performance regarding crash history and operational characteristics, economic evaluations of SHV operations, and the formulation of a policy aimed at reducing impacts on bridge and pavement load posting requirements.

The methodology used to evaluate bridge consumption was based on the Rider 36 Study (Section 2.3), based on live load bending moments as surrogates for the stress range. This approach considered bridge consumption as a function of the deck area, deck cost, asset value per square foot of deck, bridge asset value responsibility in percentage, live-load bending moment for the inventory rating, the axle loads, the type of bridge material, and the number of allowable load cycles that define the bridge design life. The methodology for the pavement analysis was also based on the Rider 36 Study (Section 2.3), relying on the ECF concept.

2.7 Mechanistic-Based Pavement Damage Associated Cost from Oversize and Overweight Vehicles in Nevada (Hajj et al., 2017)

The Nevada Department of Transportation (NDOT) developed a pavement damage associated cost (PDAC) associated to OW vehicles that was based on locally-calibrated pavement distress models, existing pavement condition, different pavement repair options, and VMT. In this proposed methodology, the damage from OW vehicles were compared to the damage caused by a reference vehicle (Hajj et al., 2017).

The study utilized a database of ten-year NDOT permits with 367,595 entries. Thousands of actual OW permit forms describing GVW, axle configurations, and load details of permitted vehicles were analyzed. This enabled the identification and classification of trends related to GVW, axle loads, and other important characteristics of OW trucks in Nevada. NDOT categorizes OW vehicles based on their GVW, length, width, and height, which can lead to classifications such as over-dimensional vehicles (ODV), shorter overweight vehicles (SOV), and longer combination vehicles (LCV).

This report specifically focus on the impact of OW vehicles on pavement performance, as it is assumed that the costs related to lighter vehicles (with a GVW less than 80,000 lbs) are already covered by regular funding sources like fuel taxes. In Nevada, a single-trip permit allows the movement of a specific OW vehicle for one pass within a limited number of days. In contrast, multi-trip permits allow OW vehicles to operate without trip restrictions for the entire duration of the permit. While issuing multi-trip permits streamlines the permit processing for state DOTs, they encounter challenges in tracking crucial information such as the number of trips made, VMT, routes taken, and timing of trips. This information is crucial for evaluating pavement-related costs.

The pavement analysis considered only flexible pavements, characterized by an asphalt layer on top of a flexible granular base, followed by a semi-infinite subgrade. Different pavement structures were used to represent typical pavement sections from NDOT highway network. The methodology proposed in this study was based on the cost-occasioned method that estimates pavement associated costs using a mechanistic-empirical approach. The PDAC was based on vehicle axle configuration, and considers the predicted pavement life reduction due to a single pass of OW vehicles. Other inputs from this method are the present worth value of repairing costs (PWV) and the VMT. To estimate the PDAC, distress performance models were used for both OW and reference vehicle loading. The reference vehicle was an 18-wheeler truck loaded with a GVW of 80,000 lbs., equipped with one steering axle with 12,000 lbs. and two tandem axles with 34,000 lbs. each.

Pavement structural responses were obtained by conducting over 8,000 3D-Move Pavement Analyses on generic pavement structures. The vertical compressive strain at mid depth of the asphalt concrete layers and maximum horizontal tensile strain at bottom of AC layers were evaluated for asphalt rutting and fatigue cracking, respectively. The analysis of structural responses considered only the peak value for each axle group to be used with the respective pavement performance model. The concept of LEF was expanded to develop a mechanistic-empirical LEF following Equation 2.1.

$$LEF = \frac{N_{18,000}}{N_{axle}} \tag{2.1}$$

Where N_{18} is the number of repetitions to failure associated with the reference vehicle, and N_{axle} is the number of repetitions to failure at the same threshold criterion for a given axle load. The procedure used to estimate the PDAC is presented below:

1. Damage curves based on performance models for the failure mechanisms were developed for both OW and reference vehicles.

2. The number of reference vehicle (RV) loading cycles required to reach the failure criterion threshold is defined as $N_{f,RV}$.

3. The amount of distress (or damage) caused by the RV after X loading repetitions, $N_{x,RV}$, is determined as $d_{RV:X}$.

4. The number of OW loading repetitions required to cause an equivalent amount of distress as the RV is determined from the OW vehicle damage curve and defined as $N_{OW:eq}$.

5. The damage caused by an additional OW pass (or loading cycle), defined as $d_{OW:eq+1}$, is converted back into equivalent RV loading cycles, $\Delta N_{RV:eq}$, allowing the calculation of pavement life reduction (LR), as shown in Equation (2.2).

$$LR = \frac{\Delta N_{\mathrm{RV:eq}}}{N_{f,\mathrm{RV}}} \tag{2.2}$$

6. The pavement service life (n) in years is determined using Equation (2.3).

$$n = \frac{N_{f,\mathrm{RV}}}{\mathrm{AADT} \times 365} \tag{2.3}$$

7. The present worth value (PWV) is then calculated by adjusting the future repair cost (RC) at the time the failure threshold is reached to present dollars using Equation (2.4).

$$PWV = \frac{1}{(1+i)^n} \times \text{RC} \tag{2.4}$$

8. The remaining service life (RSL) of the pavement at the time of the OW movement is a function of the year in which the OW movement occurs (OW_{year}), the year of the last structural repair ($LastRepair_{year}$), and the year of the next scheduled structural repair ($NextRepair_{year}$), as shown in Equation (2.5).

$$RSL = 1 - \frac{OW_{year} - LastRepair_{year}}{NextRepair_{year} - LastRepair_{year}} \tag{2.5}$$

9. Finally, the PDAC is calculated as the product of PWV, LR, and RSL, as presented in Equation (2.6).

$$PDAC = PWV \times LR \times RSL \tag{2.6}$$

Single-trip permits were easier to track, since part of the permit requirements is to provide a route identification, which helps to estimate the pavement damage deterministically. Conversely, multi-trips permits were addressed with a probabilistic approach through Monte-Carlo (MC) simulations. A MC produced distributions of possible outcomes values for LEF and PDAC, based on different routing scenarios, GVW, axle configuration, axle weight, and pavement structure. After each simulation step, the number of repetitions to reach either rutting or fatigue cracking failure were calculated for OW and the RV.

In the probabilistic analysis, three functional road classes were taken into consideration: freeways, major arterials, and collectors. It was assumed that OW vehicles do not operate on roads of lower functional class and structural capacity, such as local roads. Based on the last Nevada's cost allocation study, freeways were exposed to 59 percent the of overall OW VMT, making them the most common road type in which those vehicles operated. Also, regular traffic VMT is almost equally divided between other road categories, with 20 percent and 21 percent on major arterials and collectors, respectively. This VMT distribution was used to randomly assign a road functional class in each simulation step. The probabilistic analysis on PDAC using MC simulations revealed that the pavement associated costs clearly depended on the structural capacity of each pavement section.

To exemplify the methodology, a vehicle with 145,000 lbs., 6 axles and 12 ft. wide, assuming the climate station in Las Vegas and a VMT of 2,000 per trip, the median values from the probabilistic simulation resulted in a PDCA of **$135.43 per trip for**

rutting, and **$692.11 per trip for fatigue cracking**. Each OW vehicle, along with its corresponding climate station and VMT, could yield a distinct PDCA value. This is why the authors chose not to summarize average values of their findings across the entire OS/OW permit spectrum, even after multiple iterations.

2.8 Overweight Permit Fee Structure Development in Arizona (Vlahos, 2018)

This study conducted by Arizona Department of Transportation (ADOT) aimed at assessing the policy on OW non-divisible loads in sealed shipping containers on the Interstate Highway System between the Mariposa Port of Entry and the Port of Tucson (Vlahos, 2018). The entire length of IH-19 was in the study corridor, as is the portion of IH-10 between Exit 260 (IH-19) and Exit 269. The intermodal terminal at the Port of Tucson is located at the northern end of the study corridor, and there is an intermodal connection to the Union Pacific railroad at the Port. This project tackled three primary questions: firstly, it addressed whether the estimated infrastructure cost reflects the damages ADOT would face by permitting heavier vehicles in the study area alongside the current flow of permitted non-divisible vehicles; secondly, it explored the fees required to recover the costs associated with any infrastructure impacts; and thirdly, it examined potential techniques and technologies to ensure compliance in the study corridor if a permit program were to be implemented.

The pavement and bridge analyses considered five possible permit scenarios: (1) a base case considering a vehicle with 80,000 lbs. and five axles, (2) a vehicle with 90,800 lbs. and five axles, (3) a vehicle with 97,000 lbs. and six axles, (4) a vehicle with 98,000 lbs. and five axles, and (5) a vehicle with 120,000 lbs. and six axles. The pavement analysis was performed using the AASHTOWare software in conjunction with Arizona's local calibration factors listed in the ADOT SPR-606 Report (Darter et al., 2014).

For the bridge analysis, eight sample structures were considered and subjected to a load rating analysis based on the load factor method using the LEAP ConBox® (Bentley Systems) and AASHTOWare Bridge software programs. The ConBox® software was used for structures with post-tensioned box girders, while the AASHTOWare Bridge program was used for the remaining structures. Data for each sample structure were obtained from ADOT. Unlike the pavement analysis, which applies the full traffic distribution to the infrastructure, the bridge structural analysis evaluates each vehicle individually. The load rating analysis assessed structural impacts using inventory and operating load rating factors. The following definitions guided the analysis and interpretation of the results:

- **Inventory load rating** measures the maximum load that can safely use the structure for an indefinite period.
- **Inventory load rating factor** is defined as the ratio of the inventory rating load that the structure is designed to carry without adverse impacts to the inventory rating load of the assumed vehicle configuration scenario.
- **Operating load rating** represents the maximum permissible live load that can be placed on the structure.
- **Operating load rating factor** is defined as the ratio of the operating rating load that the structure is designed to carry without adverse impacts to the operating rating load of the assumed vehicle configuration scenario.

Inventory and operating load rating factors below 1.0 indicate that the structure would experience adverse impacts from the addition of the vehicle to the system. Because none of the bridges had been posted to restrict travel to legal-weight vehicles at the time of the analysis, both inventory and operating load rating factors were assumed to exceed 1.0. The specific magnitude above 1.0 was not considered critical; for example, rating factors of 1.03 and 1.11 both indicate the absence of adverse effects. A permit scenario was therefore considered to have adverse impacts if the scenario vehicle resulted in a rating factor of less than 1.0.

Given the characteristics of the network in the study area (and the lower levels of damage in cases for which infrastructure replacement was not an option), a simplified approach focused on the maintenance and rehabilitation options available to alleviate the expected damage from the permitted vehicles. A total damage cost ranging from 5.16 to 5.38 (in 2017 dollars) per permitted truck, per direction, was estimated. Of this total, 0.03 was attributed to bridges, while 5.13 to 5.35 was attributed to pavements. These estimates differ substantially from those reported in most comparable studies.

It is important to note that this study assumed steady traffic levels throughout the year because the ADOT data were aggregated and averaged. As a result, permit volumes were estimated for all 365 days rather than a more realistic 250 operating days. However, the total costs were also distributed across a larger number of permits. Although assuming year-round permitted traffic may slightly increase the estimated costs, this effect is minor and does not meaningfully affect the overall accuracy of the results given the level of precision in the available traffic data.

2.9 Best Practices in Permitting OS/OW Vehicles (Schaefer and Todd, 2018)

This study provides an extensive literature review focused on State OS/OW permitting to identify best practices, including automated permitting systems and pilot escort certification (Schaefer and Todd, 2018). The survey of automated permitting systems identified functionalities common to all or most states. All states include permanent and temporary route restrictions in their permit routing algorithms and all include height restrictions.

The states either use “minimum of the maximum” height thresholds for bridges with variable lane heights, or do not auto-issue permit for these types of structures. All systems included edit checks based on existing state rules that ensure permit applications are linked to the correct type of permit. Each State’s system also includes a library function that allows carriers to store company data, power unit and trailer configuration information, and previously issued permits. Some States have also developed State-approved routes for certain types of loads that motor carriers may also use when requesting permits. Nevertheless, there is significant variation between states regarding local roads and local permit requirements. While most states include local roads on their state road maps, very few issues “local” permits. A broad comparison of the permit’s structure between states near Texas is presented in Table 2.

Table 2: Summary of OS/OW state information scan

Permit System Feature	**TX**	**KS**	**IA**	**CO**	**NE**	**IL**
Map with complete State and local roads	✓	✓	✓	✓	*NA*	✓
Ability to issue local permits	*NA*	*NA*	*Pilot test*	*Pilot test*	*NA*	*NA*
Embedded link to local permit information	*NA*	*NA*	✓	*NA*	*NA*	✓
Separate link to local permit information	*NA*	*NA*	*NA*	✓	✓	*NA*
Auto-routing around route restrictions	✓	✓	✓	✓	✓	✓
Permanent route restrictions identified on map	✓	✓	✓	✓	✓	✓
Temporary route restriction information updated to system as received	✓	✓	✓	✓	✓	✓
Height threshold included in system - permanent and temporary	✓	✓	✓	✓	✓	✓
Edit checks linking permit application with correct permit type	✓	✓	✓	✓	✓	✓
Library function including carrier information, power, units, trailer, configurations, and previous permits	✓	✓	✓	✓	✓	✓
Electronic payment	✓	✓	✓	✓	✓	✓
Notice of changes in route restrictions and permit status issued to all holders of open permits	✓	✓	✓	✓	*NA*	✓

2.10 HB-2223 Study of Motor Vehicle Impacts on the Roads and Bridges of Texas (Prozzi et al., 2022c)

The 87th Texas Legislature passed House Bill 2223 (HB 2223) to study the impact of certain classifications of motor vehicles on Texas roads and bridges (Prozzi et al., 2022c). The framework established during the Rider 36 Study has since been the standard to evaluate and quantify the impact that OW vehicles on the Texas surface transportation network. Thus, the HB 2223 study could be considered a continuation of Rider 36, updating previous models to capture more pavement types and their respective main failure mechanisms. One important aspect from the HB 2223 study was the use of an extensive *pavement design library*, with detailed structural information, provided by TxDOT Maintenance Division with actual projects built from 2017 to 2021, that allowed the project team to conducted more realistic mechanistic-empirical analyses.

The pavement consumption evaluation was based on the ECF concept. For flexible pavements, the responses and performance were computed through the AASHTOWare software. For rigid pavements, a finite element analysis was used to compute stresses and strains. The critical pavement responses were then correlated to field distresses using empirical relationships (transfer functions) calibrated based on field observations.

The bridge consumption methodology was based on bridge fatigue concepts, established during Rider 36, maintaining consistency across the various aspects of the analysis. The concept was applied to 20 representative vehicle configurations, including commercial and OS/OW vehicles. Furthermore, separate analysis were conducted for routed and non-routed permits. For the latter, because the routes were not known, segments were randomly assigned using a MC simulation to approximately fulfill the established annual mileage for each representative traffic configuration, obtained by educated estimates with TxDMV. The MC simulation selected road segments from the database using a SAS™ computerized routine to generate a set of approximately 20,000 annual miles of road segments with the respective bridges. Each run repeats the MC simulation four times[7].

Bridge density (bridge count per road segment) was also relevant during the consumption calculations. Statistical analyses of bridge count per mile showed a significant difference in bridge density for East and West Texas counties. To properly consider this issue, two separate analysis was conducted, one for East and one for West Texas counties. The total consumption cost are presented in Table 3 and Table 4 for commercial

[7]The number of repetitions was determined through a sensitivity analysis and it was verified that four runs resulted in similar bridge consumption.

and OW vehicles respectively.

Table 3: Consumption costs due to commercial and OS trucks

Commercial Motor Vehicles	**Pavement Consumption (per mile)**	**Bridge Consumption (per mile)**
Class 4	$0.06	$0.01
Class 5	$0.0027	$0.00085
Class 6	$0.04	$0.02
Class 7	$0.08	$0.06
Class 8	$0.02	$0.01
Class 9	$0.08	$0.03
Class 10	$0.09	$0.04
Class 11	$0.08	$0.03
Class 12	$0.05	$0.00
Class 13	$0.10	$0.04

Table 4: Consumption costs per mile due to OW vehicles

Permit Type	**Category**	**Pavement Consumption (per mile)**	**Bridge Consumption (per mile)**
General	80,000 - 120,000 lbs	$0.61	$0.13
	120,001 - 160,000 lbs	$0.65	$0.22
	160,001 - 200,000 lbs	$0.66	$0.43
	200,000 - 254,300 lbs	$1.02	$0.66
Hubometer	5-axle (120,000 lbs)	$0.98	$0.18
	6-axle (114,000 lbs)	$0.46	$0.14
Envelope	Company	$0.61	$0.13
	Truck	$0.61	$0.13

Of the 14 OW permit types issued by TxDMV, four categories (General, Hubometer, Envelope Truck- and Company-specific) accounted for 95.8 percent of the permits and 90.7 percent of the VMT and, therefore, only these OW permit types were assessed during the study.

2.11 HB-2319: Study Concerning Permit for Intermodal Shipping Container in Texas-Arkansas Border (Prozzi et al., 2022a)

This study was conducted to evaluate the impacts of permits issued under the provisions of House Bill 2319 (HB 2319) of the 85th Texas Legislative Session, as implemented under Texas Transportation Code, Chapter 623: *Permits for Oversize or Overweight Vehicles* (Prozzi et al., 2022a). The House Bill 2319 addresses the movement of vehicles transporting *intermodal shipping containers* (ISC). Specifically, the bill authorizes the TxDMV to issue an annual permit for the international transportation of an ISC moved by a truck-tractor and semitrailer combination with six total axles, provided that the following conditions are met:

- The gross vehicle weight of the combination does not exceed 93,000 lbs.;
- The longitudinal distance between the front axle of the truck-tractor and the last axle of the semitrailer is approximately 647 in.;
- The truck-tractor is configured as follows:
  - One single axle not exceeding 13,000 lbs.;
  - One two-axle group not exceeding 37,000 lbs., with no axle in the group exceeding 18,500 lbs.; and
  - A longitudinal distance between the individual axles of the two-axle group of not less than 51 in. and not more than 52 in.;
- The semitrailer is configured as follows:
  - One three-axle group not exceeding 49,195 lbs., with no axle in the group exceeding 16,400 lbs.; and
  - A longitudinal distance of 60 in. between the individual axles of the three-axle group.

The pavement analysis was based on the HB 2223 Study, using the concept of ECF where pavement consumption is expressed in relative terms to the consumption of the pavement by an ESAL. Each pavement was designed to reach terminal distress values under a given traffic and environmental conditions by the end of its design period (typically 20 years). However, due to inherent differences in the failure mechanisms, it is impossible to reach all terminal distress levels simultaneously at the end of the design period. Thus, it was necessary to determine the traffic volume that would result in a terminal distress value for each of the failure criteria separately and then obtain a weighted average. Considering the GVW limits, the six-axle configuration and axle-loads, a sensitivity analysis that considered four possible load distributions (capturing extreme cases) was performed. The results average consumption cost from from HB 2223 was used as reference and applied to the 93,000 lbs. six-axle vehicle, resulting on a consumption cost of $0.19 per mile.

The methodology for bridge consumption treated each passage of the representative vehicle configuration (axle loads and spacings) as a fractional consumption of the bridge's design life. This methodology was also based on the HB 2223 study. One pass of the proposed vehicle configuration resulted in a bridge consumption of $3.78. Dividing this by the mileage of the segment (2.5 miles), the bridge consumption cost per mile for this segment was $1.51. This value could then be combined with the pavement consumption calculated to achieve a total consumption cost per mile for the specific vehicle configuration of this Bill.

2.12 SB-1524: Study Concerning Vehicles Operating under ISC Permit (Prozzi et al., 2022b)

This study was conducted to evaluate the impacts of permits issued under the provisions of Senate Bill 1524 (SB 1524) of the 85th Texas Legislative Session, as implemented under Texas Transportation Code, Chapter 623: *Permits for Oversize or Overweight Vehicles* (Prozzi et al., 2022b). The Senate Bill 1524 addresses the movement of vehicles transporting ISC, which authorizes the TxDMV to issue a $6,000 annual permit for motor carriers to transport a sealed ISC using a truck-tractor and semitrailer combination that meets one of the following configurations:

1. A truck-tractor and semitrailer combination with six total axles with a GVW not exceeding 93,000 lbs., and meeting the following requirements:
    - The longitudinal distance between the front axle of the truck-tractor and the last axle of the semitrailer is approximately 647 in.;
    - The truck-tractor is configured as follows:
        - One single axle not exceeding 13,000 lbs.;
        - One two-axle group not exceeding 37,000 lbs., with no axle in the group exceeding 18,500 lbs.; and

- A longitudinal spacing between the individual axles of the two-axle group of not less than 51 in. and not more than 52 in.;

- The semitrailer is configured as follows:
  - One three-axle group not exceeding 49,195 lbs., with no axle in the group exceeding 16,400 lbs.; and
  - A longitudinal spacing of 60 in. between the individual axles of the three-axle group.

2. A truck-tractor and semitrailer combination with seven total axles with a GVW not exceeding 100,000 lbs., and meeting the following requirements:
   - The longitudinal distance between the front axle of the truck-tractor and the last axle of the semitrailer is approximately 612 in.;
   - The truck-tractor is configured as follows:
     - One single axle not exceeding 15,000 lbs.;
     - One three-axle group not exceeding 44,500 lbs., with no axle in the group exceeding 14,900 lbs.; and
     - A longitudinal spacing between the individual axles of the three-axle group of not less than 51 in. and not more than 52 in.;
   - The semitrailer is configured as follows:
     - One three-axle group not exceeding 46,200 lbs., with no axle in the group exceeding 15,400 lbs.; and
     - A longitudinal spacing of 60 in. between the individual axles of the three-axle group.

A permit issued under SB 1524 does not authorize operation of a truck-tractor and semitrailer combination on the Interstate Highway System or on load-restricted roads or bridges, including any roadway or bridge for which a maximum weight or load limit has been established and posted by TxDOT. Accordingly, Interstate bridges were excluded from the bridge consumption calculations.

The pavement consumption analysis was based on the HB 2223 study (Section 2.10), using the concept of ECF, where pavement consumption was expressed in relative terms to the consumption of the pavement by an ESAL. Three failure criteria were considered on the HB 2223 study for flexible pavements and three for rigid pavements. However, from a practical point of view, a given axle configuration and load should have a single ECF, and not three. A weighing mechanism should consider fundamental engineering principles such as the prevailing distress mechanism, climate conditions and pavement type. The inherent variability of ECFs was another key concern. For instance, an ECF calculated using the rutting criteria could result in a lower standard error (that is, lower uncertainty) as compared to an ECF obtained using the cracking or roughness criteria, which were predicted with the highest uncertainty. Thus, the authors of this study recommend that ECFs with lower variability receive a relatively higher weight in these instances. In analyzing the corridors subject of this Bill, the ECFs utilized correspond to the 84th percentile value that was obtained as the average value plus one standard deviation.

The methodology for bridge consumptions treated each pass of the representative vehicle configuration (axle loads and spacings) as a fractional consumption of the bridge's design life. This methodology was also based on the HB 2223 study. The average consumption cost for the six- and seven-axle vehicles were \$0.19/mile and \$0.16/mile, respectively.

2.13 Background Summary

This section presents a comprehensive review of truck permitting literature published over the past two decades. The review examined both state and federal technical and research reports to gain insight into how transportation agencies and engineers assess pavement and bridge consumption rates, as well as how the associated costs are incorporated into truck permitting frameworks. The key findings from the literature review are summarized below:

- For a given distance traveled and GVW, pavement damage costs decrease significantly as the number of axles increases, following a nonlinear relationship.
- An effective pavement consumption model should account for the full range of failure mechanisms for each pavement type. This may be achieved through a weighted average or other appropriate engineering methodologies to ensure a comprehensive evaluation.
- Analyses of non-routed permits often employ probabilistic approaches informed by the experience of DOTs and transportation engineers. Empirical knowledge of traffic behavior, combined with predictive modeling, is essential for producing reliable estimates.
- Most studies rely on the concept of relative damage, evaluating pavement impacts in terms of ESALS, and bridge impacts relative to a design vehicle.

- Weigh-in-motion data play a critical role in characterizing truck configurations, achieving standard errors of less than 10 percent for both spatial and axle load measurements. However, determinations regarding the legal status of trucks (permitted versus non-permitted) are often based on authors' empirical judgment.

- Mechanistic–empirical pavement design and analysis software, such as AASHTOWare, has been shown to produce highly informative results. These evaluations, which typically rely on linear elastic assumptions, are considered reasonable for the stress and strain levels commonly observed on highway pavements.

- Incremental analysis approaches, even with minor modifications, have been identified as direct and effective methods for quantifying the economic impacts of OW vehicles on pavement and bridge infrastructure.

- Several studies recommend allocating a small portion of truck permit fees to fund a dedicated committee responsible for monitoring OS/OW permit compliance. Such efforts can support continued research and improve understanding of OS/OW impacts on infrastructure assets, ultimately enhancing infrastructure management.

3. CURRENT TRUCK PERMITING PRACTICES IN TEXAS

Texas has specific size and weight thresholds for vehicles and loads traveling with or without an OS/OW permit. For motor carriers operating without an OS/OW permit, adherence to federal regulations governing maximum GVW and axle load on the interstate system is mandatory, as detailed in Table 5.

Table 5: Legal weight limits without a Texas permit

Description	**Load (lbs)**
Gross Vehicle Weight	80,000
Single axle[1]	20,000
Tandem axle group[2]	34,000
Triple axle group (Tridem)	42,000
Quad axle group	50,000

[1] There is no differentiation between single axles equipped with single- or dual-wheels.

[2] An axle group must have a minimum spacing of 40 in. and a maximum of 96 in. between two consecutive axles within the same group.

In addition to specific axle configurations, motor carriers operating in Texas are also required to adhere to the Federal Bridge Formula (FBF) weights. These weights were established by Congress in 1975 (FHWA, 2019) and dictate the permissible weight-to-length ratio for a vehicle crossing a bridge, ensuring structural integrity and safety. The FBF formula is detailed in Equation 3.1.

$$W = 500 \times \left(\frac{L + N}{N - 1} + 12N + 36) \right) \tag{3.1}$$

Where W is the overall gross weight on any group of two or more consecutive axles to the nearest 500 lbs.; L is the distance in feet between the outer axles of any group of two or more consecutive axles; and N is the number of axles in the group under consideration.

Regarding the vehicle dimensions, motor carriers must comply with width, height, and length. Width is measured from the outside points of the widest extremities, excluding safety devices. Height is measured from the roadbed to the highest point of the load or vehicle, whichever is higher. Length is measured from the foremost point of the vehicle or load, whichever extends further, to the rearmost point of the vehicle or load, whichever extends further. The maximum dimensions allowed to operate on Texas' highways without a permit are presented in Table 6

Table 6: Legal size limits for each vehicle type without a Texas permit

Vehicle type	Width	Height	Length
Passenger vehicle	8’	14’	45’
Single motor vehicle	8’6”	14’	45’
Truck-tractor	8’6”	14’	*
Semitrailer, of 2-vehicle combination	8’6”	14’	59’
2-vehicle combination, other than truck-tractor[1]	8’6”	14’	65’
3-vehicle combination, other than truck-tractor[2]	8’6”	14’	65’
Each trailer or semitrailer of a twin-trailer combination	8’6”	14’	28.5’
Stinger-steered auto/boat or traditional auto/boat transporter (truck-tractor)[3]	8’6”	14’	*
Truck towing a trailer transporting boats	8’6”	14’	65’
Front overhang	8’6”	14’	3’
Rear overhang	8’6”	14’	4’

[1]Length limit may only be increased with a permit if the vehicle combination complies with the permit requirements both with and without a load.

[2]Length may not be increased with a permit.

[3]Semitrailer length may not be increased with a permit.

*Unlimited.

3.1 Permit Types

Motor carriers that exceed the size and weight restrictions specified in Tables 5 and 6 are required to obtain an OS/OW permit issued with the TxDMV. The distinct OS/OW permit types currently available in Texas are summarized below:

- **General**: A single-trip permit for any non-divisible load requiring continuous movement between a single origin and destination.

- **Manufactured Housing**: A permit issued either as a single-trip permit for transporting manufactured housing and industrialized buildings with continuous movement between a single origin and destination, or as an annual permit for transporting new homes to temporary storage locations within a 20-mile radius. Annual permits may be used by multiple vehicles.

- **Portable Building**: A single-trip permit for transporting portable buildings and compatible cargo with continuous movement between a single origin and destination.
- **Super Heavy**: A single-trip permit issued when the GVW exceeds 254,300 lbs., or exceeds 200,000 lbs. with less than 95 ft. of axle spacing. This permit may authorize axle group weights exceeding standard limits.
- **House Move**: A single-trip permit for transporting houses exceeding 20 ft. in width, with continuous movement between a single origin and destination.
- **Intermodal Shipping Container Port**: An annual permit for ISC movements within a 30-mile radius of port authorities or ports of entry.
- **Crane (SP & Mileage)**: A single-trip, mileage-based permit for the movement of self-propelled and trailer-mounted cranes. The permit is valid for up to seven consecutive days, from a specific origin to a specific destination, and allows return travel to the origin or another location provided all route mileage is charged.
- **Well Service Unit (Mileage)**: A single-trip permit for unladen lift equipment with fixed-load machinery used to drill, service, or clean oil wells. This permit follows the same operational restrictions as the Crane (SP & Mileage) permit.
- **Self-Propelled Off-Road Equipment**: A single-trip permit allowing off-road equipment to operate on state roadways with continuous movement between a single origin and destination.
- **30-, 60-, and 90-Day Width/Length**: A category aggregating six combinations of temporary permits for vehicles exceeding TxDOT dimensional limits.
- **Exempt (TxDOT Agency Only)**: A temporary permit issued exclusively for TxDOT-owned vehicles and equipment.
- **Envelope Company-Specific**: An annual permit issued to a specific company for operation of any properly registered truck owned or leased by that company that meets a defined envelope of dimensions and weight. Only one vehicle may operate at a time under a given permit, although a company may purchase multiple permits.
- **Envelope Truck-Specific**: An annual permit issued for a specific truck that meets a defined envelope of dimensions and weight.

- **Fracking Trailer**: An annual permit for a vehicle combination consisting of a truck-tractor and semitrailer designed with a tank and pump unit for transporting liquid hydraulic fracturing products, liquid oil well waste products, and unrefined liquid petroleum products to or from oil wells not connected to a pipeline.
- **Hay**: An annual permit for transporting cylindrical (round) hay bales loaded side by side, with a maximum allowable width of 12 ft.
- **Hubometer (Quarterly)**: A temporary 91-day permit for transporting hubometer-equipped fixed-load machinery and cranes, with fees assessed based on mileage.
- **Implements of Husbandry**: An annual permit for transporting farm implements, machinery, and tools used in agricultural operations, including vehicles for spreading fertilizer or agricultural chemicals and vehicles designed to deliver feed to livestock.
- **Mobile Crane**: An annual permit for transporting mobile cranes exceeding legal width and weight limits. The permit expires one year from the designated "movement to begin" date.
- **Well Servicing Unit**: An annual permit for the movement of oil well servicing units registered with a Texas "permit" license plate.
- **Over Axle (1547) & GVW Tolerance**: An annual permit allowing axle weights to exceed TxDOT limits by up to 10 percent and gross vehicle weight to exceed limits by up to 5 percent.
- **Rig-Up Truck**: An annual permit for trucks equipped with a winch and gin poles.
- **Utility Pole**: An annual permit for transporting poles used in electrical power transmission and distribution. Nighttime movement is permitted for emergency situations.
- **Water Well Drilling Machinery & Related Equipment**: An annual permit for self-propelled or mounted machinery used exclusively for drilling water wells.
- **Timber**: An annual permit for transporting unrefined timber, wood chips, or woody biomass on state-maintained and county roads in designated counties.
- **Ready-Mixed Concrete Trucks**: An annual permit for three-axle trucks transporting ready-mixed concrete. Axle weights may exceed legal limits by up to

10 percent, provided the GVW does not exceed 69,000 lbs. (maximum single-axle weight of 25,300 lbs. and tandem-axle weight of 50,600 lbs.).

- **Overlength**: An annual permit for transporting non-divisible overlength loads.
- **Federal Disaster Relief**: A temporary permit valid for 120 days following a presidential disaster declaration, allowing vehicles to transport relief supplies or assist with debris removal, provided the entire load consists of disaster-related materials.
- **North Texas Intermodal**: An annual permit for intermodal shipping container movements within 5 mi of the Texas–Arkansas border.
- **Fluid Milk Transport**: An annual permit for transporting fluid milk along routes approved by TxDOT.

3.2 Size and Weight Limits with a Texas Permit

For vehicles that are issued a permit, TxDOT established another set of size and weight restrictions. An OS/OW permit can relax one of these limits (or more, if a combination of different permits is issued). Besides each specific permit purpose, the motor carrier must comply with size and weight limits for moving within Texas' infrastructure system. The size and weight limit for those under a Texas permit are presented in Table 7 and Table 8, respectively.

Table 7: Legal weight limits with a Texas permit

Description	**Load (lbs.)**
Single axle	25,000
Tandem (2-axle group)	46,000
Triple (3-axle group)	60,000
Quad (4-axle group)	70,000
Quint (5-axle group)	81,400
Six or more axles	Require analysis by MCD[1]

[1]Motor Carrier Division from TxDMV

Table 8: Dimension restrictions for carriers with a permit on Texas highways

Description	**Width[1]**	**Height**	**Length[2]**
Maximum width permitted on holidays	14'	16'	110'
Maximum width permitted on controlled access highways (Interstate Highway System)	16'	18'11"	125'
A truck width permitted without a route inspection certification by applicant on file	20'	18'11"	125'

[1]Manufactured housing may exceed these limits.

[2]A truck or single vehicle has maximum of 75 ft. length, the maximum front overhang allowed is 25 ft., and the maximum rear overhang allowed is 30 ft.

3.3 Size and Weights Exemptions

Beyond the specified limitations for vehicles operating with or without a Texas permit, there are provisions that allow certain vehicles to exceed size and weight restrictions for the purpose of transporting specific goods. This flexibility is vital for striking a balance between sustaining infrastructure and fostering economic development, which sometimes requires operations beyond the state's allowable boundaries. However, such exemptions are carefully regulated, as detailed in this section.

- **Alternatively Fueled Vehicles**: Vehicles powered primarily by natural gas or electric battery power may exceed the maximum GVW by up to 2,000 lbs., provided the GVW does not exceed 82,000 lbs.

- **Ready-Mixed Concrete Trucks**: Ready-mixed concrete trucks may not exceed 23,000 lbs. on a single axle or 46,000 lbs. on a tandem axle.

- **Vehicles Transporting Milk**: Vehicles used exclusively to transport milk may operate on Texas roadways if the distance between the front wheel of the forward tandem axle group and the rear wheel of the rear tandem axle group is at least 28 ft. and no axle group exceeds 68,000 lbs. These vehicles may not operate on interstate highways.

- **Vehicles Transporting Timber or Timber Products**: Vehicles used exclusively to transport poles, piling, or unrefined timber may operate provided the total vehicle length, including the load, does not exceed 90 ft and the distance between the origin and destination does not exceed 125 mi. These vehicles are exempt from legal limits on rear overhang, except for truck-tractor or truck-tractor combinations. Vehicles with an outer bridge distance of 39 ft or more may operate with a maximum GVW of 80,000 lbs.

- **Vehicles Transporting Poles or Pipe**: Vehicles used exclusively to transport poles or pipe may operate provided the total length, including the load, does not exceed 65 ft. This limitation does not apply to truck-tractor or truck-tractor combinations.

- **Cotton, Chile Pepper, and Related Equipment**: Vehicles used exclusively to transport cotton, chile pepper, and related equipment may operate provided they do not exceed the following limits:

  - 10 ft. in width;
  - 48 ft. in length;
  - 14 ft. 6 in. in height;
  - 64,000 lbs. GVW when transporting cotton or related equipment; and
  - 54,000 lbs. GVW when transporting chile pepper or related equipment.

  These vehicles may not operate on interstate highways. In addition, a truck-tractor and semitrailer combination used to transport seed cotton or cotton may not exceed 14 ft. 6 in. in height.

- **Vehicles Transporting Recyclable Materials**: A single motor vehicle equipped with a container roll-off unit or a front-end loader and used exclusively to transport recyclable materials may operate provided it does not exceed 21,000 lbs. on a single axle, 44,000 lbs. on a tandem axle, or 64,000 lbs. GVW.

- **Highway Building or Maintenance Machinery**: Highway building or maintenance machinery may operate during daylight hours or on the Interstate Highway System, provided the travel distance does not exceed 50 mi.

- **Farm Tractors and Implements of Husbandry**: Farm tractors and implements of husbandry may operate during daylight hours or on the Interstate Highway System, provided travel is limited to 50 mi.

- **Water Well Drilling Machinery**: Machinery used exclusively for drilling water wells, whether self-propelled or mounted, may operate during daylight hours or on the Interstate Highway System, provided travel is limited to 50 mi.

- **Fire Department Vehicles**: Vehicles owned or operated by a public, private, or volunteer fire department are exempt from size and weight limitations.

- **Fertilizer Transport and Spreading Vehicles**: Motor vehicles used exclusively to transport and spread fertilizer may operate provided the vehicle is registered under Texas Transportation Code, Section 502.431.

- **Recreational Vehicles**: Recreational vehicles may exceed width limits if the excess width is attributable to an appurtenance (including awnings, grab handles, lighting equipment, or vents) that extends no more than 6 in. beyond a fender on one or both sides of the vehicle.

- **Natural Gas or Petroleum Machinery**: Truck-tractor, truck-tractor combination, or truck–trailer combination vehicles used exclusively to transport machinery, materials, and equipment associated with the construction, operation, and maintenance of facilities for the discovery, production, and processing of natural gas or petroleum are permitted.

- **Drive-Away Saddle-Mount Combinations**: Drive-away saddle-mount vehicle transporters may operate provided the overall length does not exceed 97 ft. and the combination includes no more than three saddle-mounted vehicles, unless the combination includes more than one full-mount vehicle.

- **Tow Trucks**: Tow trucks are exempt when towing a vehicle to the nearest authorized repair facility, terminal, or unloading destination if the towed vehicle cannot be normally driven or was abandoned on a highway. These vehicles may not operate on interstate highways under this weight exception when exceeding legal weight limits.

- **Custom Harvesting Operations**: Vehicle combinations used to transport harvesting machinery for custom agricultural operations may operate with an overall length between 75 ft. and 81.5 ft. when not traveling on interstate highways. A truck-tractor operating in combination with both a semitrailer and a trailer, or with two semitrailers, may be up to 81.5 ft. in overall length provided the movement occurs outside the Interstate Highway System and within a county with a population of fewer than 300,000.

- **Idle Reduction Systems**: Vehicles or vehicle combinations equipped with idle reduction systems may exceed maximum GVW and axle weight limits by an amount necessary to compensate for the added weight of the system, not to exceed 400 lb. Upon request by law enforcement, the vehicle operator must provide proof that the idle reduction system is fully functional and that the weight allowance is not used for any other purpose.

4. TEXAS PERMITTING & ROUTING OPTIMIZATION SYSTEM

The Texas Permitting & Routing Optimization System (TxPROS) is a web-based integrated GIS-based mapping system with real time restriction management that provides automated routing for transportation OS/OW loads on the Texas maintained infrastructure network. The real-time restriction management provide a specific route based on vehicle information and infrastructure constraints, such as vertical clearance, lane width, load ratings, scheduled construction, and maintenance services etc. The database of the system is synchronized with reports from district officials, resulting in a reliable mapping of possible routes, reducing possible congestion or misleading paths.

The TxPROS routing algorithm enables the user to select its origin and destination, and by checking the respective vehicle configuration with the system infrastructure, return a specified route in compliance with state restrictions. In combination with size-weight-limits, TxPROS also uses a modified dual Dykstra routing algorithm on direct and reverse graphs, which is popular for finding shortest-path between two locations in transportation-based networks. In addition to mapping and managing restriction for OS/OW routes, TxPROS also generates an inventory of permits issued with 13 different reports regarding routes used by OS/OW vehicles, axle configuration, and administrative status of permitting processes. Each report is further detailed in the subsequent section.

4.1 Permit Reports

After completing the required data entry in the TxPROS interface, the motor carrier's details are categorized into 35 permit types and the system generates 13 distinct reports. These software-generated reports delineate information pertaining to OS/OW vehicle configurations, including axle weight, axle spacing, and number of tires, along with corresponding company or carrier information such as load description, commodity type, issuing date, permit number, and truck make (that is, administrative reports). Among the 13 reports, only 4 are typically employed for pavement and bridge consumption analyses, as outlined below:

- **Permit base report:** This report aggregates all information necessary to identify both the company and the specific vehicle for which a permit was issued. It is commonly referred to as the ground-truth database, as it includes all OS/OW permits issued.

- **Axle report:** This report consolidates information for most OS/OW vehicles, particularly those required to demonstrate compliance with weight or length restrictions.
- **Route report:** This report contains vehicles for which routing is a determining factor in allowing or restricting OS/OW cargo movement. Only single-trip and select temporary permits are required to include routing information, resulting in limited records for annual permits.
- **County report:** This report aggregates all counties in which the recipient of a given permit is authorized to operate. The inclusion of this report stems from recommendations made during the Rider 36 study.

4.2 Permit Data Base

The available TxPROS database covers data from 2012 to the present day. However, for this research study, a dataset spanning from **2018 to 2023** was chosen to comprehensively capture traffic trends before, during, and after the COVID-19 pandemic. A summary of all permits and their issuance frequency is provided in Tables 9 and 10.

Table 9: Oversize Permits by Calendar Year

Permit Type	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
30-day Length	6,887	8,160	5,896	4,573	5,157	5,857
30-day Width	13,383	14,123	11,483	11,374	12,648	14,615
60-day Length	563	506	487	364	326	384
60-day Width	555	565	521	489	622	613
90-day Length	4,435	4,148	3,126	2,497	2,416	2,711
90-day Width	12,667	12,812	10,653	9,749	9,662	9,886
Annual Overlength	454	627	518	454	541	562
Cylindrical Bales of Hay (Annual)	789	718	618	592	656	607
Exempt (TxDOT)	174	173	116	138	76	69
Federal Disaster Relief	10	6	705	927	662	349
Fluid Milk Transport	1	4	0	0	0	0
Fracing Trailer (Annual)	15	12	13	27	22	14
Housemove (General)	1,666	1,607	1,378	1,560	1,599	1,417
Intermodal Shipping Container	159	213	240	275	326	401
Manufactured Housing	99,200	97,780	89,301	97,513	103,098	88,284
Manufactured Housing (Annual)	9	8	8	9	6	5
North Texas Intermodal	6	0	0	0	17	2
Portable Building	20,119	18,982	18,453	18,321	18,266	16,116
Self-Propelled Off-Road Equipment	36	16	15	17	12	14
Utility Pole (Annual)	334	298	306	294	275	345

Table 10: Overweight Permits by Calendar Year

Permit Type	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Crane (Annual)	838	844	761	771	809	830
Crane (S/P Mileage)	4,125	4,005	3,881	4,390	4,690	4,191
Envelope - Company (Annual)	3,574	3,668	3,061	3,102	3,260	3,226
Envelope - Truck (Annual)	3,612	3,580	2,781	2,689	2,792	2,770
General	534,207	570,640	428,392	416,570	447,492	470,039
Hubometer (Quarterly)	41,556	41,140	30,335	31,334	31,537	31,817
Implement of Husbandry (Annual)	867	904	892	963	1,005	1,033
Over-Axle (1547)	56,717	59,693	54,053	51,385	53,707	57,297
Ready-Mixed Concrete Truck (Annual)	5,572	5,451	5,498	5,146	5,650	5,346
Rig-Up Truck / Unladen Lift (Annual)	305	303	208	176	175	150
Super-Heavy	842	1,819	1,517	998	920	1,020
Timber (Annual)	247	400	453	519	562	543
Water Well Drilling Machinery & Equipment	143	168	152	146	145	121
Well Servicing Unit (Annual)	208	140	113	128	202	166
Well Servicing Unit (S/P Mileage)	13,404	16,159	10,174	15,018	18,898	17,942

4.3 Traffic Classification

From all the permits presented in Table 10, only a few had an axle report. The axle configuration (weight and spacing) is paramount information for the consumption analysis and the ultimate evaluation of the permit fee structure. In past studies, the OS were commonly grouped with regular commercial trucks, particularly because they still comply with state weight restrictions (Inoue et al., 2024; Middleton et al., 2012; Prozzi et al., 2012, 2022c; Schaefer and Todd, 2018; Weissmann et al., 2024). This grouping imposes only a dimensional concern regarding their envelope while crossing underneath bridges and making turns/curves in specific locations throughout the highway network (both on- and off-system[8]). Therefore, this study focused exclusively on the effects of OW vehicles on pavements and bridges, as they are responsible for increased deterioration rates of these infrastructure assets, with particular emphasis on permit types for which axle load reports were available. A list of OW permits of interest with existent axle report, between 2018 and 2023, is presented in Table 11.

[8] *On-system* concerns the infrastructure assets owned and maintained by the state, while *off-system* concerns the assets owned and maintained by a county or city, which are not part of the state's highway system.

Table 11: Overweight permits that have an axle report issued

Permit Type	Calendar Year					
	2018	2019	2020	2021	2022	2023
Crane (Annual)	838	844	761	777	809	830
Crane (S/P Mileage)	4,125	4,005	3,881	4,389	4,690	4,191
General	330,742	364,320	269,388	261,762	273,178	288,065
Housemove - General[1]	236	227	191	189	219	191
Hubometer	41,556	41,136	30,329	31,317	31,527	31,809
Implement of Husbandry	330	361	355	377	376	373
Rig-Up Truck/Unladen Lift (Annual)	305	303	208	176	175	150
Self-Propelled Off-Road Equip.	36	16	15	17	12	14
Super-Heavy[2]	842	1,819	1,517	998	920	1,020
Water Well Drilling Machinery & Equipment	143	168	152	146	145	121
Well Serv. Unit (S/P Mileage)	13,404	16,159	10,174	15,018	18,898	17,942
Total	**392,672**	**429,678**	**317,242**	**315,231**	**331,009**	**345,761**

[1]The vehicles under this permit usually have their VMT restricted to a specific maneuver location (e.g., construction site, ranch entrance etc.). Additionally, the number of permits issued is relatively low, having no significant impact on the O/W analysis, and hence they were not considered.

[2]The Super-heavy permit requires a specific route evaluation, usually conducted by TxDOT along with a consultant firm. Hence, type of permit was not considered.

4.4 Notation for Vehicle Classification

Before any engineering analysis, first is necessary to organize the existent vehicles on the dataset.The proposed classification based on the axle configuration utilizes integer numbers to represent the number of axles within each axle-group. Combining these numbers and spacing them by a hyphen (-) it results on a numerical vehicle configuration. By summing all the numbers from the notation, the total number of axles is found. For example, an 18-wheeler that consists of one steering axle, two tractor axles (in tandem), and two semi-trailer axles (in tandem) would be classified as 1-2-2, with a total of 5 axles. Other examples are depicted in Figure 2.

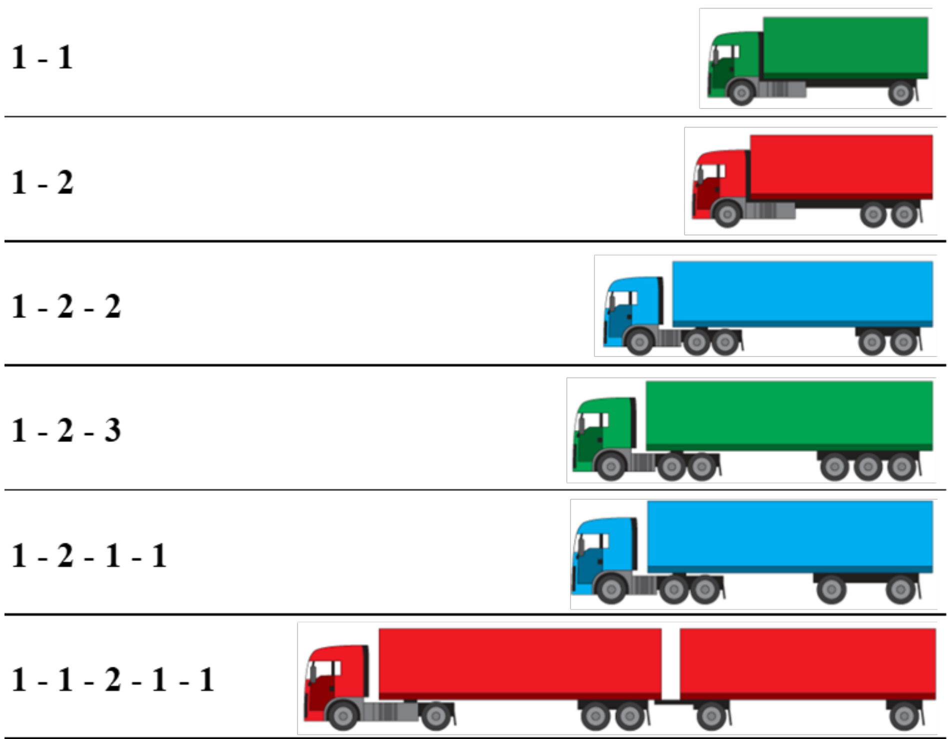

Figure 2: Example of vehicle axle-based classification

The top 30 most frequent vehicle configuration, among the 1,028 different configurations identified on the dataset, represented more than 90 percent of the total axle group arrangements. These are shown in Table 12.

Table 12: Vehicle Configuration Distribution

Rank	Vehicle Configuration	Frequency	Percentage	Cumulative
1	1-2-3	395,654	18.6%	18.6%
2	1-3-4	271,467	12.7%	31.3%
3	1-3-3	171,028	8.0%	39.3%
4	1-2-5	164,943	7.7%	47.1%
5	1-2-2	153,427	7.2%	54.3%
6	1-3-5	143,101	6.7%	61.0%
7	1-2-4	135,792	6.4%	67.3%
8	1-3-3-1	55,372	2.6%	69.9%
9	1-2-1-1	50,530	2.4%	72.3%
10	2-3	46,873	2.2%	74.5%
11	1-3-3-3-3	40,850	1.9%	76.4%
12	1-2-2-2-2	32,469	1.5%	77.9%
13	1-3-3-2	28,426	1.3%	79.3%
14	1-2-2-3	27,267	1.3%	80.6%
15	2-2	23,489	1.1%	81.7%
16	1-2-3-3	21,725	1.0%	82.7%
17	1-3-2-2-2	17,860	0.8%	83.5%
18	1-2	17,013	0.8%	84.3%
19	1-2-3-3-3	16,838	0.8%	85.1%
20	1-3-5-2	15,992	0.8%	85.9%
21	1-3-2-3-2	14,245	0.7%	86.5%
22	1-2-2-3-2	12,654	0.6%	87.1%
23	1-3-2	12,381	0.6%	87.7%
24	1-3-3-3-2	11,916	0.6%	88.3%
25	1-4	10,885	0.5%	88.8%
26	1-3-3-3	9,159	0.4%	89.2%
27	1-2-3-2-3	9,014	0.4%	89.6%
28	1-2-2-2	7,872	0.4%	90.0%
29	1-2-2-5	7,576	0.4%	90.3%
30	1-4-3-5-2	6,912	0.3%	90.7%

The histogram of the total number of axles among the top 30 vehicle configurations is presented in Figure 3.

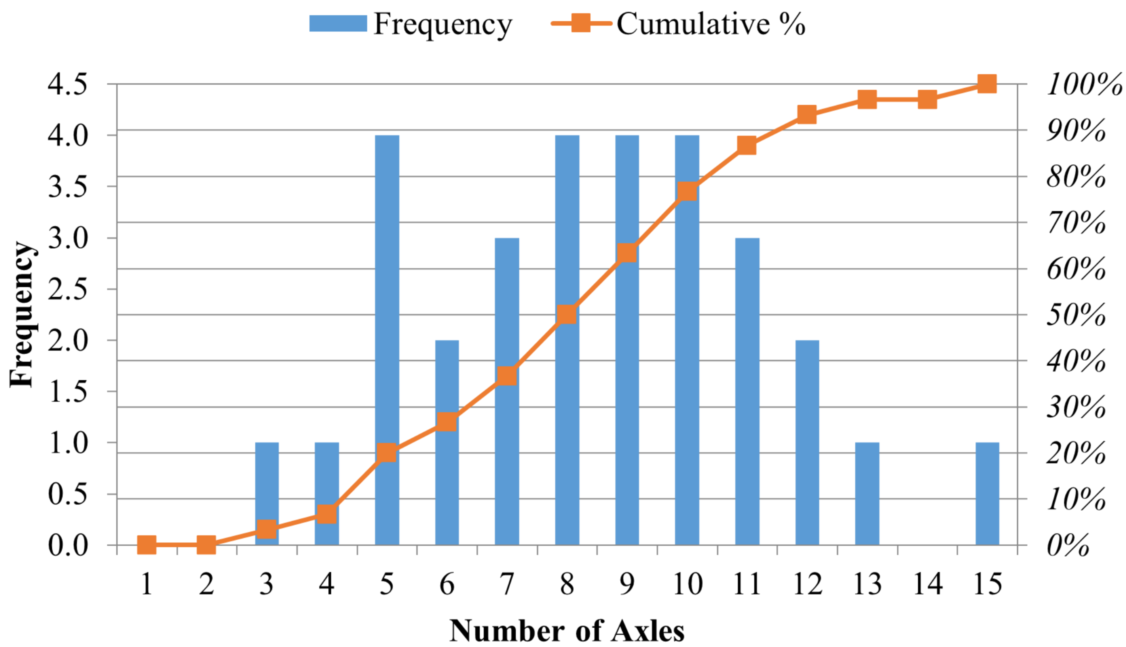

Figure 3: Histogram of the number of axles for the 30 most frequent configurations

5. REPRESENTATIVE OVERWEIGHT VEHICLES

The research project concern different permit types, and not exactly each individual truck configuration. Thus, this section introduces the characteristics of the so-called *representative vehicles*, which is used to establish the appropriate axle load spectra and axle spacings for each permit type during the bridge and pavement consumption analyses.

Due to the large number of vehicle configurations, analyzing all of them would not be feasible. Even if such analysis was possible, the computational demand would exceed the project's time frame. A proven method from previous permitting studies involves selecting representative vehicles—typically those with the highest issuance frequency or VMT. For this study, the former approach was adopted, focusing on OW permits recorded in the TxPROS database. Vehicle configurations representing *more than one percent* of the total permit fleet were extracted from the database for analysis. However, the sheer number of configurations (1,028) made it challenging to ensure proper representation and, as a result, the *five most* frequent vehicle configurations for each permit type were selected as representative.

5.1 Crane Annual

The Crane Annual permit had 51 different vehicle configurations. Those configurations that represented more than one percent of this permit type were ranked by frequency and are presented in Table 13.

Table 13: Most frequent vehicle configurations with a Crane Annual permit

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2	2,180	44.9%	44.9%
2	1-3	951	19.6%	64.5%
3	2-2	641	13.2%	77.7%
4	2-3	251	5.2%	82.9%
5	1-4	241	5.0%	87.9%
6	3-3	81	1.7%	89.5%
7	1-5	68	1.4%	90.9%
8	1-1-2	56	1.2%	92.1%
9	1-1	47	1.0%	93.1%

The distribution of the number of axles for the Crane Annual permit is presented in

Figure 4.

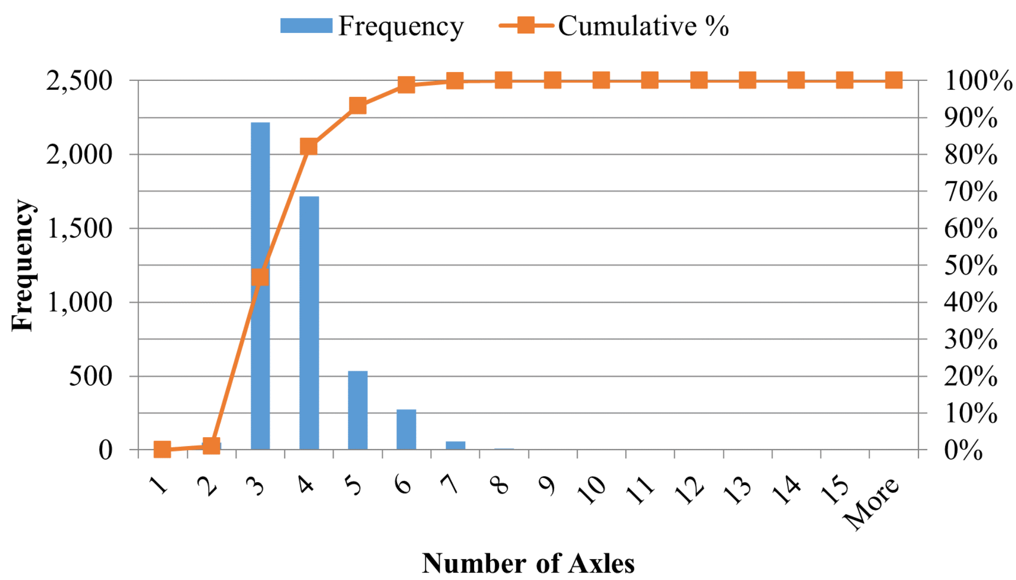

Figure 4: Distribution of the number of axles for Crane Annual permit

The statistical analysis for the five most frequent vehicle configurations under a Crane Annual permit is presented in the next sections.

5.1.1 Crane Annual – Rank 1

As presented in Table 13, the most frequent vehicle configuration is the “1-2”, with its GVW distribution presented in Figure 5.

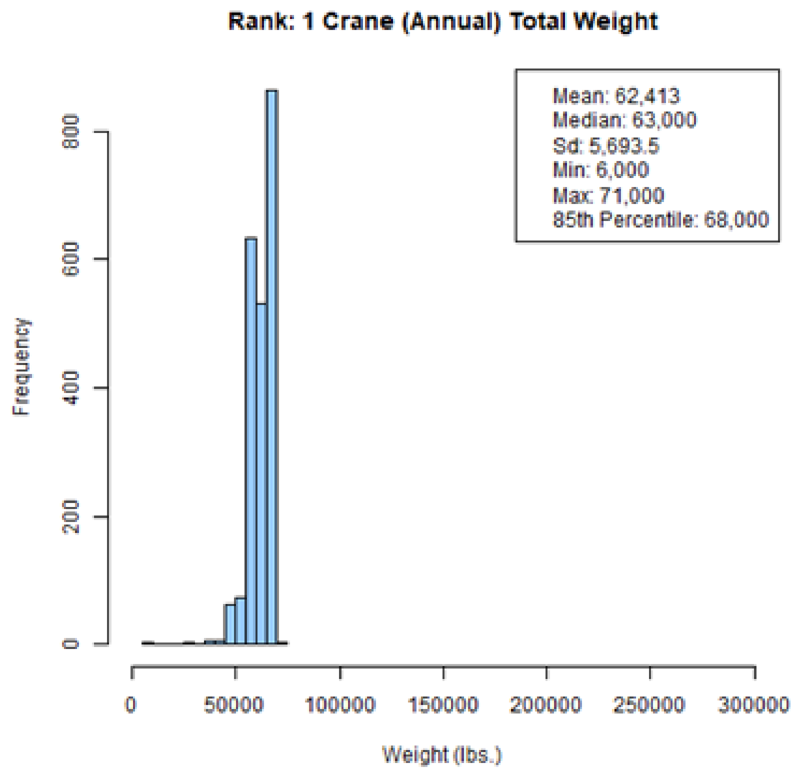

Figure 5: Gross vehicle weight distribution for Crane Annual (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 14 and Table 15, summarizing the axle weight and axle spacing respectively.

Table 14: Axle weight statistics for Crane Annual (Rank 1)

Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	20,144	20,000	1,625.97	16,000	25,000	22,000
2	Axle 2	21,565	22,000	1,599.77	16,070	23,000	23,000
	Axle 3	21,567	22,000	1,599.34	16,070	23,100	23,000

Table 15: Spacing statistics for Crane Annual (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	210	204	32.39	132	300	252
Spacing 2	51	48	5.60	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 6.

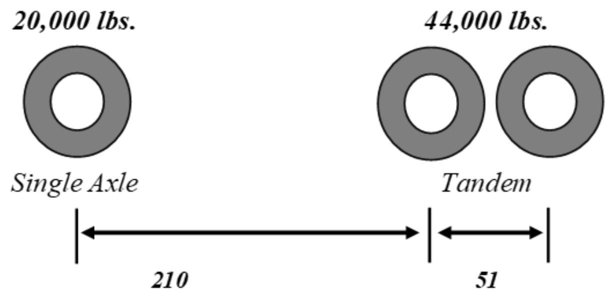

Figure 6: Schematic configuration for a vehicle with a Crane Annual (Rank 1)

5.1.2 Crane Annual – Rank 2

The second most frequent vehicle configuration under a Crane Annual permit is the "1-3", with its GVW distribution presented in Figure 7.

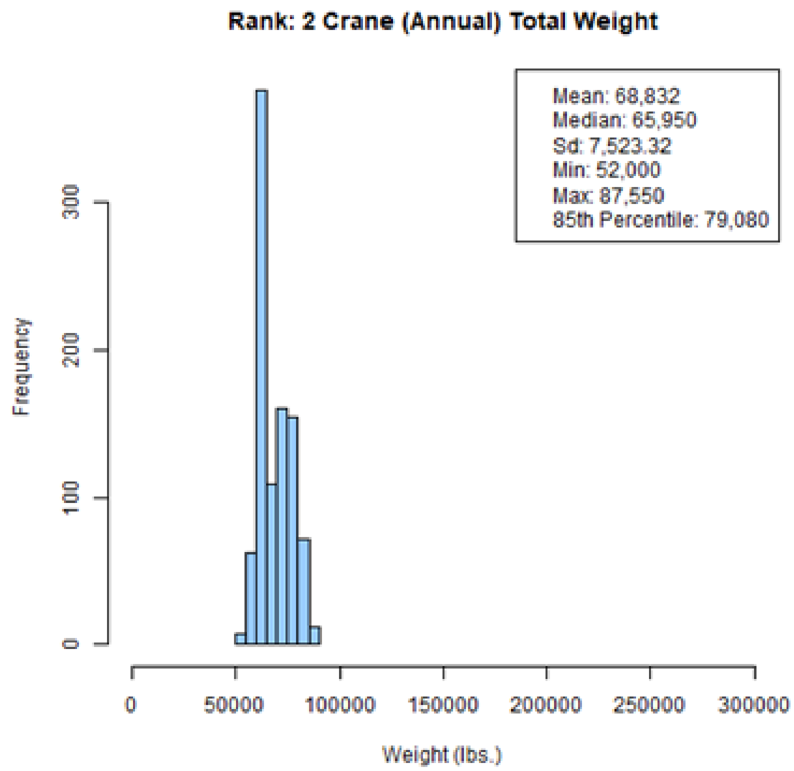

Figure 7: Gross vehicle weight distribution for Crane Annual (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 16 and Table 17, summarizing the axle weight and axle spacing respectively.

Table 16: Axle weight statistics for Crane Annual (Rank 2)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
1	Axle 1	18,707	18,000	1,662	11,400	25,000	20,000
2	Axle 2	13,368	14,786	5,939	3,550	21,850	20,000
	Axle 3	18,938	19,987	1,948	12,094	21,850	20,000
	Axle 4	17,818	19,999	3,705	5,000	21,850	20,000

Table 17: Axle weight statistics for Crane Annual (Rank 2)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	236	240	125.27	120	2,532	252
Spacing 2	54	48	8.43	0	84	60
Spacing 3	58	60	6.33	0	84	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 8.

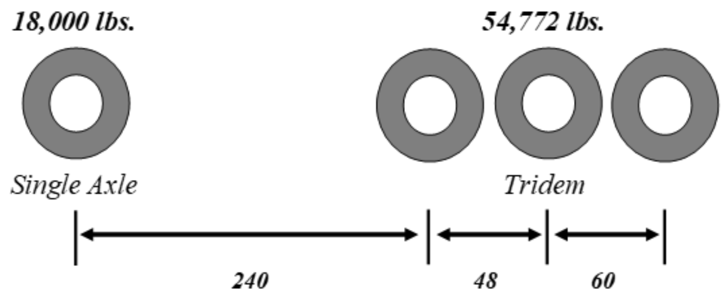

Figure 8: Schematic configuration for a vehicle with a Crane Annual (Rank 2)

5.1.3 Crane Annual – Rank 3

The third most frequent vehicle configuration under a Crane Annual permit is the "2-2", with its GVW distribution presented in Figure 9.

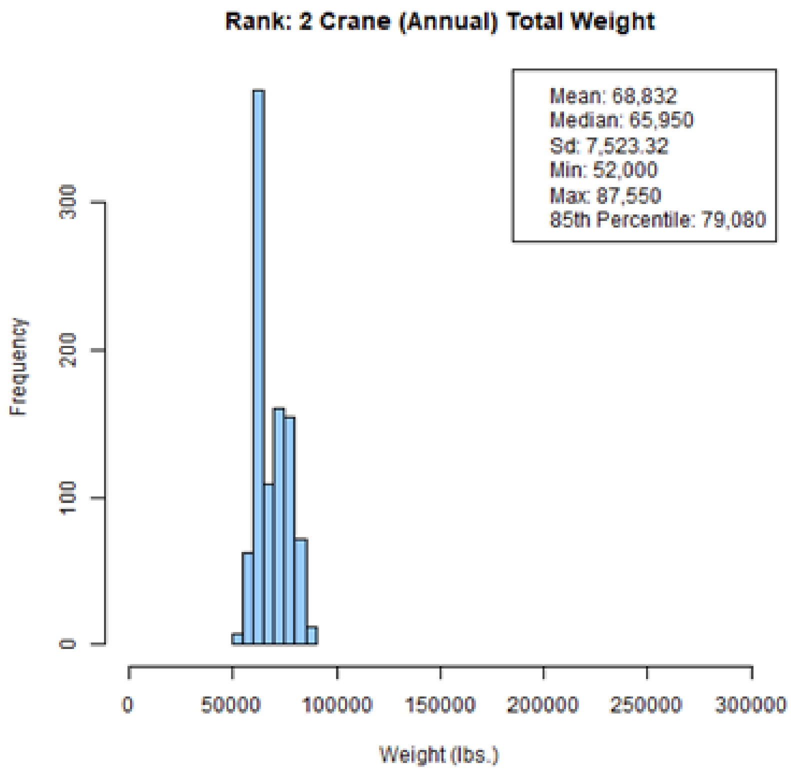

Figure 9: Gross vehicle weight distribution for Crane Annual (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 18 and Table 19, summarizing the axle weight and axle spacing respectively.

Table 18: Axle weight statistics for Crane Annual (Rank 3)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
2	Axle 1	20,508	22,000	2,509	12,000	23,000	23,000
	Axle 2	20,645	22,000	2,437	12,000	23,000	23,000
2	Axle 3	22,115	23,000	1,539	14,500	23,000	23,000
	Axle 4	22,072	23,000	1,861	2,800	23,000	23,000

Table 19: Spacing statistics for Crane Annual (Rank 3)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	64	60	13.83	48	84	84
Spacing 2	179	180	74.51	96	1,968	192
Spacing 3	52	48	6.07	48	84	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 10.

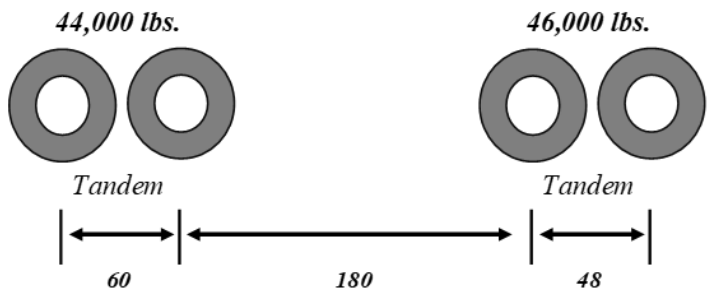

Figure 10: Schematic configuration for a vehicle with a Crane Annual (Rank 3)

5.1.4 Crane Annual – Rank 4

The fourth most frequent vehicle configuration under a Crane Annual permit is the "2-3", with its GVW distribution presented in Figure 11.

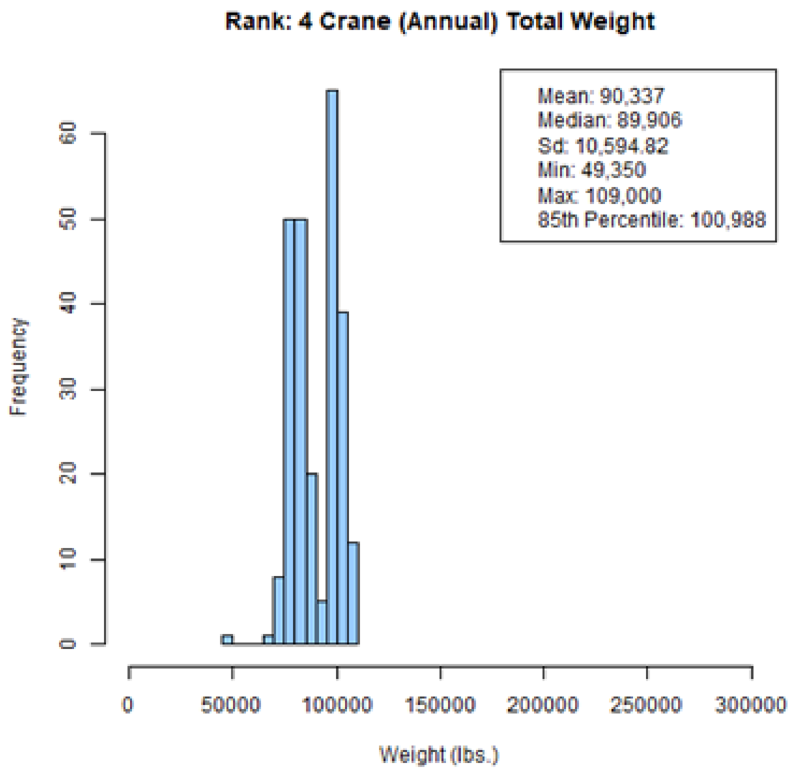

Figure 11: Gross vehicle weight distribution for Crane Annual (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 20 and Table 21, summarizing the axle weight and axle spacing respectively.

Table 20: Axle weight statistics for Crane Annual (Rank 4)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
2	Axle 1	17,709	17,858	3,010	1,450	23,000	20,060
	Axle 2	17,820	18,000	2,917	8,800	23,000	20,580
3	Axle 3	17,536	18,030	3,194	6,000	21,000	20,000
	Axle 4	18,536	19,723	2,052	10,150	21,000	20,500
	Axle 5	18,735	19,500	1,797	9,700	21,000	20,500

Table 21: Spacing statistics for Crane Annual (Rank 4)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	73	72	8.03	48	84	84
Spacing 2	200	192	114.72	108	1,872	252
Spacing 3	58	60	6.86	48	84	60
Spacing 4	58	60	6.15	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 12.

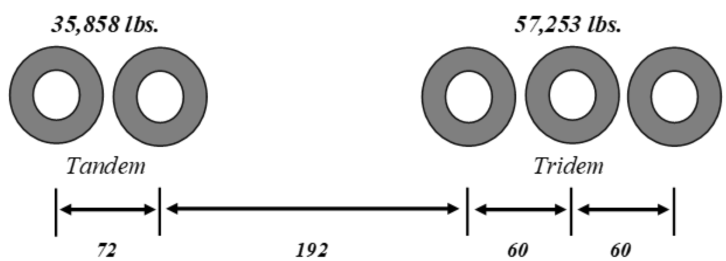

Figure 12: Schematic configuration for a vehicle with a Crane Annual (Rank 4)

5.1.5 Crane Annual – Rank 5

The fifth most frequent vehicle configuration under a Crane Annual permit is the "1-4", with its GVW distribution presented in Figure 13.

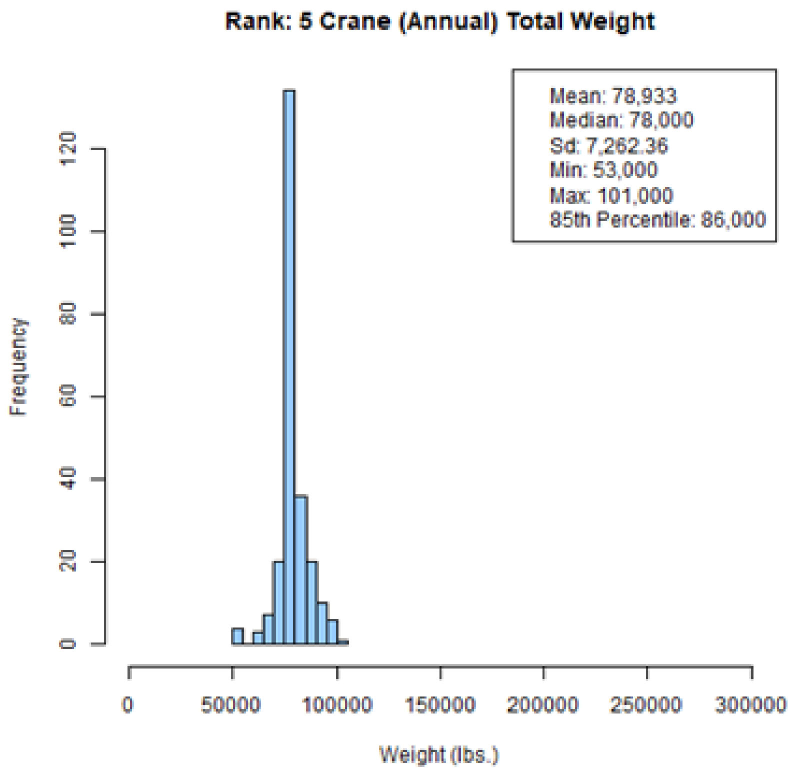

Figure 13: Gross vehicle weight distribution for Crane Annual (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 22 and Table 23, summarizing the axle weight and axle spacing respectively.

Table 22: Axle weight statistics for Crane Annual (Rank 5)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
1	Axle 1	18,154	17,660	2,059	10,000	23,400	20,000
4	Axle 2	15,584	15,890	2,803	2,340	21,000	17,500
	Axle 3	16,181	16,000	1,651	11,000	20,000	17,500
	Axle 4	16,199	16,000	1,671	11,000	20,000	17,500
	Axle 5	12,814	13,480	3,093	3,340	20,000	15,270

Table 23: Spacing statistics for Crane Annual (Rank 5)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	213	204	124.90	96	2,100	228
Spacing 2	60	60	4.75	48	84	60
Spacing 3	60	60	4.17	48	84	60
Spacing 4	58	60	6.28	48	84	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 14.

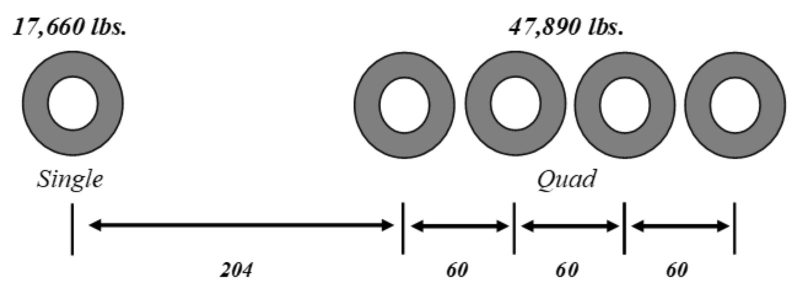

Figure 14: Schematic configuration for a vehicle with a Crane Annual (Rank 5)

5.2 Crane Self-Propelled Mileage

The Crane SP Mileage permit had 159 different vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 24.

Table 24: Common vehicle configurations with a Crane SP Mileage permit

Rank	Classification	Frequency	Percentage	Cumulative
1	1-4	4,526	17.9%	17.9%
2	2-2	4,509	17.8%	35.7%
3	1-2-2	1,707	6.8%	42.5%
4	2-3	1,683	6.7%	49.1%
5	1-2-2-3	1,228	4.9%	54.0%
6	1-2	1,175	4.6%	58.7%
7	2-2-2	988	3.9%	62.6%
8	2-2-2-3	853	3.4%	65.9%
9	1-3	755	3.0%	68.9%
10	6	727	2.9%	71.8%
11	1-4-2	565	2.2%	74.0%
12	1-4-3	458	1.8%	75.8%
13	2-4	371	1.5%	77.3%
14	2-5-3	347	1.4%	78.7%
15	2-3-3	307	1.2%	79.9%
16	1-2-2-2	302	1.2%	81.1%
17	4	302	1.2%	82.3%
18	3-5	247	1.0%	83.3%

The distribution of the number of axles for the Crane SP Mileage permit, among the different vehicle configurations, is presented in Figure 15.

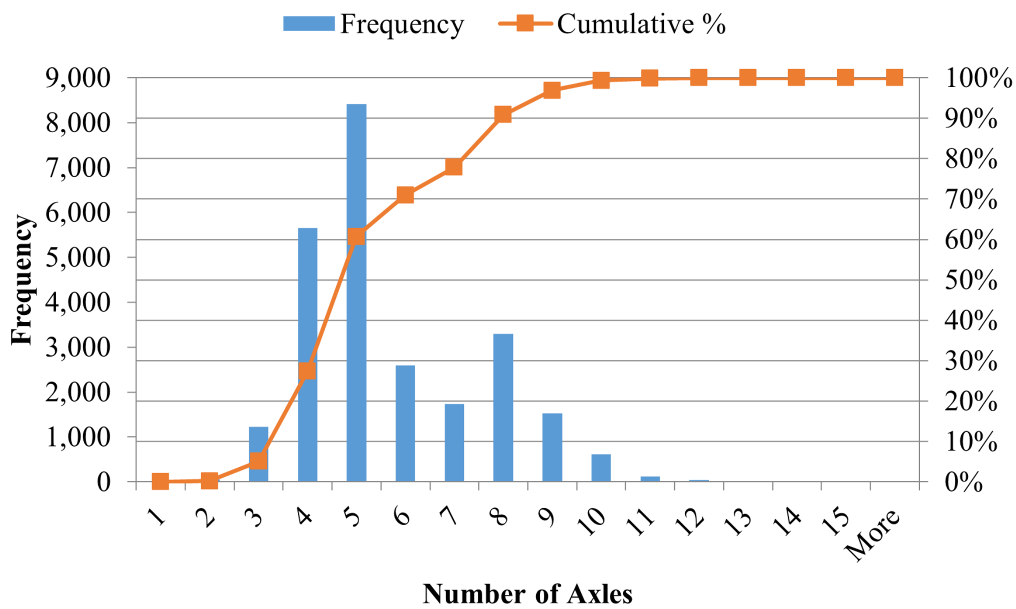

Figure 15: Distribution of the number of axles for Crane SP Mileage

The statistical analysis for the five most frequent vehicle configurations under a Crane Annual permit is presented in the next sections.

5.2.1 Crane SP Mileage – Rank 1

As presented in Table 24, the most frequent vehicle configuration is the "1-2", with its GVW distribution presented in Figure 16.

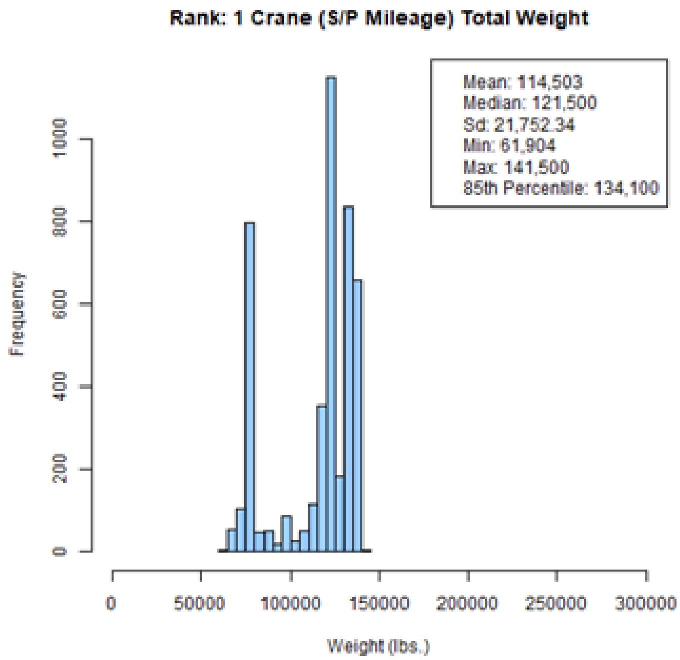

Figure 16: Gross vehicle weight distribution for Crane SP Mileage (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 25 and Table 26, summarizing the axle weight and axle spacing respectively.

Table 25: Axle weight statistics for Crane SP Mileage (Rank 1)

Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	23,914	24,300	2,963.71	11,000	30,000	26,500
4	Axle 2	22,955	24,300	4,256.52	11,000	30,000	27,000
	Axle 3	23,018	24,300	4,324.10	11,000	30,000	27,100
	Axle 4	22,967	24,300	4,310.40	10,750	30,000	27,000
	Axle 5	22,919	24,300	5,315.49	10,420	30,000	27,100

Table 26: Spacing statistics for Crane SP Mileage (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	105	102	6.58	96	156	108
Spacing 2	63	64	3.02	53	72	65
Spacing 3	72	72	9.02	48	90	81
Spacing 4	68	66	4.23	55	79	72

Lastly, a schematic configuration for the “1-4” vehicle, developed based on the statistical analysis, is depicted in Figure 17.

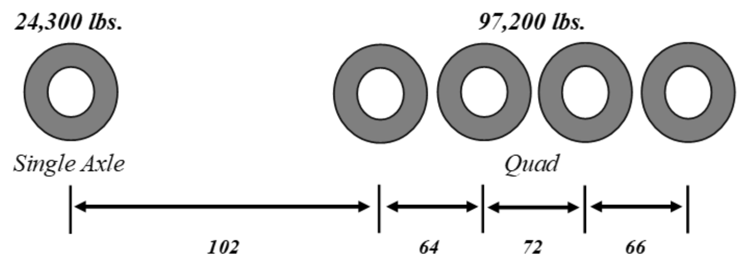

Figure 17: Schematic configuration for a vehicle with a Crane SP Mileage (Rank 1)

5.2.2 Crane Sp Mileage – Rank 2

The second most frequent vehicle configuration under a Crane SP Mileage permit is the "2-2", with its GVW distribution presented in Figure 18.

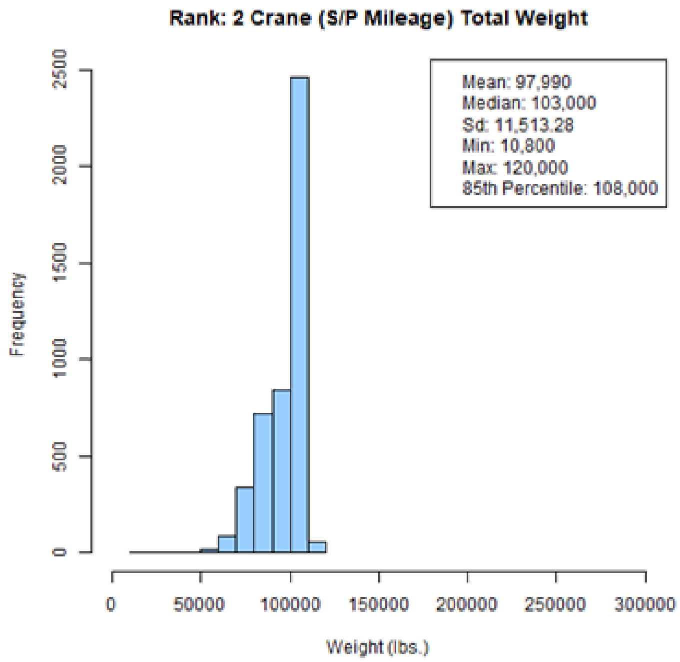

Figure 18: Gross vehicle weight distribution for Crane SP Mileage (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 27 and Table 28, summarizing the axle weight and axle spacing respectively.

Table 27: Axle weight statistics for Crane SP Mileage (Rank 2)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
2	Axle 1	20,508	22,000	2,509	12,000	23,000	23,000
	Axle 2	20,645	22,000	2,437	12,000	23,000	23,000
2	Axle 3	22,115	23,000	1,539	14,500	23,000	23,000
	Axle 4	22,072	23,000	1,861	2,800	23,000	23,000

Table 28: Spacing statistics for Crane SP Mileage (Rank 2)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	64	60	13.83	48	84	84
Spacing 2	179	180	74.51	96	1,968	192
Spacing 3	52	48	6.07	48	84	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 19.

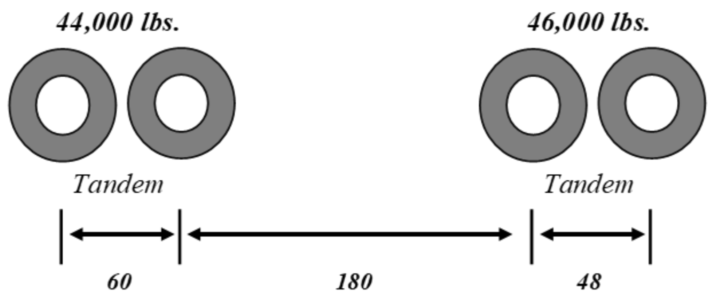

Figure 19: Schematic configuration for a vehicle with a Crane SP Mileage (Rank 2)

5.2.3 Crane Sp Mileage – Rank 3

The third most frequent vehicle configuration under a Crane SP Mileage permit is the "1-2-2", with its GVW distribution presented in Figure 20.

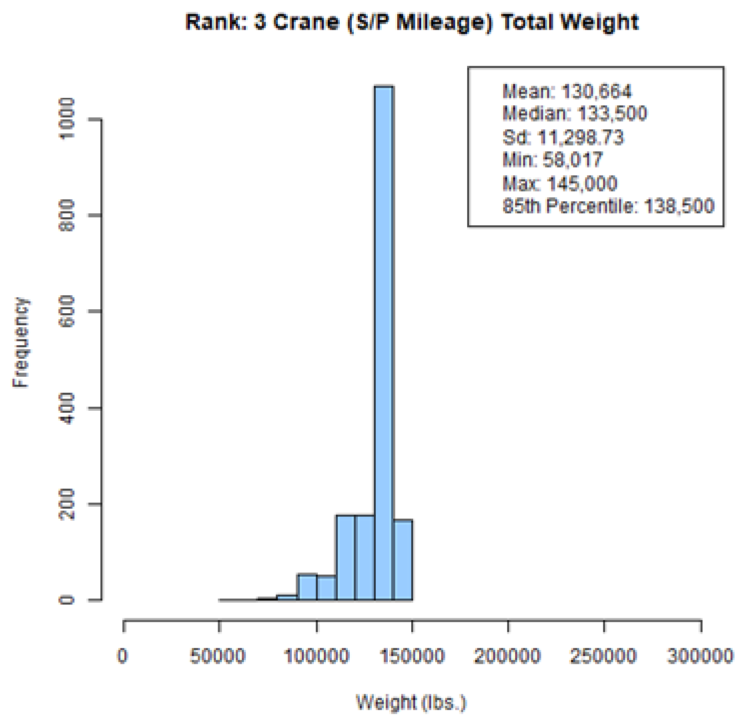

Figure 20: Gross vehicle weight distribution for Crane SP Mileage (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 29 and Table 30, summarizing the axle weight and axle spacing respectively.

Table 29: Axle weight statistics for Crane SP Mileage (Rank 3)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
1	Axle 1	26,344	27,000	2,806	9,360	30,000	28,500
2	Axle 2	26,192	26,500	2,522	8,190	30,000	28,250
	Axle 3	25,943	26,500	2,467	8,190	30,000	27,500
2	Axle 4	26,084	26,500	2,561	11,996	30,000	28,500
	Axle 5	26,101	26,500	2,625	4,000	30,000	28,500

Table 30: Spacing statistics for Crane SP Mileage (Rank 3)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	107	106	11.46	96	232	108
Spacing 2	65	65	2.65	48	89	67
Spacing 3	100	96	29.81	96	480	97
Spacing 4	65	65	2.70	48	89	67

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 21.

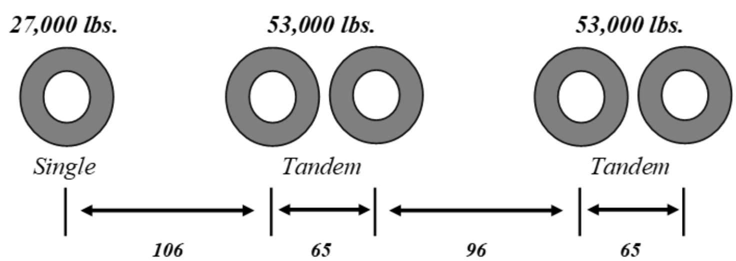

Figure 21: Schematic configuration for a vehicle with a Crane SP Mileage (Rank 3)

5.2.4 Crane Sp Mileage – Rank 4

The forth most frequent vehicle configuration under a Crane SP Mileage permit is the "2-3", with its GVW distribution presented in Figure 22.

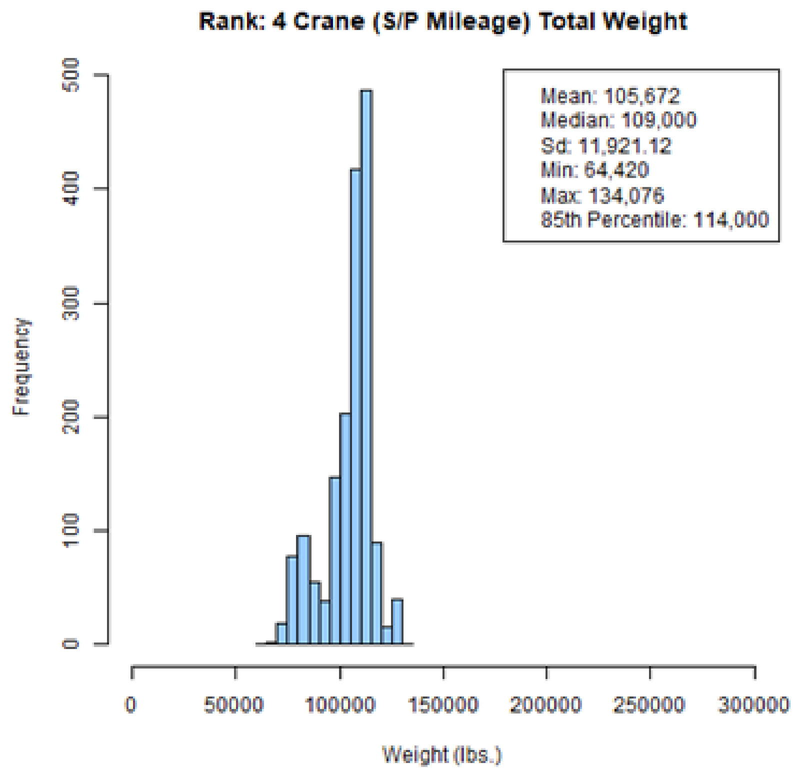

Figure 22: Gross vehicle weight distribution for Crane SP Mileage (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 31 and Table 32, summarizing the axle weight and axle spacing respectively.

Table 31: Axle weight statistics for Crane SP Mileage (Rank 4)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
2	Axle 1	20,877	22,000	2,836	8,000	29,130	23,000
	Axle 2	20,668	22,000	2,773	8,620	29,130	22,000
3	Axle 3	21,245	22,000	2,858	1,500	29,000	23,000
	Axle 4	21,473	22,000	2,342	12,040	29,000	23,000
	Axle 5	21,408	22,000	2,454	6,340	27,000	23,000

Table 32: Spacing statistics for Crane SP Mileage (Rank 4)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	71	72	6.57	48	93	75
Spacing 2	181	174	33.23	98	370	210
Spacing 3	56	54	3.15	48	78	59
Spacing 4	56	55	3.35	48	82	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 23.

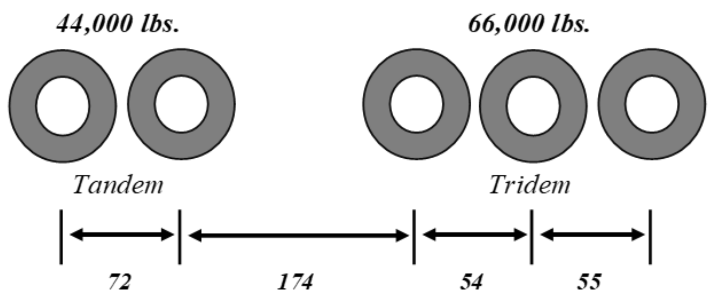

Figure 23: Schematic configuration for a vehicle with a Crane SP Mileage (Rank 4)

5.2.5 Crane Sp Mileage – Rank 5

The fifth most frequent vehicle configuration under a Crane SP Mileage permit is the "1-2-2-3", with its GVW distribution presented in Figure 24.

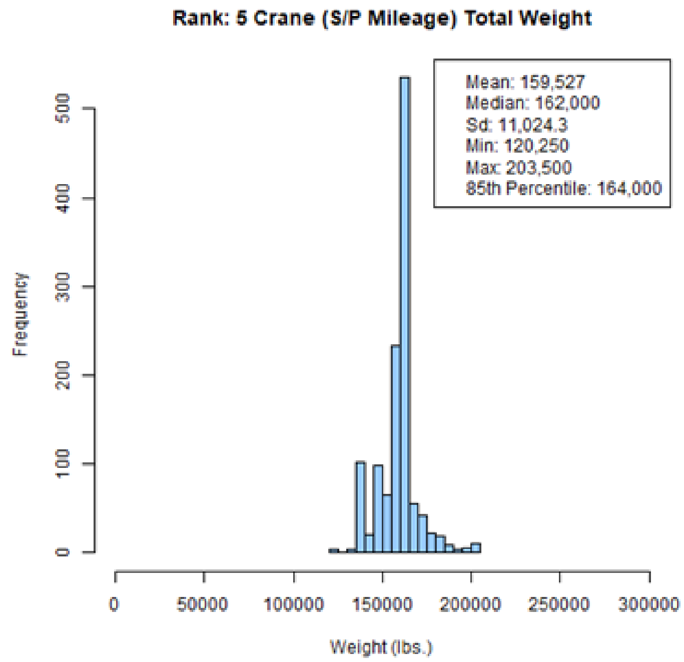

Figure 24: Gross vehicle weight distribution for Crane SP Mileage (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 33 and Table 34, summarizing the axle weight and axle spacing respectively.

Table 33: Axle weight statistics for Crane SP Mileage (Rank 5)

Group	Description	Mean	Median	SD	Min	Max	85th Perc.
1	Axle 1	21,128	22,000	2,175	13,100	28,000	23,000
2	Axle 2	21,736	22,600	2,239	14,400	28,000	23,000
	Axle 3	21,962	23,000	2,064	16,250	28,000	23,000
2	Axle 4	22,005	23,000	2,082	15,896	28,000	23,190
	Axle 5	22,011	23,000	2,083	15,896	28,000	23,420
3	Axle 6	16,940	16,000	2,133	6,166	24,000	19,500
	Axle 7	16,933	16,000	2,118	6,166	24,000	19,500
	Axle 8	16,812	16,000	2,482	1,700	24,000	19,500

Table 34: Spacing statistics for Crane SP Mileage (Rank 5)

Description	Mean	Median	SD	Min	Max	85th Perc.
Spacing 1	115	120	12.53	96	185	121
Spacing 2	64	64	1.83	53	72	65
Spacing 3	97	97	4.25	96	139	97
Spacing 4	64	64	1.83	59	72	65
Spacing 5	195	184	30.46	114	468	223
Spacing 6	55	54	2.96	48	72	60
Spacing 7	55	54	2.95	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 25.

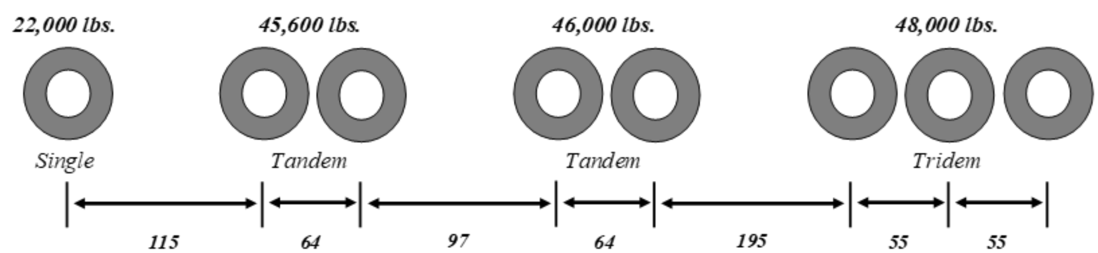

Figure 25: Schematic configuration for a vehicle with a Crane SP Mileage (Rank 5)

5.3 General

The General permit category comprises the most frequent OW permit issued, and also comprises a wide spectrum of GVW. General permits are further divided into four subcategories according to their GVM as follows:

- 80,000 $\leq$ GVW $\leq$ 120,000 lbs.
- 120,001 $\leq$ GVW $\leq$ 160,000 lbs.
- 160,001 $\leq$ GVW $\leq$ 200,000 lbs.
- 200,000 $\leq$ GVW $\leq$ 254,300 lbs.

5.3.1 General: 80,000 to 120,000 lbs.

This subcategory had 273 vehicle configurations. Those configurations that represented more than one percent of this subcategory fleet were ranked by frequency and are presented in Table 35.

Table 35: Vehicle configurations with GVW between 80,000 and 120,000 lbs.

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2-3	276,006	44.4%	44.4%
2	1-2-2	97,378	15.7%	60.0%
3	1-2-4	65,867	10.6%	70.6%
4	1-3-3	55,449	8.9%	79.5%
5	1-2-5	29,421	4.7%	84.3%
6	1-2-1-1	27,790	4.5%	88.7%
7	1-3-4	13,727	2.2%	90.9%
8	1-3-2	6,396	1.0%	92.0%

The distribution of the number of axles for this subcategory, among the different vehicle configurations, is presented in Figure 26.

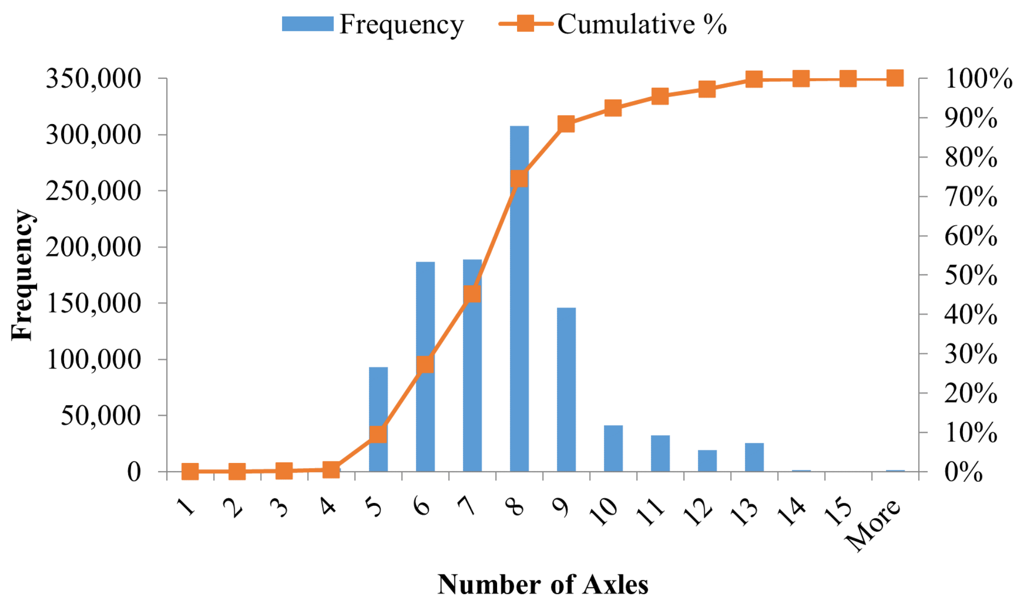

Figure 26: Distribution of the number of axles for General with GVW between 80,000 and 120,000 lbs.

As presented in Table 26, the most frequent vehicle configuration is the "1-2-3;; therefore this was selected as the representative vehicle configuration for this subcategory within General permits. Its GVW distribution is presented in Figure 27.

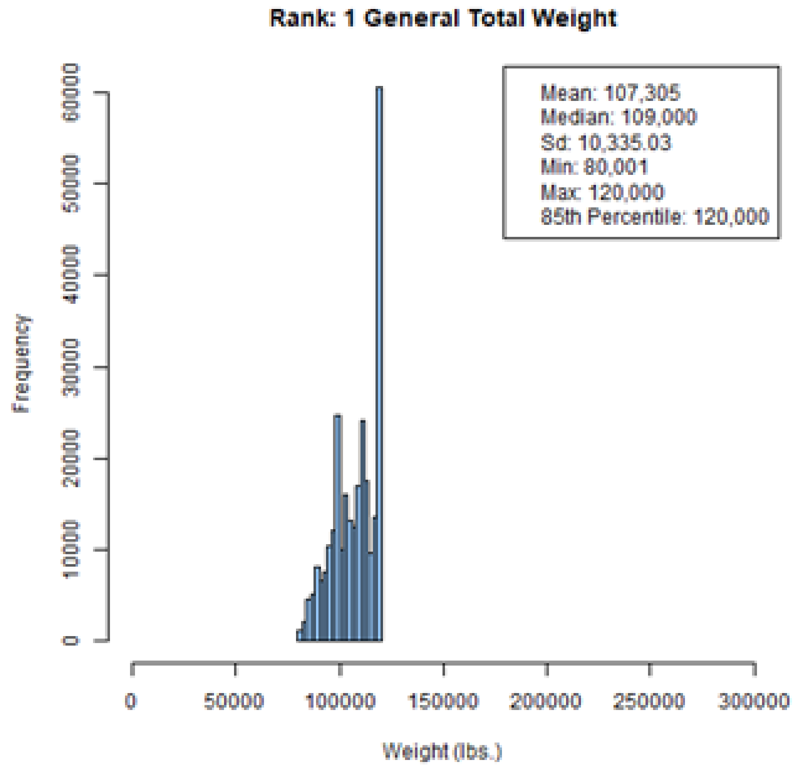

Figure 27: Gross vehicle weight distribution for General permit with with GVW between 80,000 and 120,000 lbs.

Descriptive statistics of the vehicle configuration are presented in Table 36 and Table 37, summarizing the axle weight and axle spacing respectively.

Table 36: Weight statistics for General permit with GVW between 80,000 and 120,000 lbs.

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	13,420	13,000	1,822.35	9,000	20,000	14,300
2	Axle 2	20,017	20,000	2,245.08	13,250	24,000	23,000
	Axle 3	20,019	20,000	2,242.42	13,250	24,000	23,000
3	Axle 4	17,984	18,400	2,148.71	11,500	21,875	20,000
	Axle 5	17,986	18,500	2,152.28	11,500	21,875	20,000
	Axle 6	17,978	18,500	2,157.33	11,500	21,875	20,000

Table 37: Spacing statistics for General permit with GVW between 80,000 and 120,000 lbs.

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	219	216	28.72	156	288	252
Spacing 2	55	60	6.03	48	72	60
Spacing 3	416	420	55.57	276	564	456
Spacing 4	57	60	6.26	48	72	60
Spacing 5	57	60	6.23	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 28.

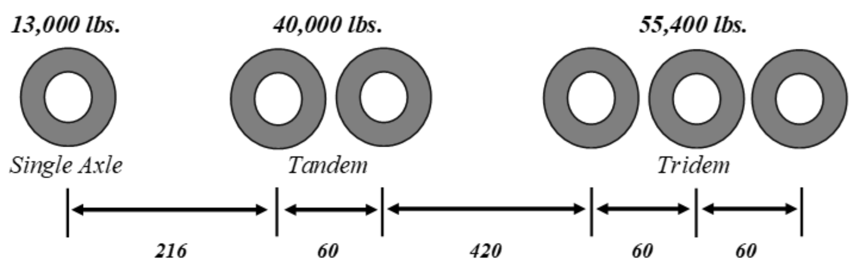

Figure 28: Schematic configuration for a vehicle with a General permit with GVW between 80,000 and 120,000 lbs.

5.3.2 General: 120,001 to 160,000 lbs.

This subcategory had 329 vehicle configurations. Those configurations that represented more than one percent of this subcategory fleet were ranked by frequency and are presented in Table 38.

Table 38: Vehicle configurations for General permits with GVW between 120,001 and 160,000 lbs.

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-3-4	249,905	34.3%	34.3%
2	1-2-5	122,432	16.8%	51.2%
3	1-3-3	105,801	14.5%	65.7%
4	1-2-4	67,896	9.3%	75.0%
5	1-3-3-1	45,227	6.2%	81.2%
6	1-3-5	43,468	6.0%	87.2%
7	1-2-3	13,982	1.9%	89.1%
8	1-2-2-3	13,473	1.9%	91.0%
9	1-2-3-3	13,263	1.8%	92.8%

The distribution of the number of axles for this subcategory, among the different vehicle configurations, is presented in Figure 29.

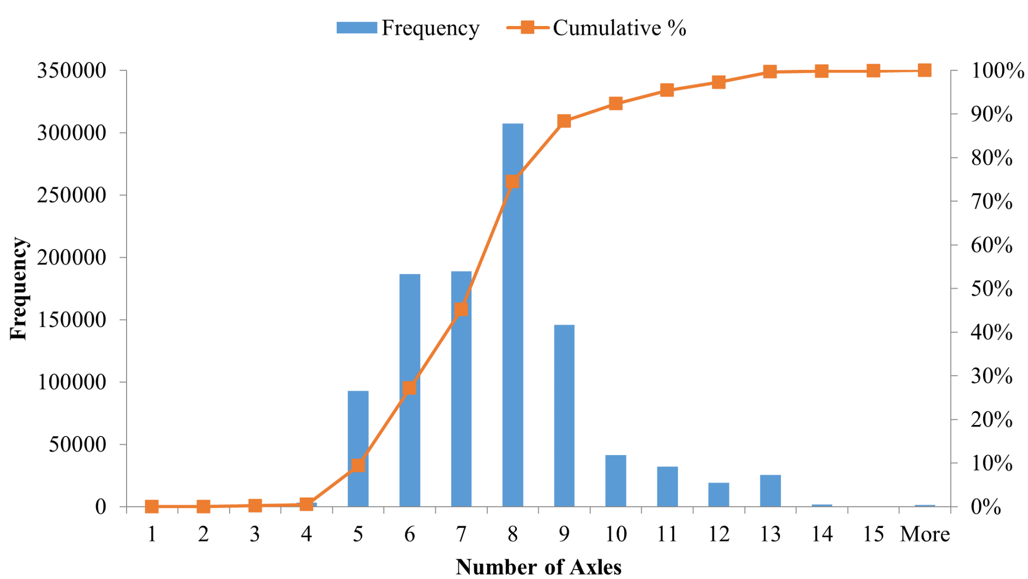

Figure 29: Distribution of the number of axles for General permit with GVW between 120,001 and 160,000 lbs.

As presented in Table 38, the most frequent vehicle configuration is the “1-3-4”, which was selected as the representative vehicle configuration for a General permit with GVW between 120,001 lbs. and 160,000 lbs. Its GVW distribution is presented in Figure 30.

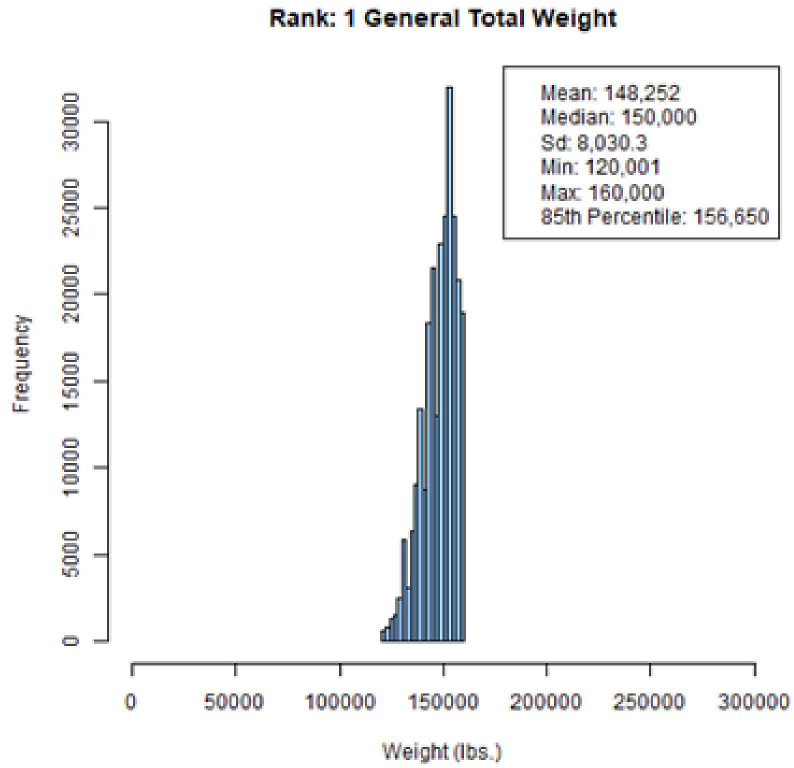

Figure 30: Gross vehicle weight distribution for the representative vehicle with a General permit with GVW between 120,001 and 160,000 lbs.

Descriptive statistics of the vehicle configuration are presented in Table 39 and Table 40, summarizing the axle weight and axle spacing respectively.

Table 39: Weight statistics for General permit with GVW between 120,001 and 160,000 lbs.

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	16,678	16,000	2,953.22	6,400	25,000	20,000
3	Axle 2	19,768	20,000	920.90	16,750	21,250	20,625
	Axle 3	20,214	20,000	312.26	19,100	21,250	20,625
	Axle 4	20,215	20,000	311.82	19,166	21,875	20,625
4	Axle 5	18,235	18,897	921.91	15,290	20,000	18,975
	Axle 6	18,234	18,899	922.21	15,290	20,000	18,975
	Axle 7	18,232	18,875	922.95	15,290	20,000	18,975
	Axle 8	18,233	18,899	925.52	15,290	21,000	18,975

Table 40: Spacing statistics for General permit with GVW between 120,001 and 160,000 lbs.

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	187	180	19.59	144	240	204
Spacing 2	60	60	0	60	60	60
Spacing 3	60	60	0	60	60	60
Spacing 4	431	432	19.27	384	480	444
Spacing 5	60	60	0	60	60	60
Spacing 6	60	60	0	60	60	60
Spacing 7	60	60	0	60	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 31.

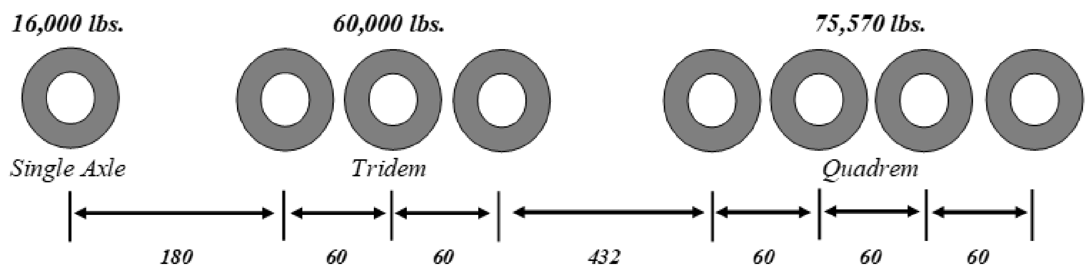

Figure 31: Schematic configuration for a vehicle with a General permit with GVW between 120,001 and 160,000 lbs.

5.3.3 General: 160,001 to 200,000 lbs.

This subcategory had 421 vehicle configurations. Those configurations that represented more than one percent of this subcategory fleet were ranked by frequency and are presented in Table 41.

Table 41: Vehicle configurations for General permits with GVW between 160,001 and 200,000 lbs.

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-3-5	96,892	32.4%	32.4%
2	1-3-3-2	22,049	7.4%	39.8%
3	1-2-2-2-2	17,934	6.0%	45.8%
4	1-3-5-2	14,237	4.8%	50.5%
5	1-2-5	12,805	4.3%	54.8%
6	1-2-2-3-2	10,955	3.7%	58.5%
7	1-3-2-3-2	9,430	3.2%	61.6%
8	1-3-3-1	8,945	3.0%	64.6%
9	1-2-3-3-3	7,539	2.5%	67.2%
10	1-2-2-5	7,381	2.5%	69.6%

The distribution of the number of axles for this subcategory, among the different vehicle configurations, is presented in Figure 32.

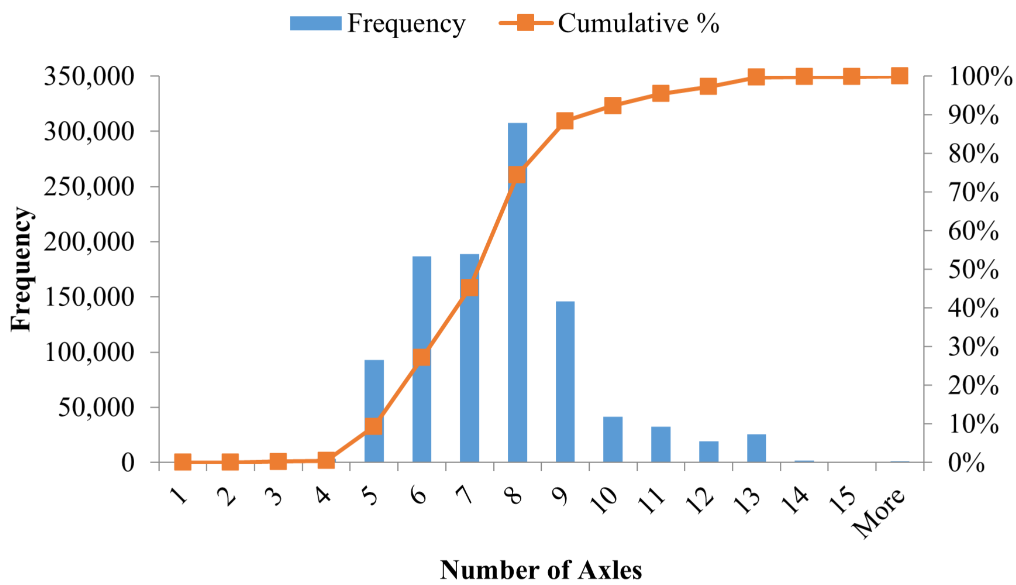

Figure 32: Distribution of the number of axles for General permit with GVW between 160,001 and 200,000 lbs.

As presented in Table 41, the most frequent vehicle configuration is the "1-3-5", which was selected as the representative vehicle configuration for a General permit with GVW between 160,001 lbs. and 200,000 lbs. Its GVW distribution is presented in Figure 33.

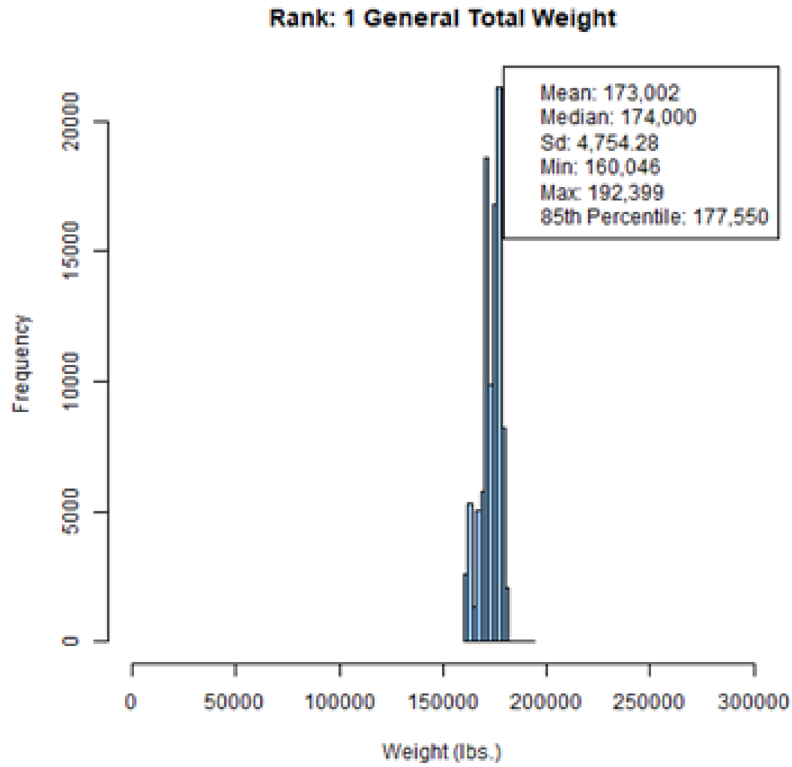

Figure 33: Gross vehicle weight distribution for the representative vehicle with a General permit with GVW between 160,001 and 200,000 lbs..

Descriptive statistics of the vehicle configuration are presented in Table 42 and Table 43, summarizing the axle weight and axle spacing respectively.

Table 42: Weight statistics for General permit with GVW between 160,001 and 200,000 lbs.

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	18,578	19,500	2,864.45	9,500	25,000	21,000
3	Axle 2	20,384	20,625	302.99	19,077	20,625	20,625
	Axle 3	20,386	20,625	296.85	19,077	20,625	20,625
	Axle 4	20,389	20,625	295.92	19,087	20,625	20,625
5	Axle 5	18,975	18,975	0.00	18,975	18,975	18,975
	Axle 6	18,975	18,975	0.00	18,975	18,975	18,975
	Axle 7	18,975	18,975	0.00	18,975	18,975	18,975
	Axle 8	18,975	18,975	0.00	18,975	18,975	18,975
	Axle 9	18,975	18,975	0.00	18,975	18,975	18,975

Table 43: Spacing statistics for General permit with GVW between 160,001 and 200,000 lbs.

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	197	192	17.83	144	240	216
Spacing 2	60	60	0.00	60	60	60
Spacing 3	60	60	0.00	60	60	60
Spacing 4	402	408	33.64	300	492	432
Spacing 5	60	60	0.00	60	60	60
Spacing 6	60	60	0.00	60	60	60
Spacing 7	60	60	0.00	60	60	60
Spacing 8	60	60	0.00	60	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 34.

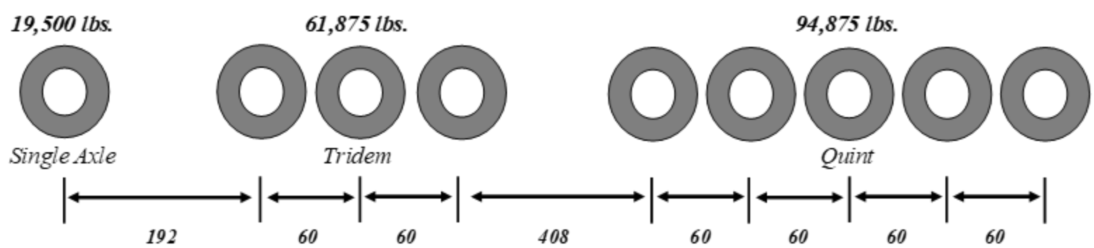

Figure 34: Schematic configuration for a vehicle with a General permit with GVW between 160,001 and 200,000 lbs.

5.3.4 General: 200,001 to 254,300 lbs.

This subcategory had 309 vehicle configurations. Those configurations that represented more than one percent of this subcategory fleet were ranked by frequency and are presented in Table 44.

Table 44: Vehicle configurations for General permits with GVW between 200,001 and 254,300 lbs.

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-3-3-3-3	35,717	40.7%	40.7%
2	1-3-2-2-2	10,331	11.8%	52.5%
3	1-2-2-2-2	8,088	9.2%	61.7%
4	1-3-3-3-2	8,055	9.2%	70.9%
5	1-2-3-3-3	4,815	5.5%	76.4%
6	1-3-2-3-2	2,836	3.2%	79.7%
7	1-2-3-2-3	1,990	2.3%	81.9%
8	1-3-5-2	1,676	1.9%	83.8%
9	1-2-3-3-2	1,593	1.8%	85.7%
10	1-3-2-5-2	1,179	1.3%	87.0%
11	1-3-3-5-2	1,166	1.3%	88.3%
12	1-2-2-3-2	956	1.1%	89.4%
13	1-2-2-5-2	870	1.0%	90.4%

The distribution of the number of axles for this subcategory, among the different vehicle configurations, is presented in Figure 35.

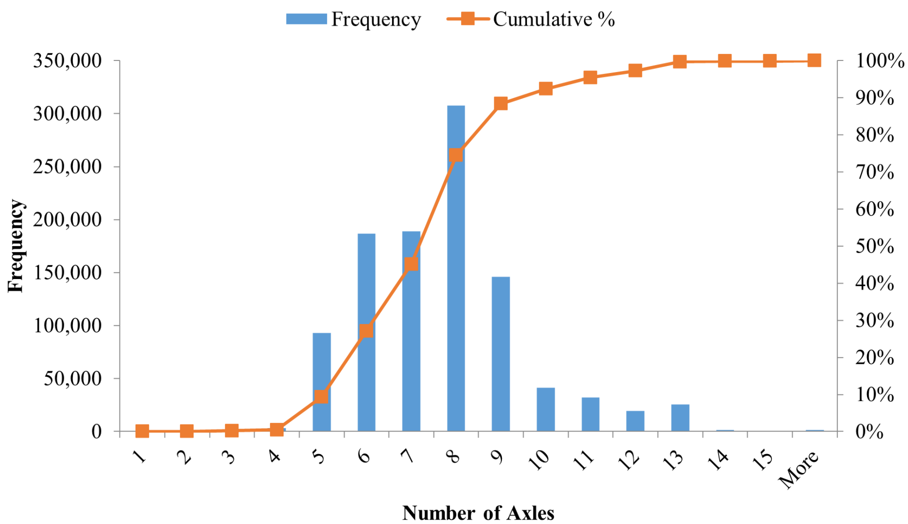

Figure 35: Distribution of the number of axles for General permit with GVW between 200,001 and 254,300 lbs.

As presented in Table 44, the most frequent vehicle configuration is the "1-3-3-3-3", which was selected as the representative vehicle configuration for a General permit with GVW between 200,001 lbs. and 254,300 lbs. Its GVW distribution is presented in Figure 36.

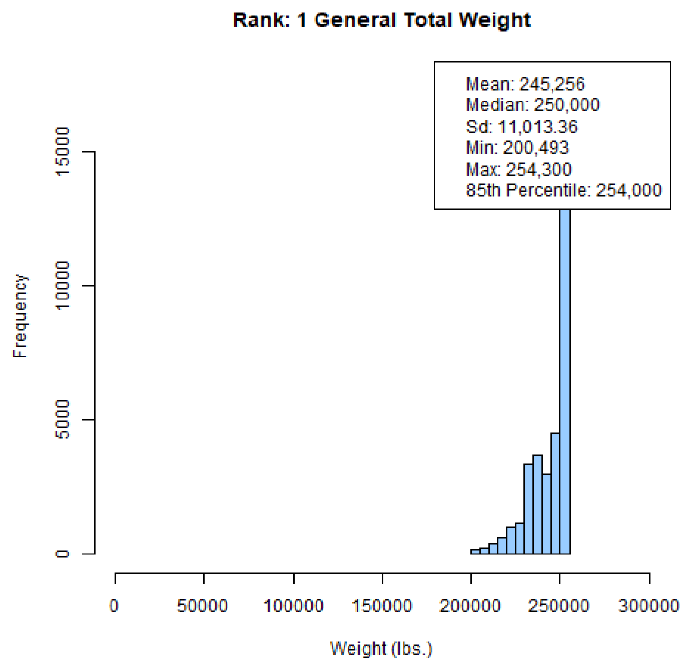

Figure 36: Gross vehicle weight distribution for the representative vehicle with a General permit with GVW between 200,001 and 254,300 lbs.

Descriptive statistics of the vehicle configuration are presented in Table 45 and Table 46, summarizing the axle weight and axle spacing respectively. A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 37.

Table 45: Weight statistics for General permit with GVW between 200,001 and 254,300 lbs.

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	16,095	16,000	1,833.31	9,500	25,000	18,000
3	Axle 2	19,210	19,500	907.39	16,408	20,625	20,000
	Axle 3	19,245	19,500	907.17	16,408	20,625	20,000
	Axle 4	19,245	19,500	898.55	16,408	20,625	20,000
3	Axle 5	19,230	19,700	948.26	16,250	20,625	20,000
	Axle 6	19,233	19,667	947.83	16,250	20,625	20,000
	Axle 7	19,221	19,667	942.97	16,250	20,625	20,000
3	Axle 8	19,216	19,500	904.24	16,416	20,625	20,000
	Axle 9	19,214	19,500	904.01	16,417	20,625	20,000
	Axle 10	19,204	19,500	902.63	16,417	20,625	20,000
3	Axle 11	19,148	19,300	894.64	16,400	20,625	20,000
	Axle 12	19,142	19,400	899.71	16,250	20,625	20,000
	Axle 13	19,134	19,300	897.71	16,250	20,625	20,000

Table 46: Spacing statistics for General permit with GVW between 200,001 and 254,300 lbs.

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	193	192	18.37	144	240	216
Spacing 2	60	60	0.00	60	60	60
Spacing 3	60	60	0.00	60	60	60
Spacing 4	186	180	18.41	132	228	204
Spacing 5	60	60	0.00	60	60	60
Spacing 6	60	60	0.00	60	60	60
Spacing 7	663	552	322.85	96	1,620	1,068
Spacing 8	60	60	0.00	60	60	60
Spacing 9	60	60	0.00	60	60	60
Spacing 10	176	168	9.96	156	192	192
Spacing 11	60	60	0.00	60	60	60
Spacing 12	60	60	0.00	60	60	60

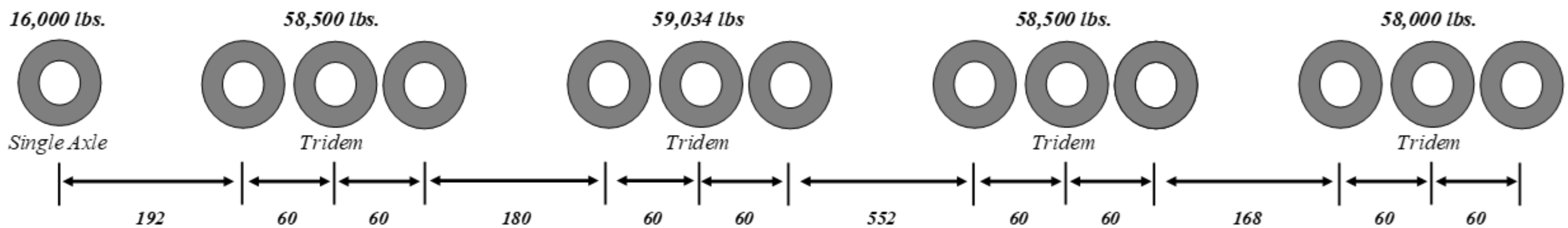

Figure 37: Schematic axle configuration for the representative vehicle under a General permit with GVW between 200,001 and 254,300 lbs.

5.4 Hubometer

The Hubometer permit had 132 vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 47.

Table 47: Common vehicle configurations with a Hubometer permit

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2-3	74,794	36.0%	36.0%
2	2-3	36,172	17.4%	53.4%
3	1-2-2	25,735	12.4%	65.8%
4	2-2	15,684	7.6%	73.4%
5	1-2	8,801	4.2%	77.6%
6	1-2-1-1	6,619	3.2%	80.8%
7	1-4	5,974	2.9%	83.7%
8	1-3-3	4,777	2.3%	86.0%
9	1-3	2,334	1.1%	87.1%
10	1-3-4	2,098	1.0%	88.1%

The distribution of the number of axles for the Hubometer permit, among the different vehicle configurations, is presented in Figure 38.

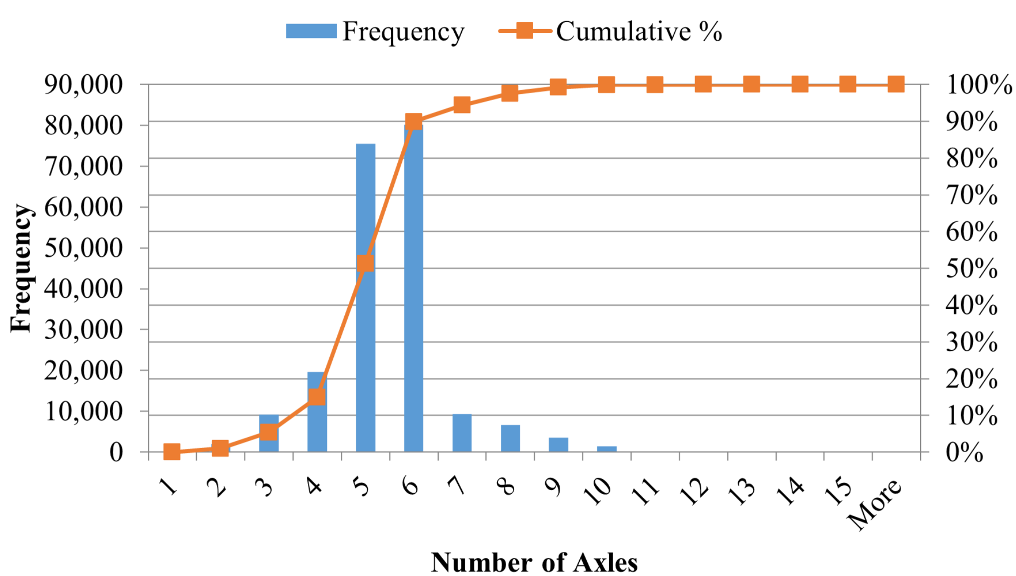

Figure 38: Distribution of the number of axles for the Hubometer permit

5.4.1 Hubometer – Rank 1

The most frequent vehicle configuration under a Hubometer permit is the "1-2-3", with its GVW distribution presented in Figure 39.

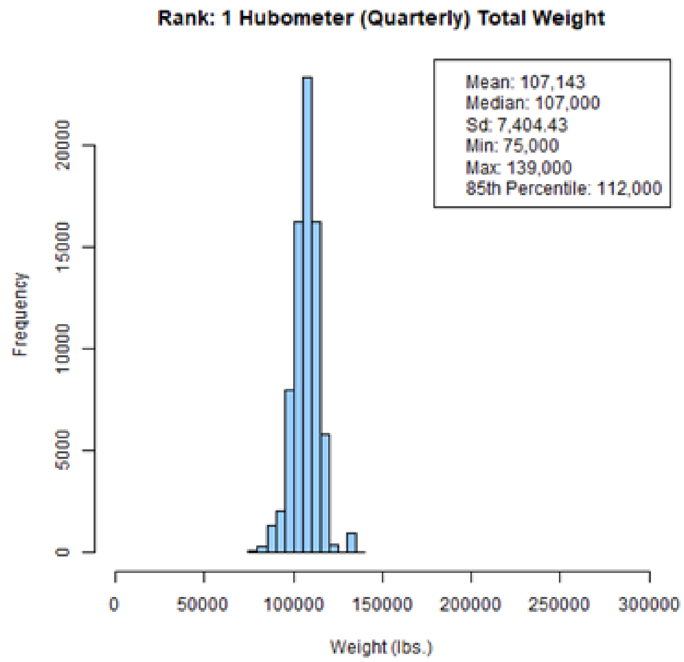

Figure 39: Gross vehicle weight distribution for the Hubometer permit (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 48 and Table 49, summarizing the axle weight and axle spacing respectively.

Table 48: Weight statistics for the Hubometer permit (Rank 1)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	12,533	12,000	903.05	10,500	16,000	13,500
2	Axle 2	19,377	20,000	1,504.52	15,000	25,000	20,000
	Axle 3	19,414	20,000	1,660.94	15,000	26,000	20,000
3	Axle 4	18,707	19,000	1,669.87	14,000	26,000	20,000
	Axle 5	18,671	19,000	1,708.59	14,000	26,000	20,000
	Axle 6	18,720	19,000	1,682.47	14,000	26,000	20,000

Table 49: Spacing statistics for the Hubometer permit (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	194.00	190.00	16.90	144.00	240.00	210.00
Spacing 2	53.00	53.00	1.24	49.00	57.00	54.00
Spacing 3	320.00	324.00	20.98	246.00	390.00	341.00
Spacing 4	56.00	54.00	4.41	48.00	69.00	60.00
Spacing 5	55.00	54.00	4.44	48.00	72.00	60.00

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 40.

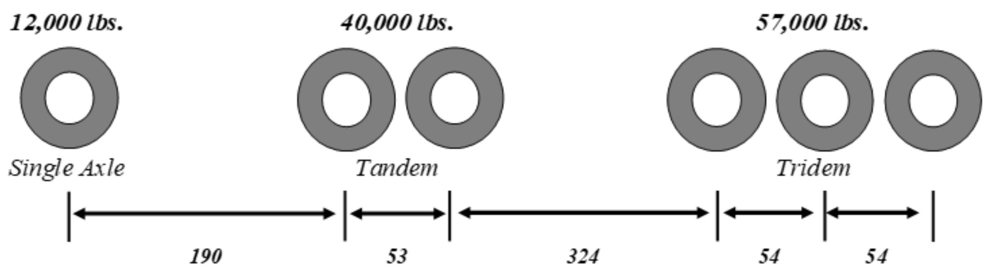

Figure 40: Schematic configuration for the Hubometer permit (Rank 1)

5.4.2 Hubometer – Rank 2

The second most frequent vehicle configuration under a Hubometer permit is the "2-3", with its GVW distribution presented in Figure 41.

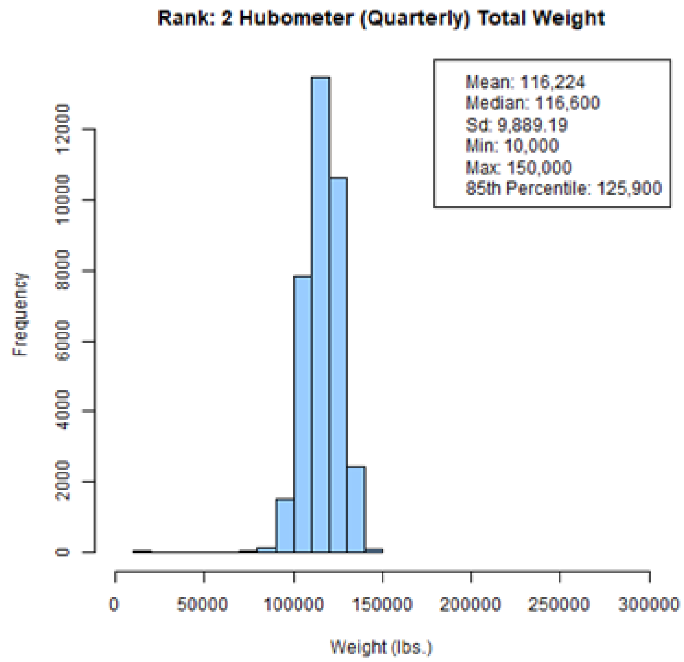

Figure 41: Gross vehicle weight distribution for the Hubometer permit (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 50 and Table 51, summarizing the axle weight and axle spacing respectively.

Table 50: Weight statistics for the Hubometer permit (Rank 2)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	22,847	23,000	2,713	1,960	30,000	25,000
	Axle 2	23,084	23,000	2,791	2,000	30,000	25,600
3	Axle 3	23,445	23,500	3,214	2,000	30,000	26,500
	Axle 4	24,121	24,000	2,628	2,000	30,000	26,750
	Axle 5	22,726	23,000	3,160	1,800	30,000	25,500

Table 51: Spacing statistics for the Hubometer permit (Rank 2)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	55	54	6.56	48	93	61
Spacing 2	216	219	34.65	96	576	242
Spacing 3	54	54	4.28	48	85	57
Spacing 4	55	54	5.29	48	85	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 42.

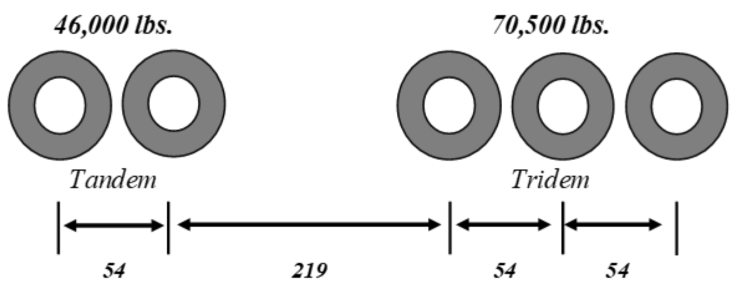

Figure 42: Schematic configuration for the Hubometer permit (Rank 2)

5.4.3 Hubometer – Rank 3

The third most frequent vehicle configuration under a Hubometer permit is the "1-2-2", with its GVW distribution presented in Figure 43.

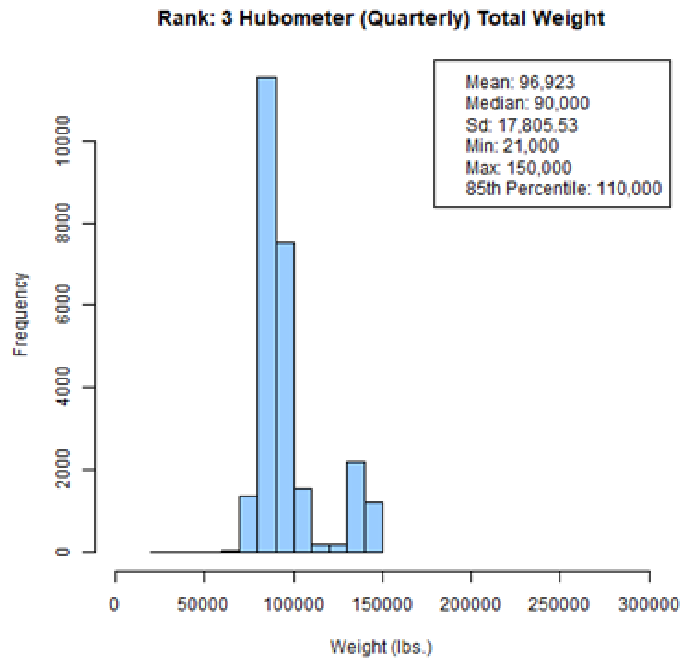

Figure 43: Gross vehicle weight distribution for the Hubometer permit (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 52 and Table 53, summarizing the axle weight and axle spacing respectively.

Table 52: Weight statistics for the Hubometer permit (Rank 3)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	14,736	12,200	5,362	1,200	30,000	19,000
2	Axle 2	20,302	20,000	3,485	2,000	30,000	23,000
	Axle 3	20,295	20,000	3,514	1,800	30,000	23,000
2	Axle 4	20,799	20,000	3,308	1,800	30,000	23,666
	Axle 5	20,790	20,000	3,275	1,800	30,000	23,250

Table 53: Spacing statistics for the Hubometer permit (Rank 3)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	176	180	34.40	96	281	205
Spacing 2	55	54	5.45	48	89	60
Spacing 3	319	332	107.23	96	660	404
Spacing 4	55	54	6.97	48	95	65

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 44.

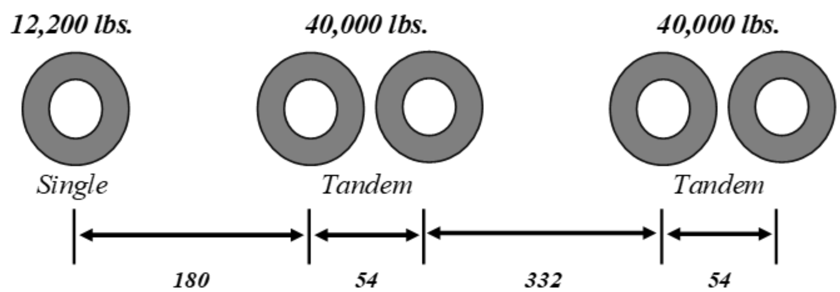

Figure 44: Schematic configuration for the Hubometer permit (Rank 3)

5.4.4 Hubometer – Rank 4

The fourth most frequent vehicle configuration under a Hubometer permit is the "2-2", with its GVW distribution presented in Figure 45.

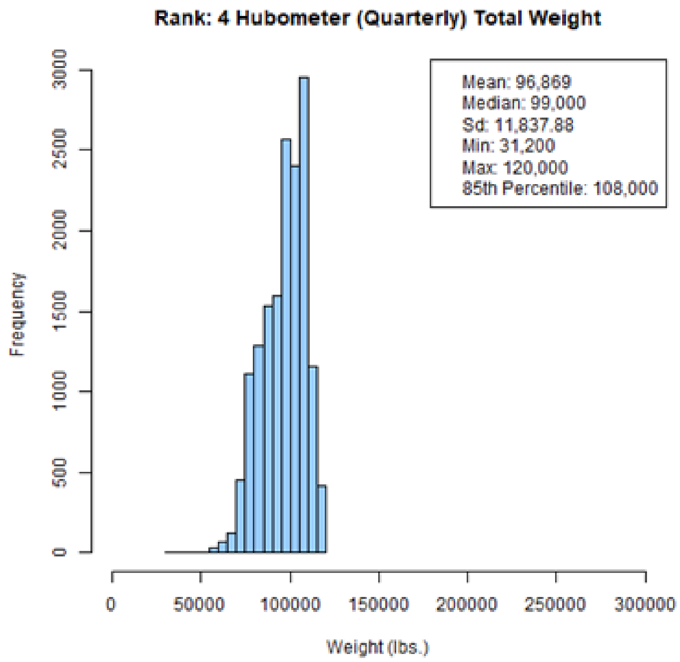

Figure 45: Gross vehicle weight distribution for the Hubometer permit (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 54 and Table 55, summarizing the axle weight and axle spacing respectively.

Table 54: Weight statistics for the Hubometer permit (Rank 4)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	22,397	22,500	3,958	7,310	30,000	26,500
	Axle 2	22,508	22,750	3,906	2,400	30,000	26,500
2	Axle 3	25,986	26,500	2,943	2,400	30,000	29,000
	Axle 4	25,979	26,500	3,016	2,400	30,000	29,000

Table 55: Spacing statistics for the Hubometer permit (Rank 4)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	58	56	8.58	48	92	66
Spacing 2	193	185	46.19	96	363	234
Spacing 3	56	55	5.94	48	89	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 46.

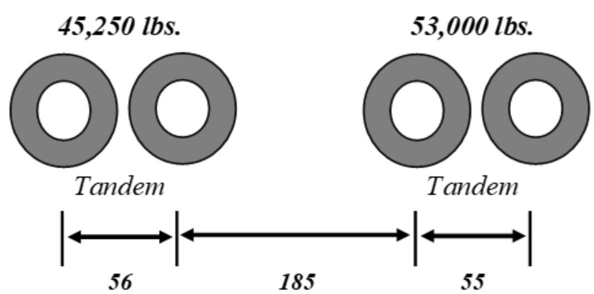

Figure 46: Schematic configuration for the Hubometer permit (Rank 4)

5.4.5 Hubometer – Rank 5

The fifth most frequent vehicle configuration under a Hubometer permit is the "1-2", with its GVW distribution presented in Figure 47.

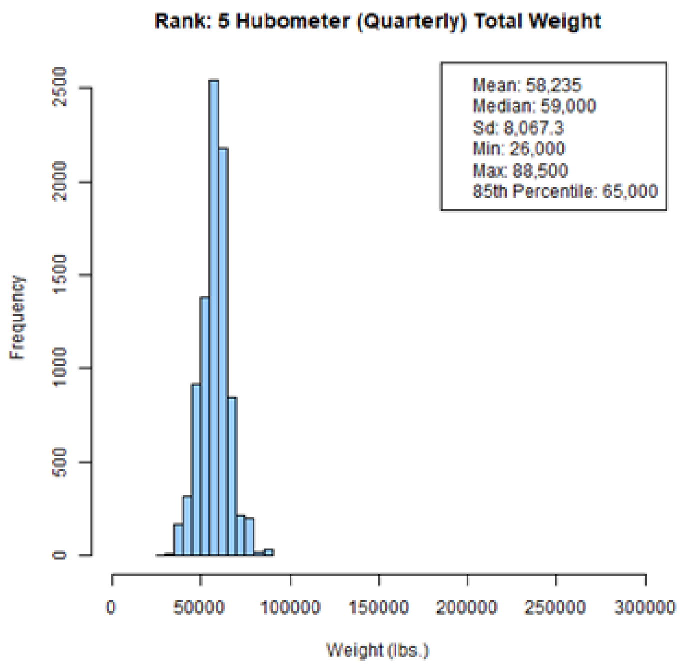

Figure 47: Gross vehicle weight distribution for the Hubometer permit (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 56 and Table 57, summarizing the axle weight and axle spacing respectively.

Table 56: Weight statistics for the Hubometer permit (Rank 5)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	17,194	18,000	3,363	2,000	29,000	20,000
2	Axle 2	20,536	20,500	3,073	2,210	30,000	23,000
	Axle 3	20,504	20,500	3,032	9,000	30,000	23,000

Table 57: Spacing statistics for the Hubometer permit (Rank 5)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	221	218	39.86	96	378	265
Spacing 2	52	52	4.00	48	89	55

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 48.

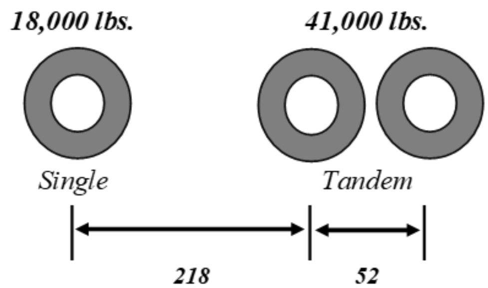

Figure 48: Schematic configuration for the Hubometer permit (Rank 5)

5.5 Implement Husbandry

The Implement Husbandry permit had 29 vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 58.

Table 58: Common configurations with an Implement Husbandry permit

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2-3	1,312	60.4%	60.4%
2	1-2-2	493	22.7%	83.1%
3	1-3-3	123	5.7%	88.8%
4	1-2-1-1	60	2.8%	91.5%
5	1-3-4	58	2.7%	94.2%
6	1-2	31	1.4%	95.6%
7	1-3-1-1	21	1.0%	96.6%

The distribution of the number of axles for the Implement Husbandry permit, among the different vehicle configurations, is presented in Figure 49.

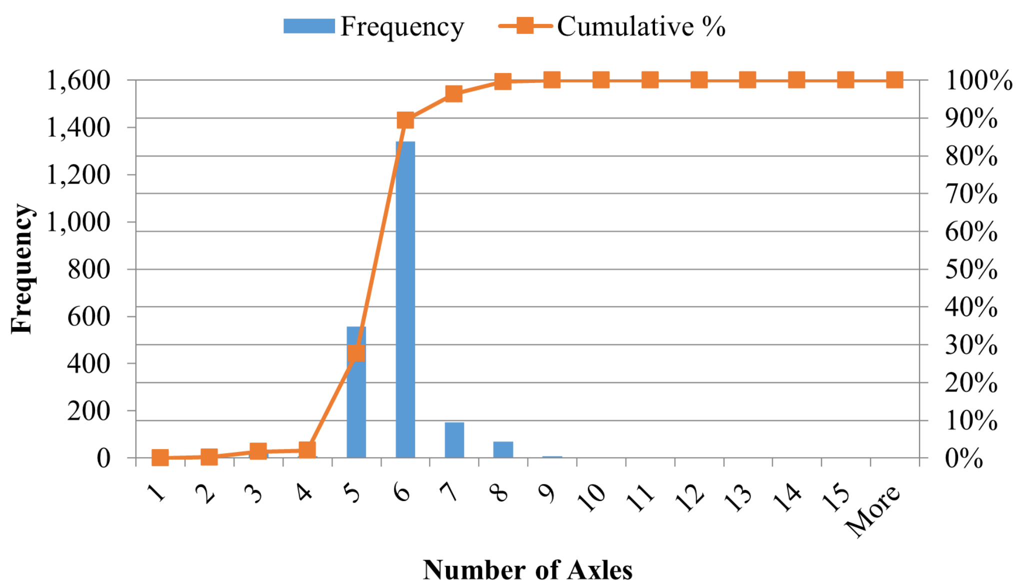

Figure 49: Distribution of the number of axles for Implement Husbandry permits

5.5.1 Implement Husbandry – Rank 1

The most frequent vehicle configuration is the "1-2-3", with its GVW distribution presented in Figure 50.

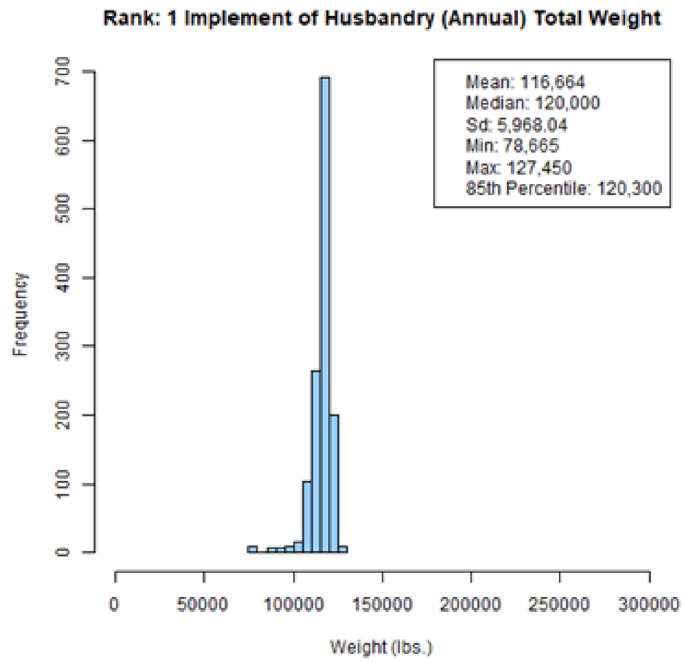

Figure 50: Gross vehicle weight distribution for the Implement Husbandry permit (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 59 and Table 60, summarizing the axle weight and axle spacing respectively.

Table 59: Weight statistics for the Implement Husbandry permit (Rank 1)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	13,340	14,000	1,199.89	10,000	20,000	14,250
2	Axle 2	21,982	23,000	1,571.75	15,600	23,000	23,000
	Axle 3	21,980	23,000	1,564.08	15,600	23,000	23,000
3	Axle 4	20,000	20,000	0.00	20,000	20,000	20,000
	Axle 5	20,000	20,000	0.00	20,000	20,000	20,000
	Axle 6	20,000	20,000	0.00	20,000	20,000	20,000

Table 60: Spacing statistics for the Implement Husbandry permit (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	216	228	32.29	120	312	240
Spacing 2	52	48	5.70	48	72	60
Spacing 3	438	456	60.67	276	600	504
Spacing 4	52	48	6.14	48	72	60
Spacing 5	53	48	6.45	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 51.

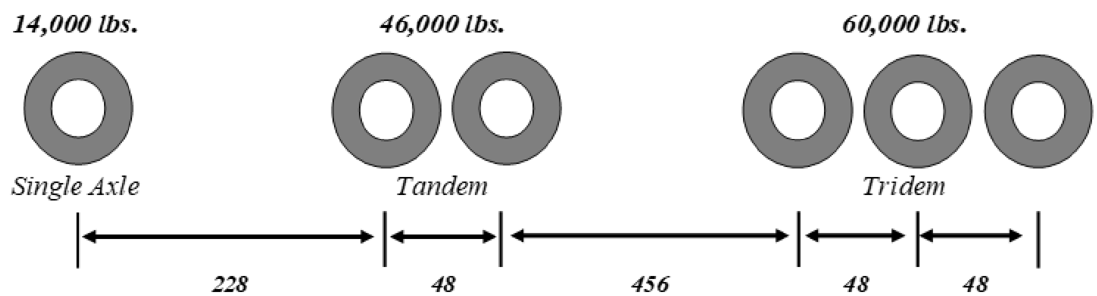

Figure 51: Schematic configuration for the Implement Husbandry permit (Rank 1)

5.5.2 Implement Husbandry – Rank 2

The second most frequent vehicle configuration is the "1-2-2", with its GVW distribution presented in Figure 52.

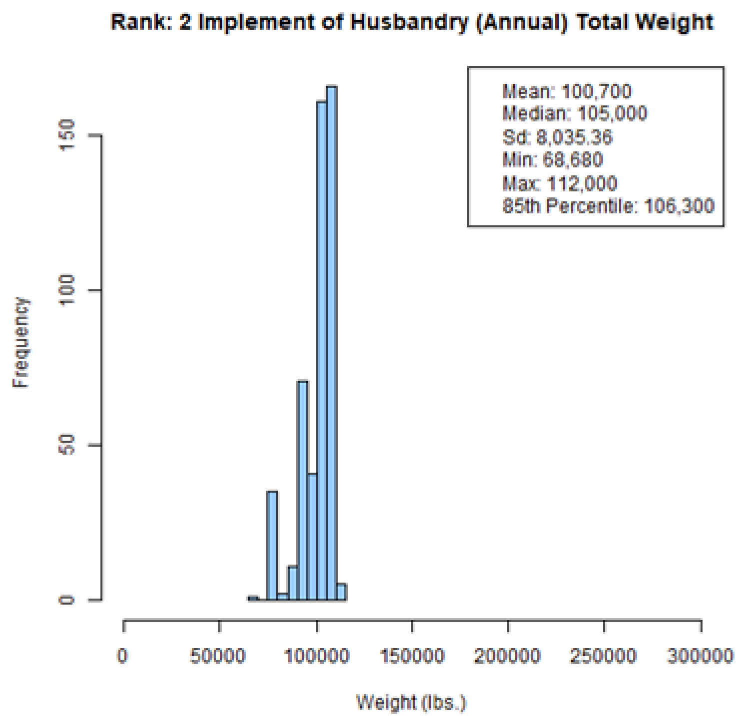

Figure 52: Gross vehicle weight distribution for the Implement Husbandry permit (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 61 and Table 62, summarizing the axle weight and axle spacing respectively.

Table 61: Weight statistics for the Implement Husbandry permit (Rank 2)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	13,212	13,000	1,246	10,000	20,000	14,300
2	Axle 2	21,891	23,000	1,929	9,100	23,000	23,000
	Axle 3	21,891	23,000	1,929	9,100	23,000	23,000
2	Axle 4	21,870	23,000	1,876	13,600	23,000	23,000
	Axle 5	21,836	23,000	2,063	2,700	23,000	23,000

Table 62: Spacing statistics for the Implement Husbandry permit (Rank 2)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	221	228	28.99	120	276	252
Spacing 2	52	48	5.74	48	72	60
Spacing 3	442	456	61.69	216	672	492
Spacing 4	52	48	5.98	48	84	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 53.

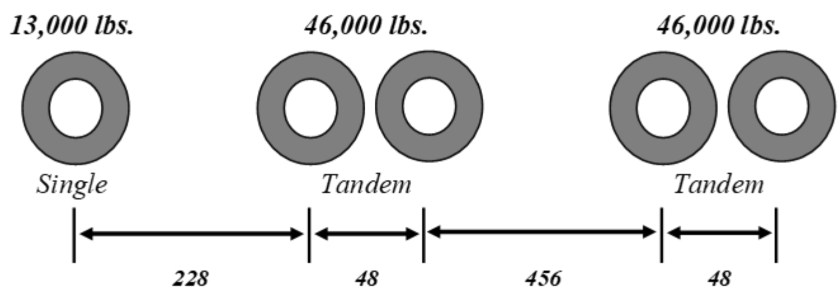

Figure 53: Schematic configuration for the Implement Husbandry permit (Rank 2)

5.5.3 Implement Husbandry – Rank 3

The third most frequent vehicle configuration is the "1-3-3", with its GVW distribution presented in Figure 54.

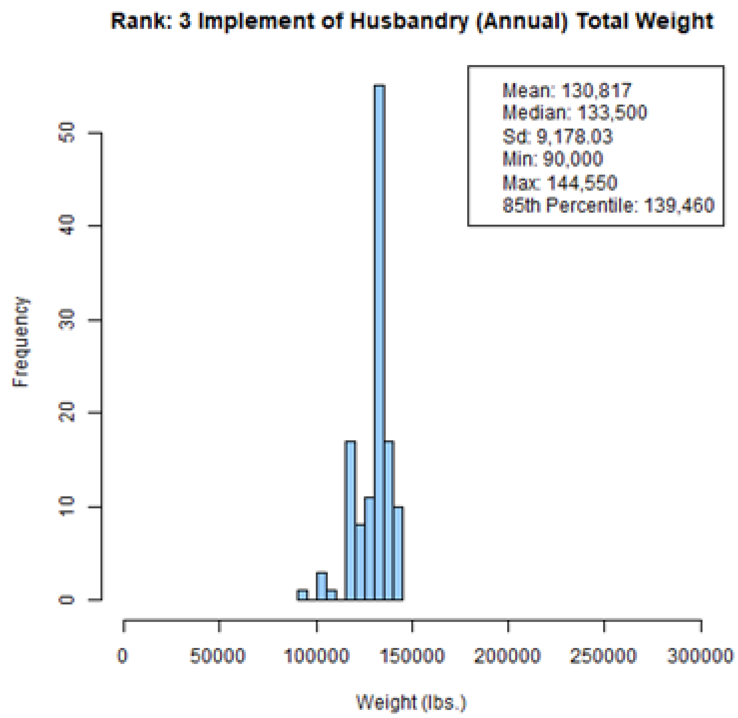

Figure 54: Gross vehicle weight distribution for the Implement Husbandry permit (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 63 and Table 64, summarizing the axle weight and axle spacing respectively.

Table 63: Weight statistics for the Implement Husbandry permit (Rank 3)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	14,639	14,000	2,732	11,700	20,800	19,460
3	Axle 2	17,650	20,000	3,984	8,000	20,625	20,000
	Axle 3	19,645	20,000	1,324	12,857	20,625	20,458
	Axle 4	19,645	20,000	1,324	12,858	20,625	20,458
3	Axle 5	19,746	20,000	1,160	12,857	20,625	20,000
	Axle 6	19,746	20,000	1,160	12,857	20,625	20,000
	Axle 7	19,746	20,000	1,160	12,857	20,625	20,000

Table 64: Spacing statistics for the Implement Husbandry permit (Rank 3)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	188	192	27.92	120	240	216
Spacing 2	54	48	7.42	48	84	60
Spacing 3	54	48	6.01	48	60	60
Spacing 4	429	432	59.53	288	516	504
Spacing 5	52	48	5.83	48	60	60
Spacing 6	53	48	5.94	48	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 55.

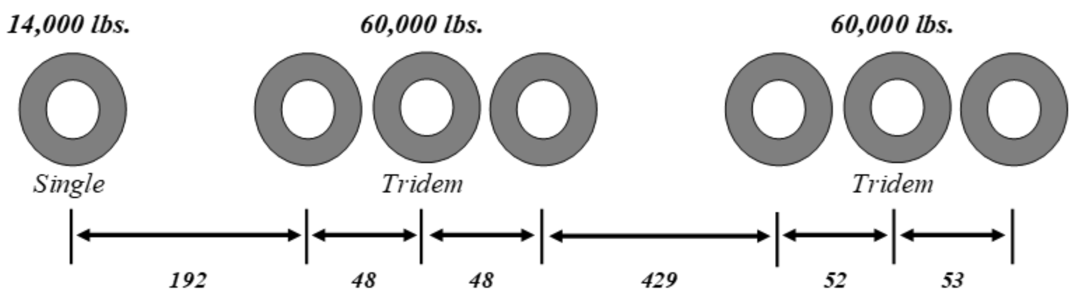

Figure 55: Schematic configuration for the Implement Husbandry permit (Rank 3)

5.5.4 Implement Husbandry – Rank 4

The fourth most frequent vehicle configuration is the "1-2-1-1", with its GVW distribution presented in Figure 56.

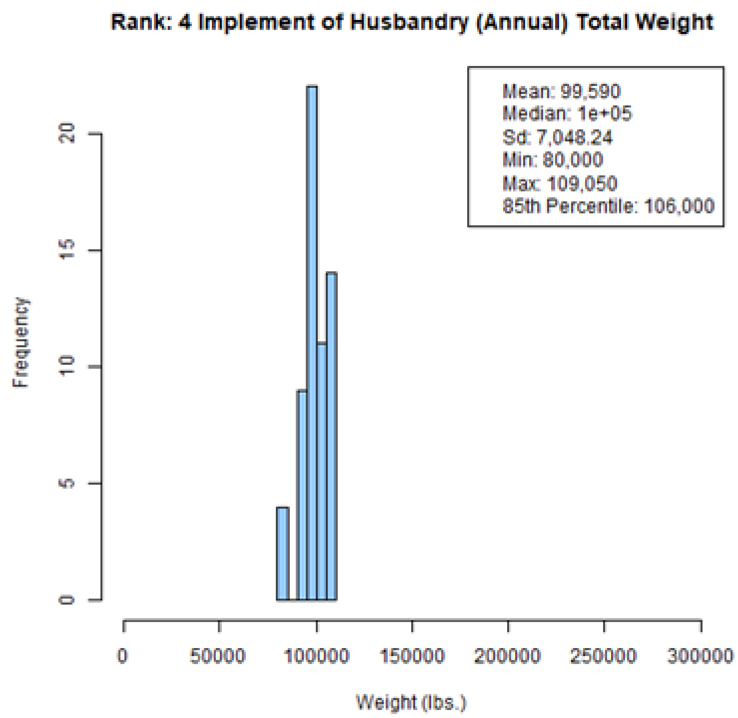

Figure 56: Gross vehicle weight distribution for the Implement Husbandry permit (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 65 and Table 66, summarizing the axle weight and axle spacing respectively.

Table 65: Weight statistics for the Implement Husbandry permit (Rank 4)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	12,953	13,000	1,045	11,050	14,300	14,250
2	Axle 2	21,644	22,000	1,678	17,000	23,000	23,000
	Axle 3	21,644	22,000	1,678	17,000	23,000	23,000
1	Axle 4	21,675	22,000	1,783	17,000	24,375	23,000
1	Axle 5	21,675	22,000	1,783	17,000	24,375	23,000

Table 66: Spacing statistics for the Implement Husbandry permit (Rank 4)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	225	228	22.84	168	288	240
Spacing 2	56	60	5.63	48	60	60
Spacing 3	415	408	42.57	336	528	444
Spacing 4	117	120	7.02	96	120	120

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 57.

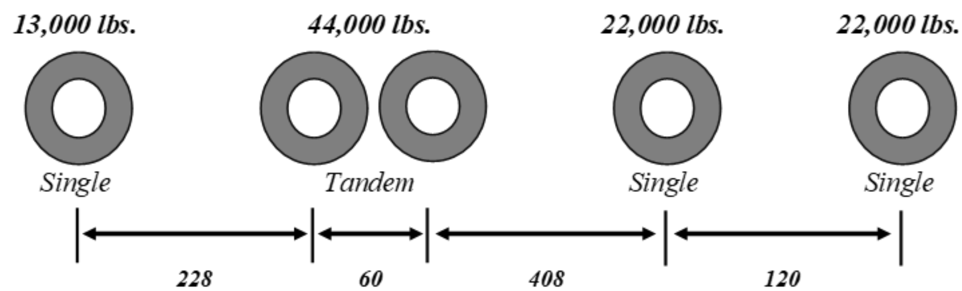

Figure 57: Schematic configuration for the Implement Husbandry permit (Rank 4)

5.5.5 Implement Husbandry – Rank 5

The fifth most frequent vehicle configuration is the "1-3-4", with its GVW distribution presented in Figure 58.

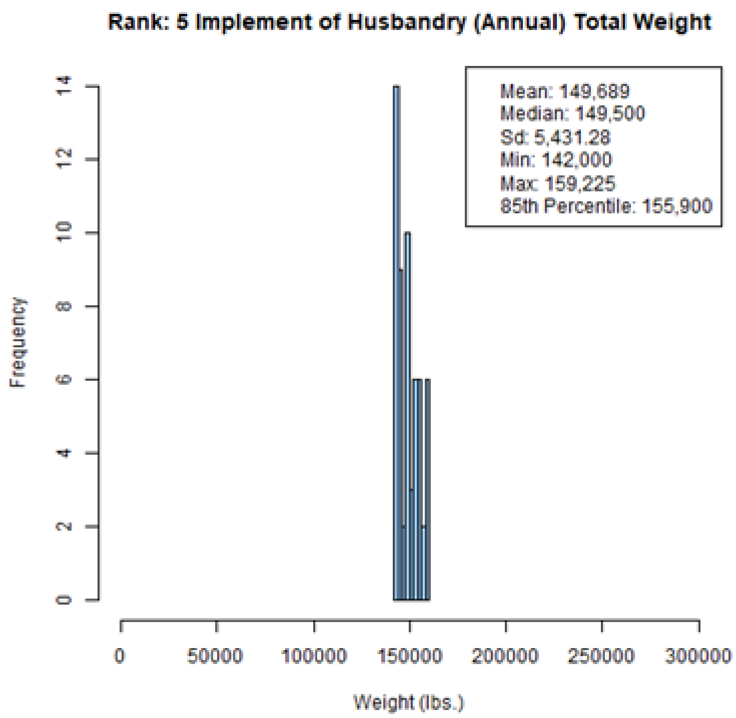

Figure 58: Gross vehicle weight distribution for the Implement Husbandry permit (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 67 and Table 68, summarizing the axle weight and axle spacing respectively.

Table 67: Weight statistics for the Implement Husbandry permit (Rank 5)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	16,600	15,850	3,303	12,000	22,100	20,000
3	Axle 2	20,066	20,000	386	18,500	20,625	20,625
	Axle 3	20,118	20,000	246	20,000	20,625	20,625
	Axle 4	20,118	20,000	246	20,000	20,625	20,625
4	Axle 5	18,197	18,000	700	17,500	18,975	18,975
	Axle 6	18,197	18,000	700	17,500	18,975	18,975
	Axle 7	18,197	18,000	700	17,500	18,975	18,975
	Axle 8	18,197	18,000	700	17,500	18,975	18,975

Table 68: Spacing statistics for the Implement Husbandry permit (Rank 5)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	184	180	27.57	144	240	216
Spacing 2	54	48	6.05	48	60	60
Spacing 3	54	48	6.04	48	60	60
Spacing 4	426	420	30.67	360	504	456
Spacing 5	55	60	5.96	48	60	60
Spacing 6	55	60	5.96	48	60	60
Spacing 7	56	60	5.68	48	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 59.

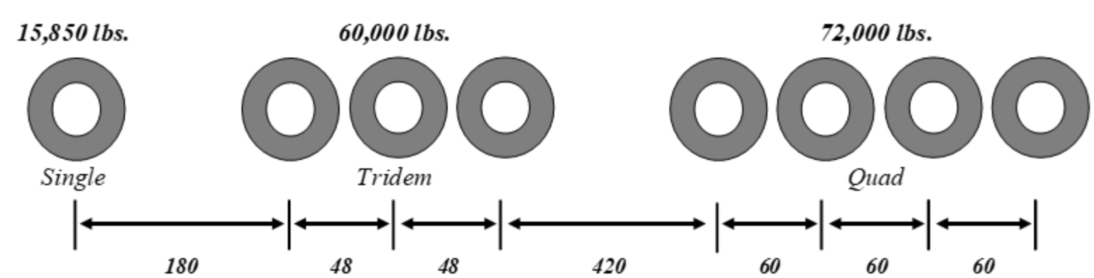

Figure 59: Schematic configuration for the Implement Husbandry permit (Rank 5)

5.6 Rig-up Truck

The Rig-up Truck permit had 14 vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 69.

Table 69: Common vehicle configurations with a Rig-up Truck permit

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2	705	53.5%	53.5%
2	2-2	513	39.0%	92.5%
3	1-1-2	58	4.4%	96.9%

The distribution of the number of axles for the Rig-up Truck permit, among the different vehicle configurations, is presented in Figure 60.

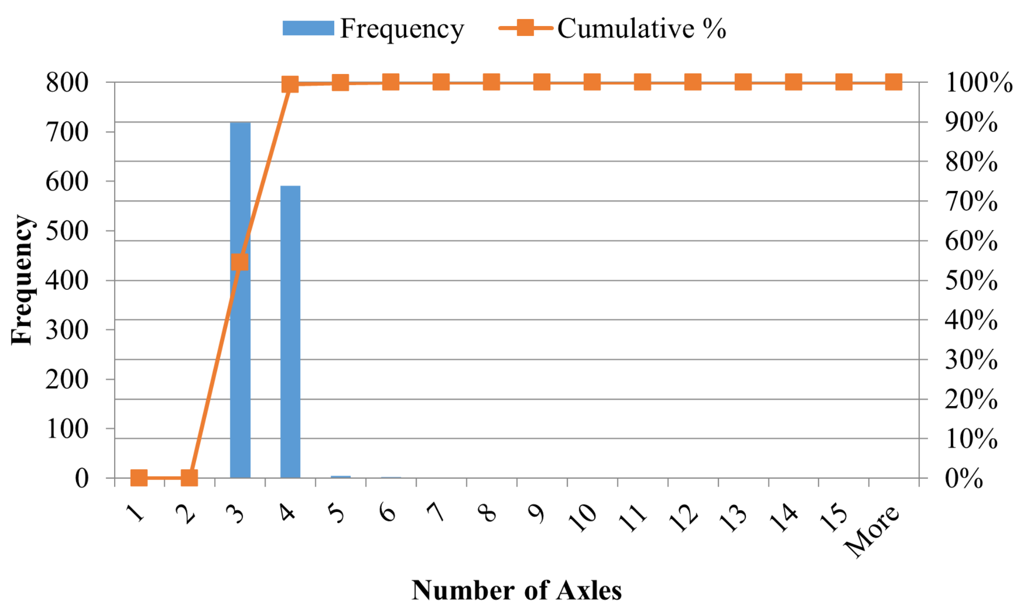

Figure 60: Distribution of the number of axles for the Rig-up Truck permit

5.6.1 Rig-up Truck – Rank 1

The most frequent vehicle configuration is the “1-2”, with its GVW distribution presented in Figure 61.

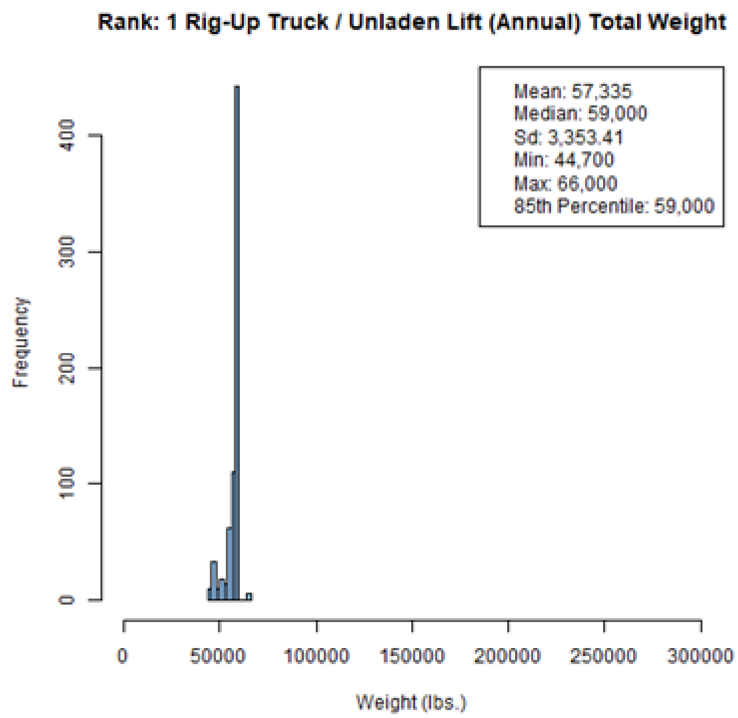

Figure 61: Gross vehicle weight distribution for the Rig-up Truck permit (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 70 and Table 71, summarizing the axle weight and axle spacing respectively.

Table 70: Weight statistics for the Rig-up Truck permit (Rank 1)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	24,369	25,000	1,070.72	21,000	25,000	25,000
2	Axle 2	17,000	17,000	0.00	17,000	17,000	17,000
	Axle 3	17,000	17,000	0.00	17,000	17,000	17,000

Table 71: Spacing statistics for the Rig-up Truck permit (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	344	338	48.09	228	432	420
Spacing 2	59	60	2.26	50	65	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 62.

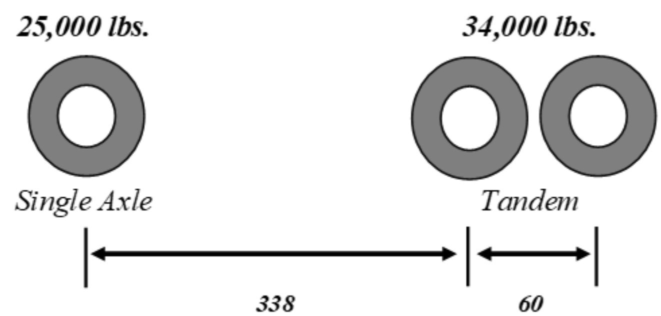

Figure 62: Schematic configuration for the Rig-up Truck permit (Rank 1)

5.6.2 Rig-up Truck – Rank 2

The second most frequent vehicle configuration is the "2-2", with its GVW distribution presented in Figure 63.

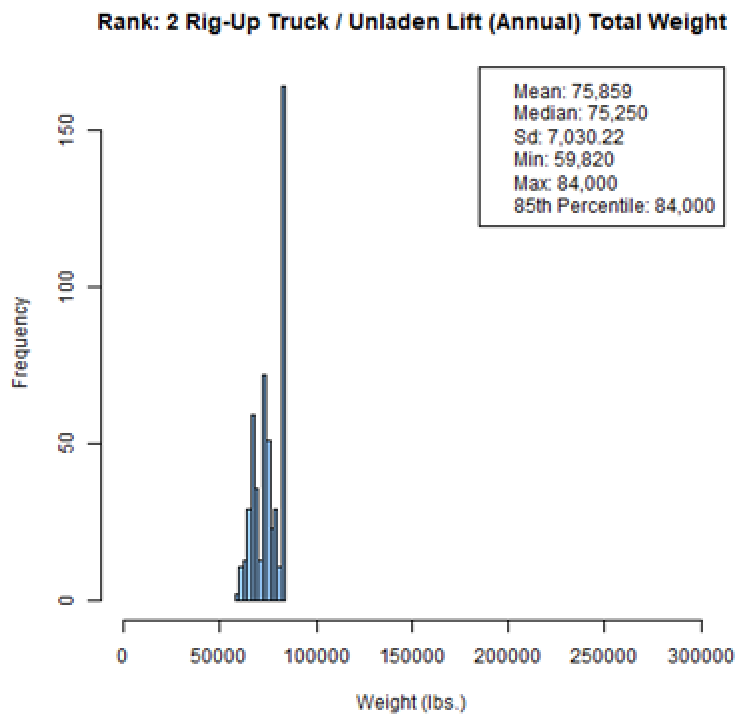

Figure 63: Gross vehicle weight distribution for the Rig-up Truck permit (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 72 and Table 73, summarizing the axle weight and axle spacing respectively.

Table 72: Weight statistics for the Rig-up Truck permit (Rank 2)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	21,207	21,000	3,370	14,300	25,000	25,000
	Axle 2	21,163	21,000	3,336	14,920	25,000	25,000
2	Axle 3	16,748	17,000	685	12,810	20,000	17,000
	Axle 4	16,741	17,000	698	12,810	20,000	17,000

Table 73: Spacing statistics for the Rig-up Truck permit (Rank 2)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	70	72	6.35	48	91	72
Spacing 2	342	324	54.41	120	456	432
Spacing 3	63	60	5.97	48	73	72

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 64.

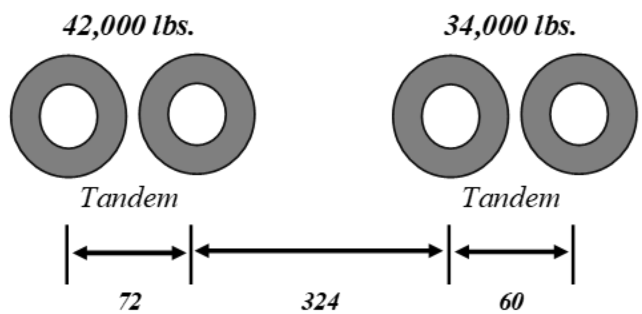

Figure 64: Schematic configuration for the Rig-up Truck permit (Rank 2)

5.6.3 Rig-up Truck – Rank 3

The third most frequent vehicle configuration is the "1-1-2", with its GVW distribution presented in Figure 65.

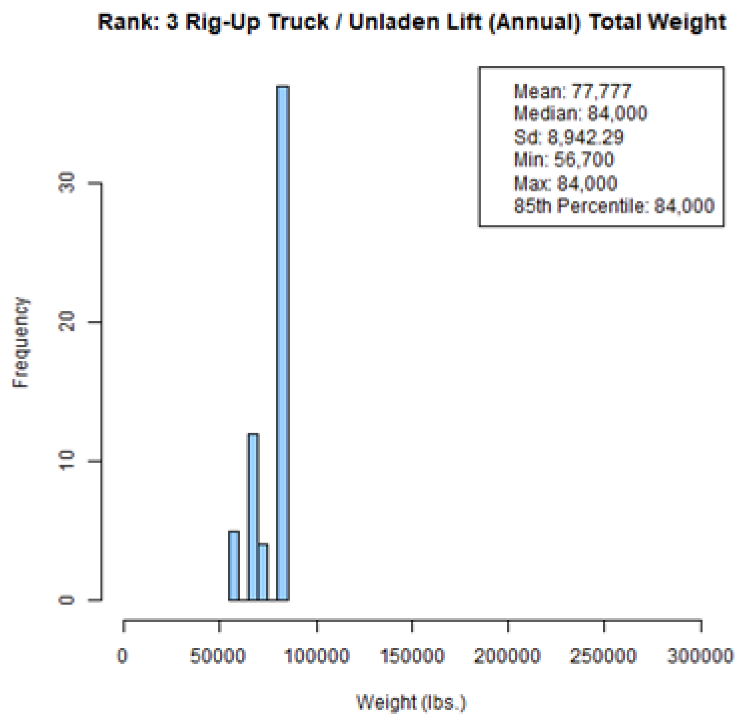

Figure 65: Gross vehicle weight distribution for the Rig-up Truck permit (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 74 and Table 75, summarizing the axle weight and axle spacing respectively.

Table 74: Weight statistics for the Rig-up Truck permit (Rank 3)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	23,085	25,000	3,162	16,200	25,000	25,000
1	Axle 2	21,619	25,000	5,063	9,000	25,000	25,000
2	Axle 3	16,536	17,000	1,424	12,000	17,000	17,000
	Axle 4	16,536	17,000	1,424	12,000	17,000	17,000

Table 75: Spacing statistics for the Rig-up Truck permit (Rank 3)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	110	96	26.28	96	270	122
Spacing 2	373	408	82.99	114	420	420
Spacing 3	63	60	4.94	60	72	72

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 66.

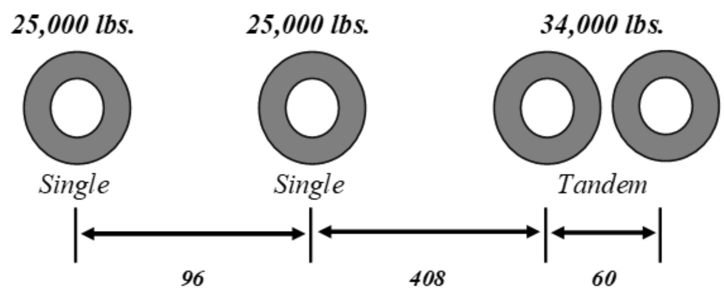

Figure 66: Schematic configuration for the Rig-up Truck permit (Rank 3)

5.7 Water Well Drilling Machinery & Related Equipment

The Water Well Drilling Machinery and Related Equipment permit had 21 vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 76.

Table 76: Common vehicle configurations with a Water Well Drilling Machinery and Related Equipment permit

Rank	Classification	Frequency	Percentage	Cumulative
1	1-2	500	57.1%	57.1%
2	1-3	76	8.7%	65.8%
3	1-2-3	65	7.4%	73.3%
4	2-3	50	5.7%	79.0%
5	2-2	37	4.2%	83.2%
6	1-3-3	20	2.3%	85.5%
7	1-1-2	19	2.2%	87.7%
8	1-2-2	19	2.2%	89.8%
9	1-2-4	18	2.1%	91.9%
10	1-1-1	15	1.7%	93.6%
11	1-3-5	12	1.4%	95.0%
12	1-1	11	1.3%	96.2%
13	1-2-5	10	1.1%	97.4%

The distribution of the number of axles for the Water Well Drilling Machinery and Related Equipment permit is presented in Figure 67.

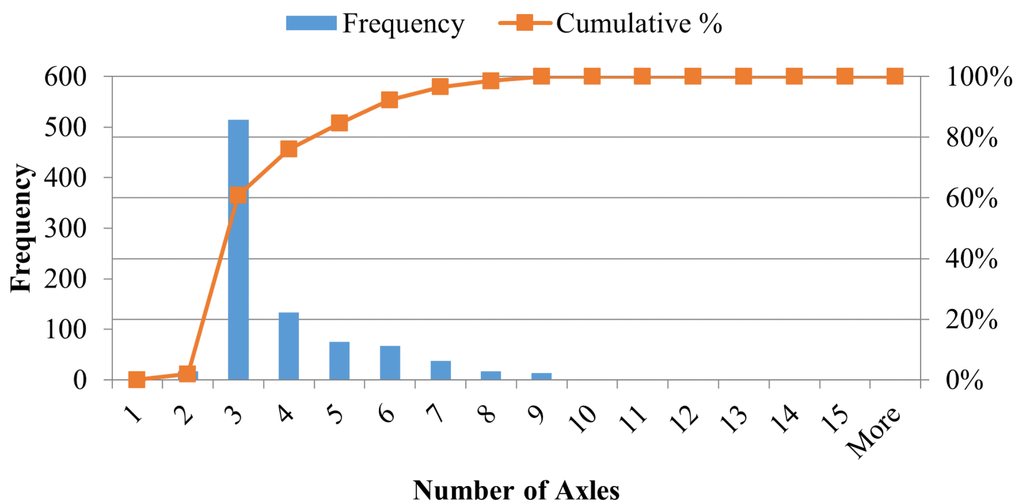

Figure 67: Distribution of the number of axles for Water Well Drilling Machinery and Related Equipment permits

5.7.1 Water Well Machinery & Related Equipment – Rank 1

The most frequent vehicle configuration is the "1-2", with its GVW distribution presented in Figure 68.

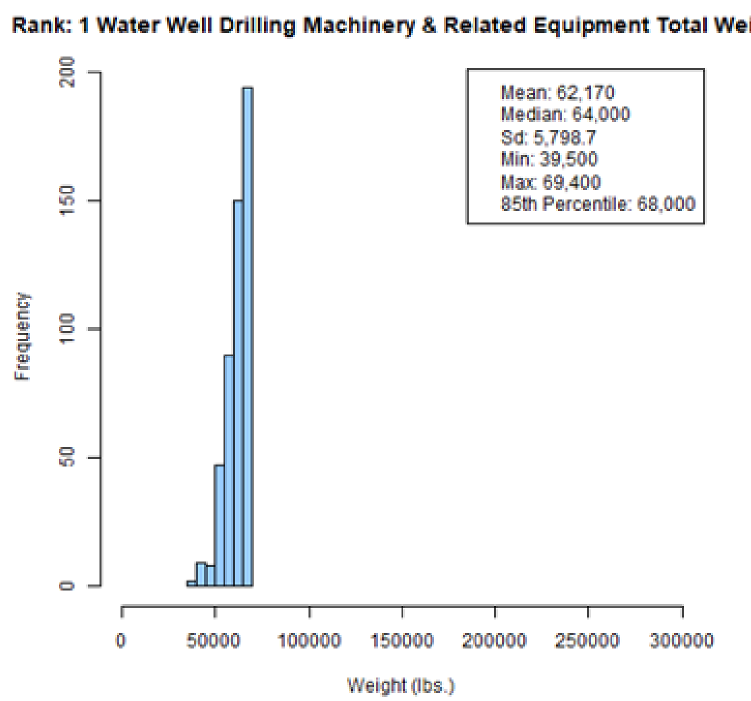

Figure 68: Gross vehicle weight distribution for the WWDMRE permit (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 77 and Table 78, summarizing the axle weight and axle spacing respectively.

Table 77: Weight statistics for the WWDMRE permit (Rank 1)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	18,349	18,800	3,111.23	9,500	23,400	22,000
2	Axle 2	22,246	23,000	1,272.89	19,000	23,000	23,000
	Axle 3	22,201	23,000	1,327.05	18,310	23,000	23,000

Table 78: Spacing statistics for the WWDMRE permit (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	211	216	10.34	192	228	216
Spacing 2	53	48	6.02	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 69.

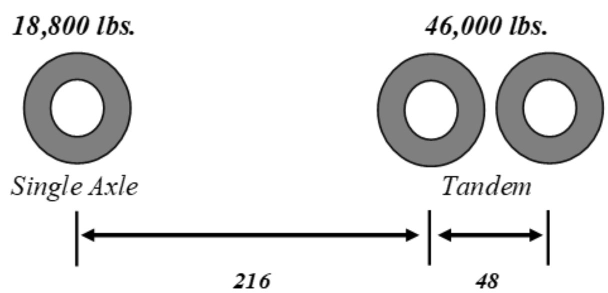

Figure 69: Schematic configuration for the WWDMRE permit (Rank 1)

5.7.2 Water Well Machinery & Related Equipment – Rank 2

The second most frequent vehicle configuration is the “1-3”, with its GVW distribution presented in Figure 70.

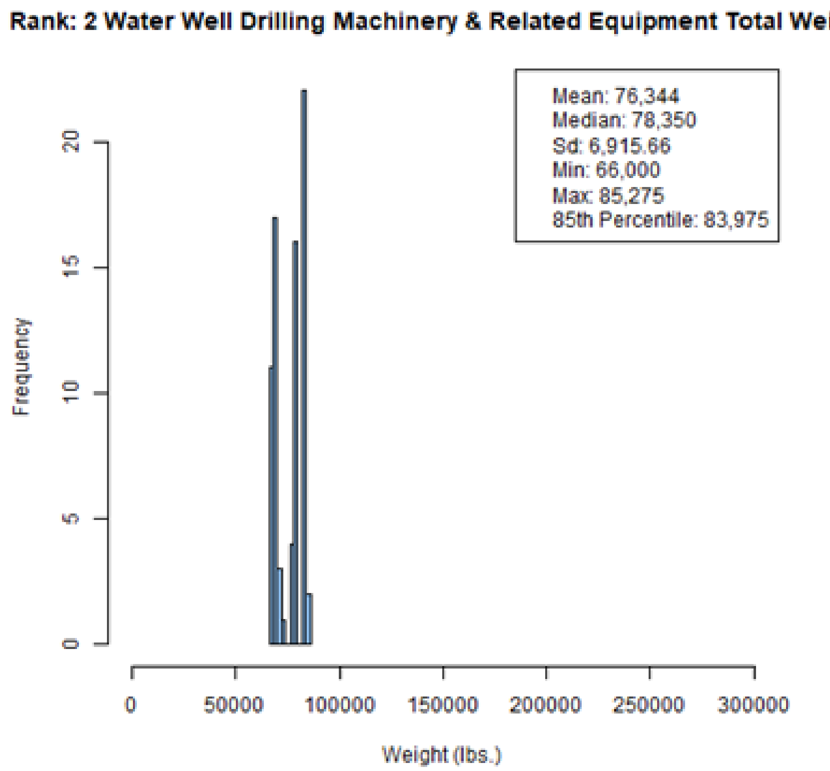

Figure 70: Gross vehicle weight distribution for the WWDMRE permit (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 79 and Table 80, summarizing the axle weight and axle spacing respectively.

Table 79: Weight statistics for the WWDMRE permit (Rank 2)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	19,956	20,000	2,418	15,000	25,000	22,100
2	Axle 2	18,075	19,333	2,519	13,260	20,625	20,625
	Axle 3	19,288	20,000	1,653	16,000	20,625	20,625
	Axle 4	19,025	20,000	2,225	10,000	20,625	20,625

Table 80: Spacing statistics for the WWDMRE permit (Rank 2)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	201	204	26.46	144	240	228
Spacing 2	59	60	5.15	48	72	60
Spacing 3	58	60	4.25	48	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 71.

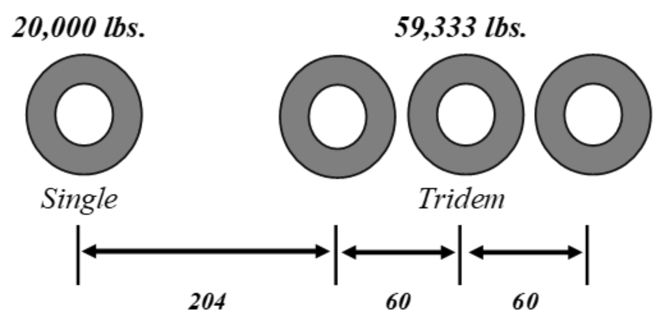

Figure 71: Schematic configuration for the WWDMRE permit (Rank 2)

5.7.3 Water Well Machinery & Related Equipment – Rank 3

The third most frequent vehicle configuration is the "1-2-3", with its GVW distribution presented in Figure 72.

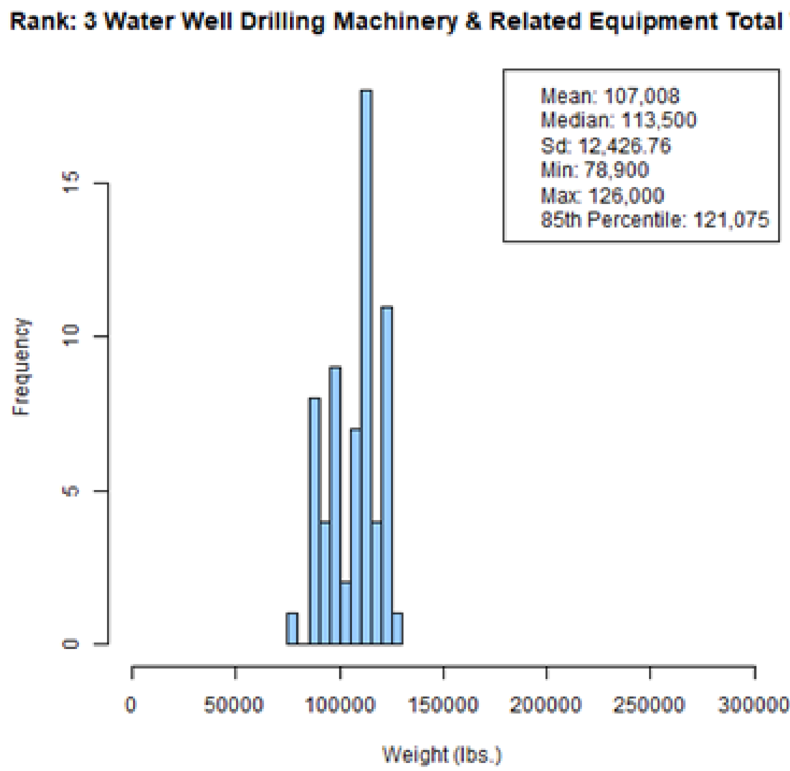

Figure 72: Gross vehicle weight distribution for the WWDMRE permit (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 81 and Table 82, summarizing the axle weight and axle spacing respectively.

Table 81: Weight statistics for the WWDMRE permit (Rank 3)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	13,602	13,200	1,703	10,580	20,000	14,760
2	Axle 2	19,784	20,000	2,882	14,000	23,000	23,000
	Axle 3	19,792	20,000	2,867	14,500	23,000	23,000
3	Axle 4	17,821	17,985	2,417	10,300	20,625	20,250
	Axle 5	18,004	18,000	2,347	10,300	20,625	20,250
	Axle 6	18,004	18,000	2,347	10,300	20,625	20,250

Table 82: Spacing statistics for the WWDMRE permit (Rank 3)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	199	192	34.97	144	300	240
Spacing 2	50	48	4.69	48	60	60
Spacing 3	378	396	80.61	168	564	432
Spacing 4	54	48	6.04	48	60	60
Spacing 5	54	48	6.04	48	60	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 73.

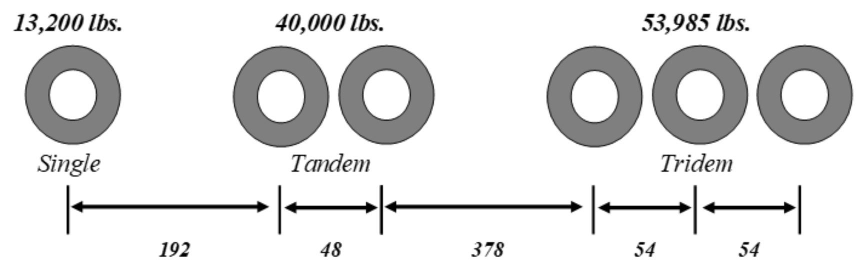

Figure 73: Schematic configuration for the WWDMRE permit (Rank 3)

5.7.4 Water Well Machinery & Related Equipment – Rank 4

The fourth most frequent vehicle configuration is the "2-3", with its GVW distribution presented in Figure 74.

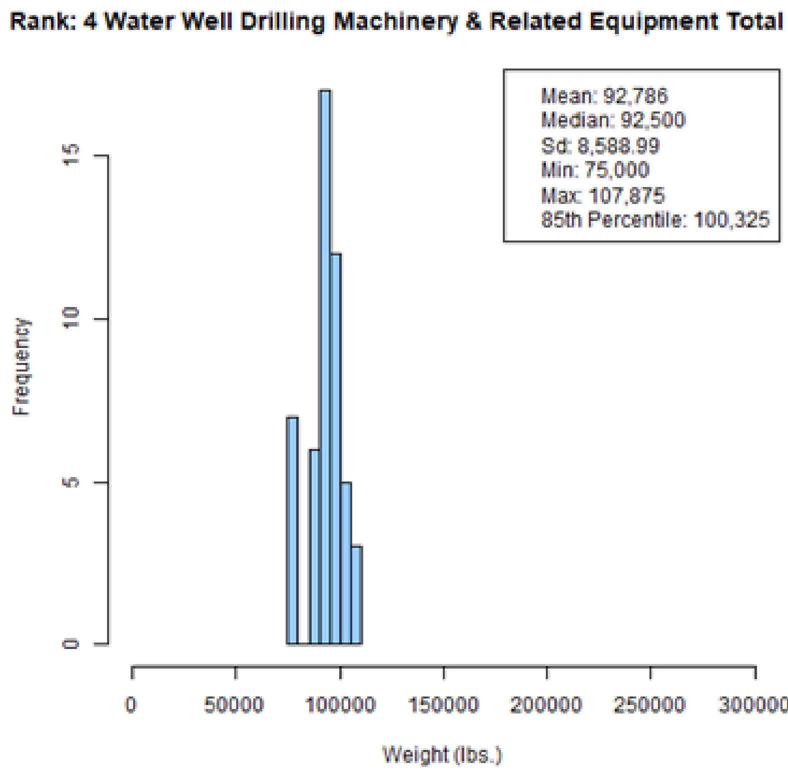

Figure 74: Gross vehicle weight distribution for the WWDMRE permit (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 83 and Table 84, summarizing the axle weight and axle spacing respectively.

Table 83: Weight statistics for the WWDMRE permit (Rank 4)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	17,595	18,500	3,460	1,900	23,000	20,000
	Axle 2	18,208	18,560	2,441	13,200	23,000	20,000
3	Axle 3	19,021	20,000	1,620	15,000	20,625	20,500
	Axle 4	19,021	20,000	1,620	15,000	20,625	20,500
	Axle 5	18,941	20,000	1,854	13,000	20,625	20,500

Table 84: Spacing statistics for the WWDMRE permit (Rank 4)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	53	48	8.45	48	72	60
Spacing 2	180	204	48.03	108	276	216
Spacing 3	53	48	5.98	48	60	60
Spacing 4	54	48	6.95	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 75.

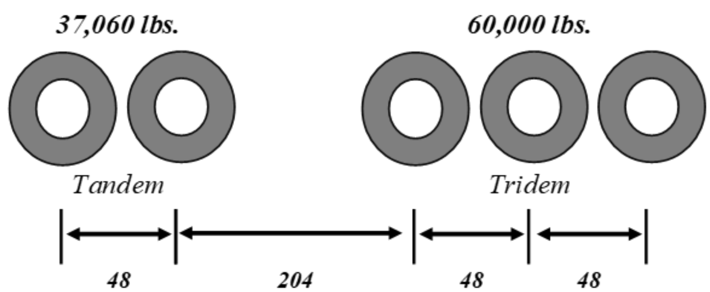

Figure 75: Schematic configuration for the WWDMRE permit (Rank 4)

5.7.5 Water Well Machinery & Related Equipment – Rank 5

The fifth most frequent vehicle configuration is the "2-2", with its GVW distribution presented in Figure 76.

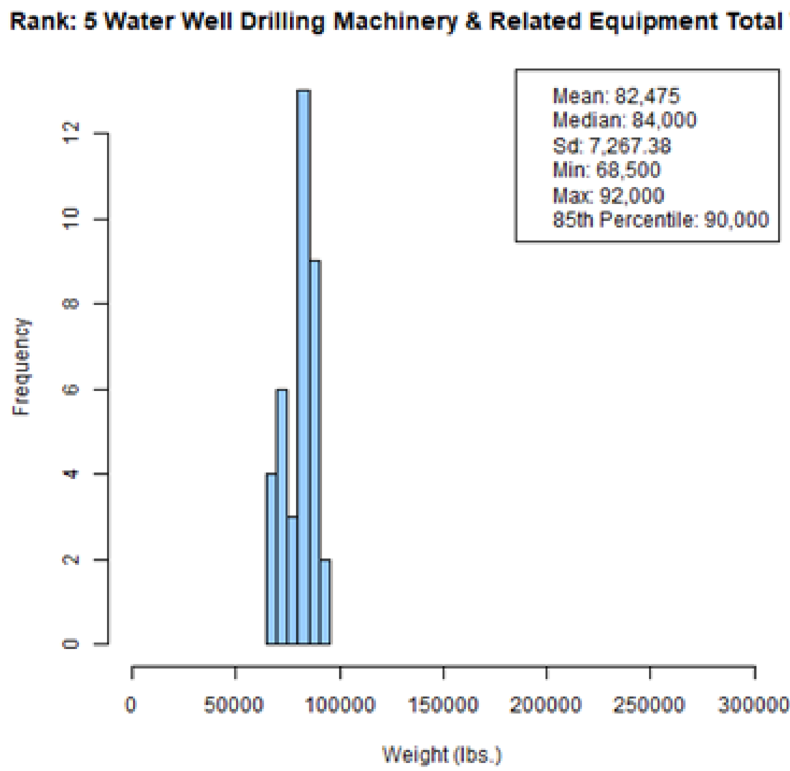

Figure 76: Gross vehicle weight distribution for the WWDMRE permit (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 85 and Table 86, summarizing the axle weight and axle spacing respectively.

Table 85: Weight statistics for the WWDMRE permit (Rank 5)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	18,966	19,500	2,807	11,850	23,000	22,000
	Axle 2	18,875	19,500	2,925	11,850	23,000	22,000
2	Axle 3	22,271	23,000	1,443	19,000	23,000	23,000
	Axle 4	22,362	23,000	1,377	19,000	23,000	23,000

Table 86: Spacing statistics for the WWDMRE permit (Rank 5)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	53	48	6.61	48	72	60
Spacing 2	191	192	26.65	96	216	216
Spacing 3	55	60	7.73	48	72	60

A schematic configuration for the representative vehicle, developed based on the statistical analysis, is depicted in Figure 77.

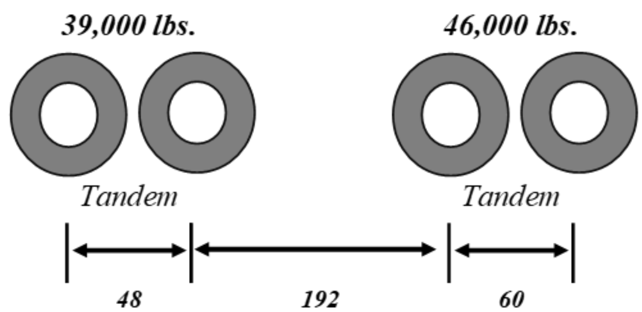

Figure 77: Schematic configuration for the WWDMRE permit (Rank 5)

5.8 Well Service Unit (S/P Mileage)

The Well Service Unit permit had 210 vehicle configurations. Those configurations that represented more than one percent of this permit fleet were ranked by frequency and are presented in Table 87.

Table 87: Common vehicle configurations with a Well Service Unit permit

Rank	Configuration	Frequency	Percentage	Cumulative
1	1-2-3	22,165	24.2%	24.2%
2	2-3	8,202	9.0%	33.2%
3	1-4-3-5-2	6,909	7.5%	40.7%
4	1-2-2	6,153	6.7%	47.4%
5	2-4-3-3-3	4,400	4.8%	52.2%
6	1-3-3	4,239	4.6%	56.8%
7	1-3-4	3,735	4.1%	60.9%
8	1-2-1-1	3,666	4.0%	64.9%
9	1-4-3-3-3	3,544	3.9%	68.8%
10	1-3-3-4-2	2,899	3.2%	72.0%
11	1-4-4	2,172	2.4%	74.3%
12	1-3-3-4-3	1,772	1.9%	76.3%
13	1-3-2-3-2	1,748	1.9%	78.2%
14	3-3	1,541	1.7%	79.9%
15	2-4-3-3	1,525	1.7%	81.5%
16	2-2	1,286	1.4%	82.9%
17	1-2	1,065	1.2%	84.1%
18	1-4-5	1,034	1.1%	85.2%

The distribution of the number of axles for the Well Service Unit permit is presented in Figure 78.

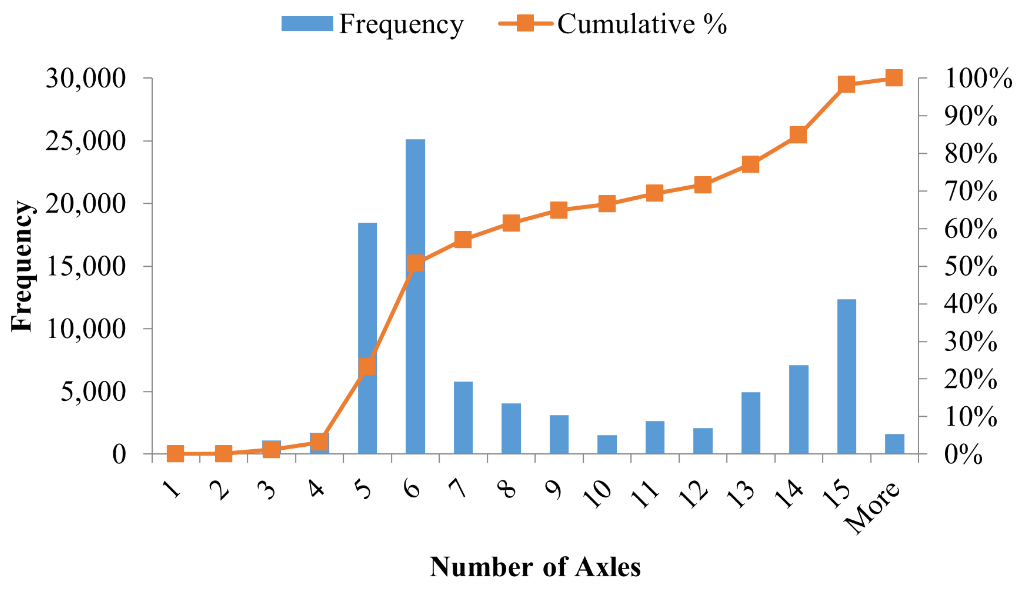

Figure 78: Distribution of the number of axles for Well Service Unit permits

5.8.1 Well Service Unit (S/P Mileage) – Rank 1

The most frequent vehicle configuration is the "1-2-3", with its GVW distribution presented in Figure 79.

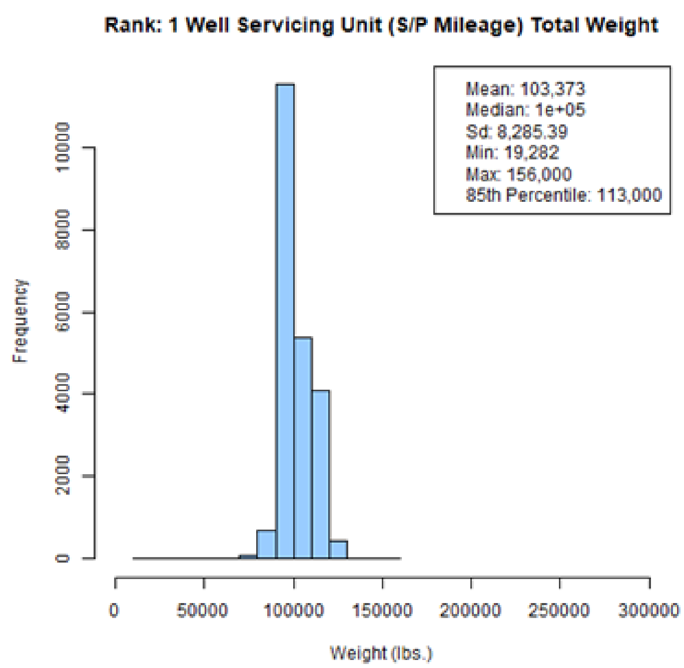

Figure 79: Gross vehicle weight distribution for the Well Service Unit permit (Rank 1)

Descriptive statistics of the vehicle configuration are presented in Table 88 and Table 89, summarizing the axle weight and axle spacing respectively.

Table 88: Weight statistics for the Well Service Unit permit (Rank 1)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	12,877	13,000	907.34	10,500	16,000	13,200
2	Axle 2	18,752	18,600	1,689.91	15,000	25,750	20,000
	Axle 3	18,737	18,600	1,692.24	15,000	25,750	20,000
3	Axle 4	17,658	16,600	1,953.69	11,000	25,000	20,000
	Axle 5	17,679	16,600	1,951.85	11,300	25,000	20,000
	Axle 6	17,672	16,600	1,953.07	11,300	25,000	20,000

Table 89: Spacing statistics for the Well Service Unit permit (Rank 1)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	201	204	9.35	173	224	205
Spacing 2	53	53	1.61	49	57	54
Spacing 3	338	334	48.98	180	504	384
Spacing 4	60	60	2.62	53	64	62
Spacing 5	59	60	3.36	50	66	61

A schematic configuration for the representative vehicle is depicted in Figure 80.

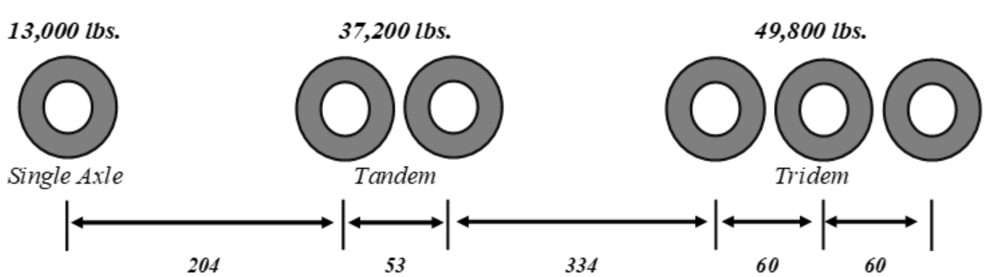

Figure 80: Schematic configuration for the Well Service Unit permit (Rank 1)

5.8.2 Well Service Unit (S/P Mileage) – Rank 2

The second most frequent vehicle configuration is the "2-3", with its GVW distribution presented in Figure 81.

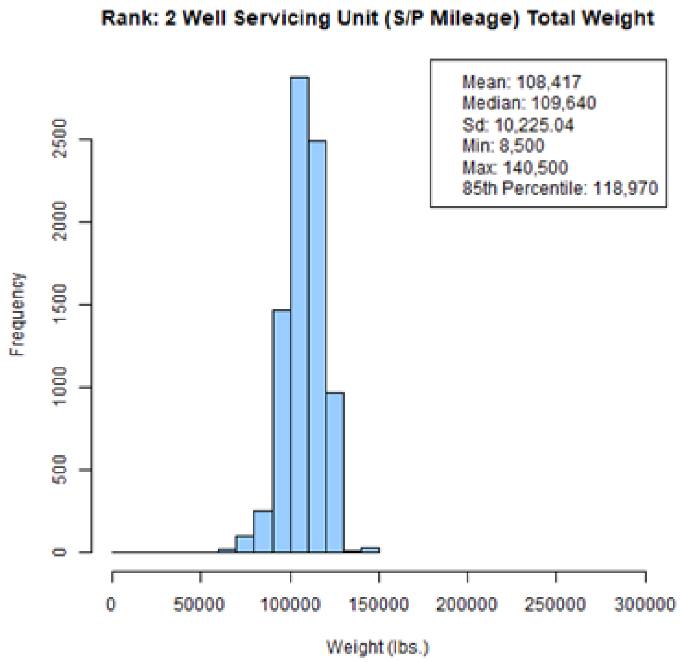

Figure 81: Gross vehicle weight distribution for the Well Service Unit permit (Rank 2)

Descriptive statistics of the vehicle configuration are presented in Table 90 and Table 91, summarizing the axle weight and axle spacing respectively.

Table 90: Weight statistics for the Well Service Unit permit (Rank 2)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	21,435	22,000	3,411	1,700	30,000	24,700
	Axle 2	21,608	22,000	3,076	1,700	30,000	24,730
3	Axle 3	21,753	22,000	2,394	1,700	30,000	23,200
	Axle 4	21,927	22,000	2,116	1,700	30,000	23,260
	Axle 5	21,694	22,000	2,252	1,700	29,550	23,000

Table 91: Spacing statistics for the Well Service Unit permit (Rank 2)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	53	52	5.63	48	84	55
Spacing 2	215	214	43.73	104	552	239
Spacing 3	53	54	3.74	48	90	54
Spacing 4	53	54	4.05	48	90	55

A schematic configuration for the representative vehicle is depicted in Figure 82.

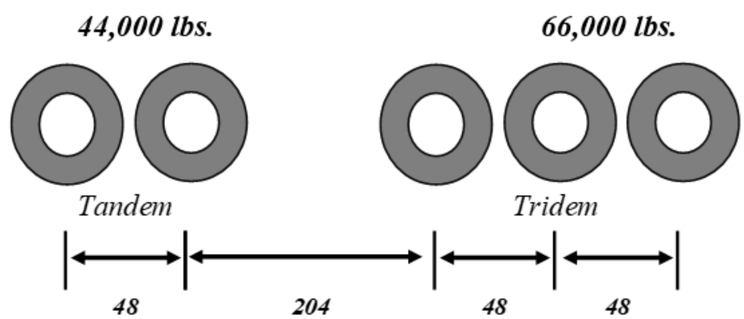

Figure 82: Schematic configuration for the Well Service Unit permit (Rank 2)

5.8.3 Well Service Unit (S/P Mileage) – Rank 3

The third most frequent vehicle configuration is the "1-4-3-5-2", with its GVW distribution presented in Figure 83.

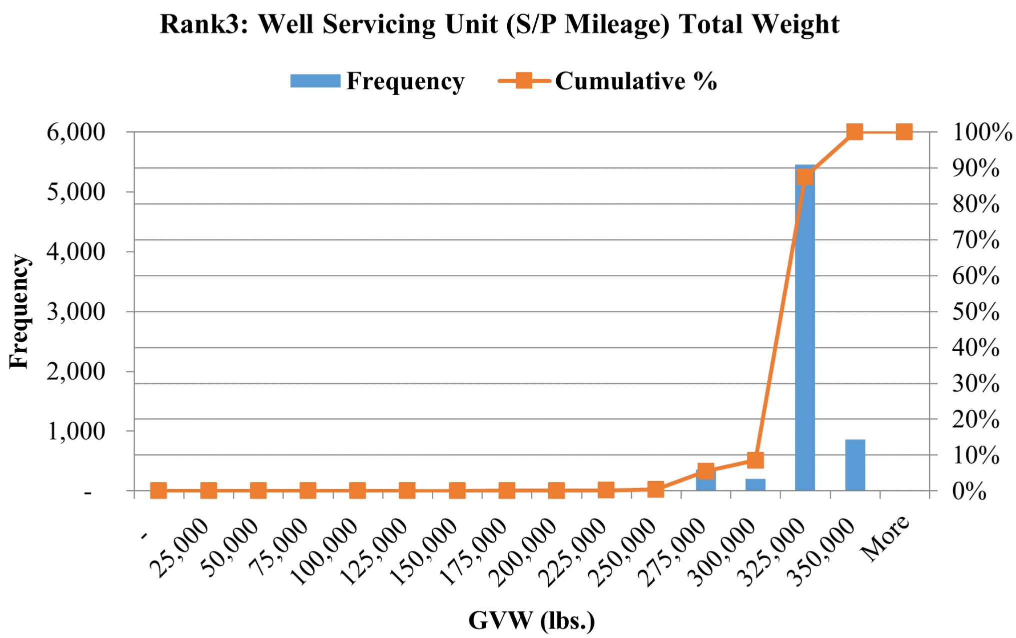

Figure 83: Gross vehicle weight distribution for the Well Service Unit permit (Rank 3)

Descriptive statistics of the vehicle configuration are presented in Table 92 and Table 93, summarizing the axle weight and axle spacing respectively.

Table 92: Weight statistics for the Well Service Unit permit (Rank 3)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	16,844	17,500	2,291	9,500	20,250	17,500
4	Axle 2	16,678	17,500	2,793	5,000	20,250	18,000
	Axle 3	18,821	19,600	2,117	7,200	24,000	20,000
	Axle 4	18,578	19,000	1,705	7,200	22,500	20,000
	Axle 5	18,641	19,000	1,580	7,200	22,500	20,000
3	Axle 6	20,986	20,300	1,911	10,000	26,000	22,000
	Axle 7	20,957	20,300	1,821	9,850	25,000	22,000
	Axle 8	20,880	20,300	1,841	7,550	25,000	22,000
5	Axle 9	24,423	25,000	1,404	10,000	26,500	25,000
	Axle 10	24,455	25,000	1,457	10,000	27,000	25,000
	Axle 11	24,480	25,000	1,646	10,000	27,800	25,000
	Axle 12	24,431	25,000	1,566	10,000	27,000	25,000
	Axle 13	24,352	25,000	1,593	10,000	27,000	25,000
2	Axle 14	18,467	18,000	2,397	2,000	27,200	20,300
	Axle 15	18,406	18,000	2,394	2,000	25,000	20,000

Table 93: Spacing statistics for the Well Service Unit permit (Rank 3)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	185	186	10.12	137	216	192
Spacing 2	57	54	2.94	48	61	60
Spacing 3	57	56	2.49	53	60	60
Spacing 4	57	56	2.49	53	60	60
Spacing 5	161	168	16.58	99	244	168
Spacing 6	57	56	2.24	48	61	60
Spacing 7	57	56	2.29	48	61	60
Spacing 8	299	300	8.80	270	343	312
Spacing 9	58	60	2.33	54	64	60
Spacing 10	58	60	2.37	54	64	60
Spacing 11	58	60	2.33	54	64	60
Spacing 12	58	60	2.35	54	64	60
Spacing 13	186	189	8.23	144	216	192
Spacing 14	57	57	2.30	48	60	60

A schematic configuration for the “1-4-3-5-2” vehicle is depicted in Figure 84.

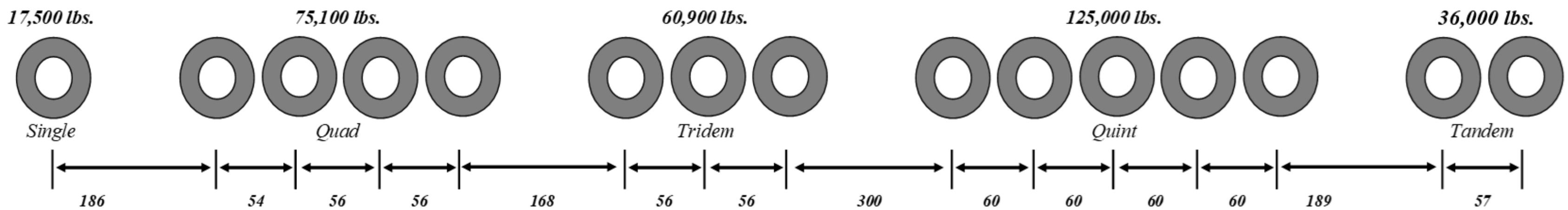

Figure 84: Schematic configuration for the Well Service Unit permit (Rank 3)

5.8.4 Well Service Unit (S/P Mileage) – Rank 4

The fourth most frequent vehicle configuration is the “1-2-2”, with its GVW distribution presented in Figure 85.

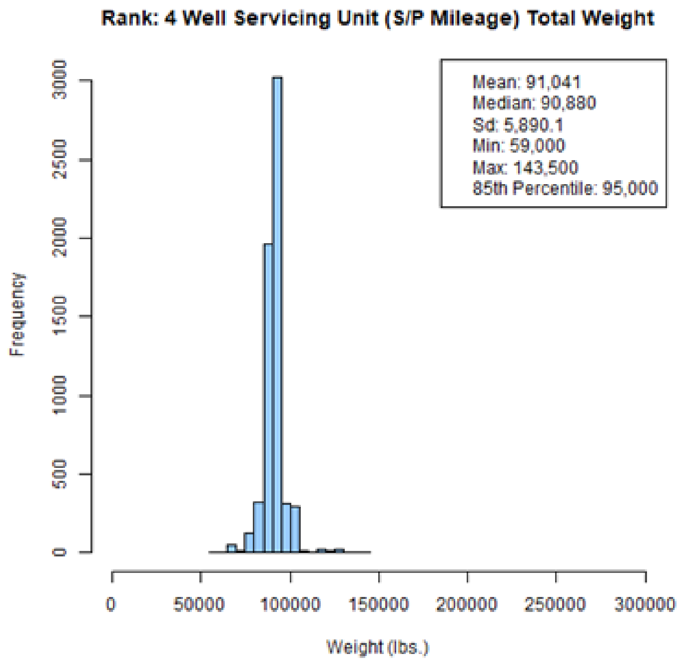

Figure 85: Gross vehicle weight distribution for the Well Service Unit permit (Rank 4)

Descriptive statistics of the vehicle configuration are presented in Table 94 and Table 95, summarizing the axle weight and axle spacing respectively.

Table 94: Weight statistics for the Well Service Unit permit (Rank 4)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
1	Axle 1	13,334	13,560	1,700	1,300	29,000	14,000
2	Axle 2	17,998	17,000	1,984	8,900	29,000	20,000
	Axle 3	17,992	17,000	1,957	1,900	30,000	20,000
2	Axle 4	20,854	21,760	1,714	2,000	30,000	22,250
	Axle 5	20,862	21,760	1,709	2,000	30,000	22,300

Table 95: Spacing statistics for the Well Service Unit permit (Rank 4)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	196	192	16.33	96	288	209
Spacing 2	57	60	4.12	48	76	60
Spacing 3	305	276	60.40	96	708	352
Spacing 4	57	60	4.11	48	80	60

A schematic configuration for the representative vehicle is depicted in Figure 86.

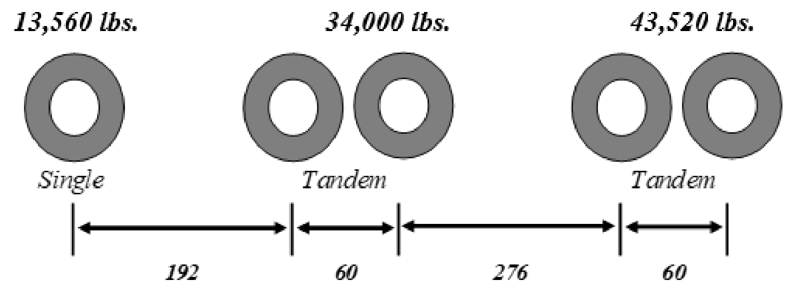

Figure 86: Schematic configuration for the Well Service Unit permit (Rank 4)

5.8.5 Well Service Unit (S/P Mileage) – Rank 5

The fifth most frequent vehicle configuration is the “2-4-3-3-3”, with its GVW distribution presented in Figure 87.

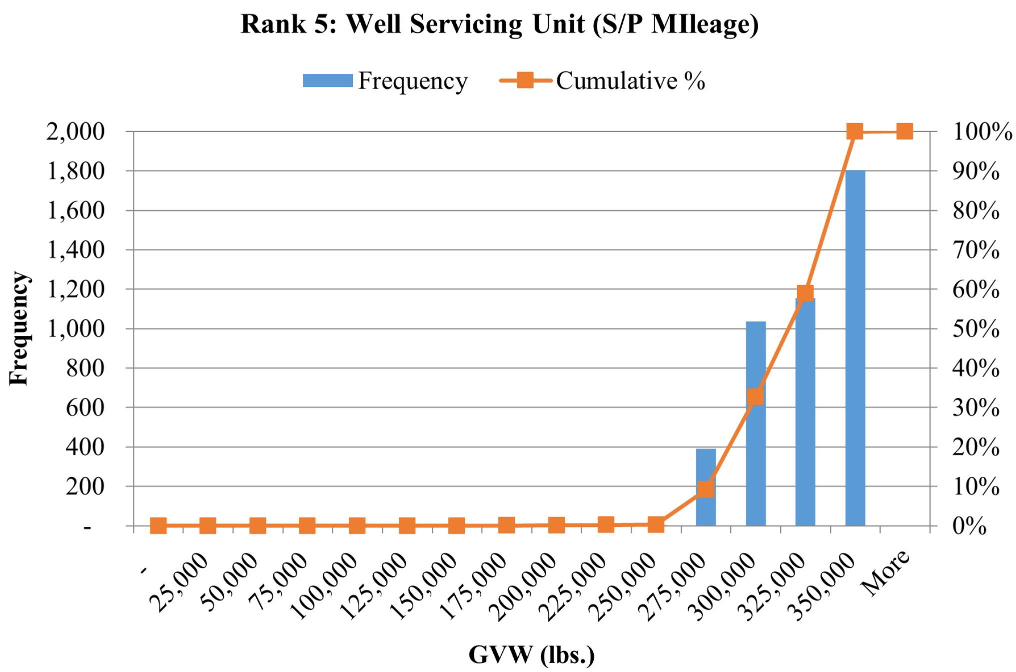

Figure 87: Gross vehicle weight distribution for the Well Service Unit permit (Rank 5)

Descriptive statistics of the vehicle configuration are presented in Table 96 and Table 97, summarizing the axle weight and axle spacing respectively. A schematic configuration for the representative vehicle is depicted in Figure 88.

Table 96: Weight statistics for the Well Service Unit permit (Rank 5)

Axle Group	Description	Mean	Median	SD	Min.	Max.	85th Perc.
2	Axle 1	17,758	18,000	2,904	10,500	22,000	20,000
	Axle 2	17,773	18,000	2,887	10,500	22,000	20,000
4	Axle 3	18,173	19,000	2,098	6,000	21,000	20,000
	Axle 4	18,556	20,000	2,069	1,000	22,000	20,000
	Axle 5	18,557	20,000	2,031	11,000	22,000	20,000
	Axle 6	18,929	20,000	2,134	7,900	23,700	20,000
3	Axle 7	20,842	20,000	1,647	4,500	25,000	22,000
	Axle 8	20,854	20,000	1,667	4,500	25,000	22,000
	Axle 9	21,293	21,000	2,108	4,500	26,600	23,700
3	Axle 10	23,518	24,500	2,130	11,000	27,400	25,000
	Axle 11	23,612	24,500	1,904	12,500	28,000	25,000
	Axle 12	23,608	24,500	1,897	12,500	27,600	25,000
3	Axle 13	23,463	24,000	2,062	12,500	29,600	25,000
	Axle 14	22,802	24,000	2,596	12,500	29,600	25,000
	Axle 15	22,794	24,000	2,579	12,500	29,600	25,000

Table 97: Spacing statistics for the Well Service Unit permit (Rank 5)

Description	Mean	Median	SD	Min.	Max.	85th Perc.
Spacing 1	72	72	1.38	60	83	73
Spacing 2	171	170	3.48	144	180	174
Spacing 3	55	54	2.24	48	62	55
Spacing 4	56	55	2.63	48	60	60
Spacing 5	56	55	2.58	48	60	60
Spacing 6	199	190	22.93	168	322	240
Spacing 7	58	60	2.34	48	60	60
Spacing 8	58	60	2.34	48	60	60
Spacing 9	325	312	24.91	113	382	340
Spacing 10	57	60	2.69	48	60	60
Spacing 11	57	60	2.69	48	60	60
Spacing 12	132	120	23.30	112	180	168
Spacing 13	57	60	2.70	48	60	60
Spacing 14	57	60	2.70	48	60	60

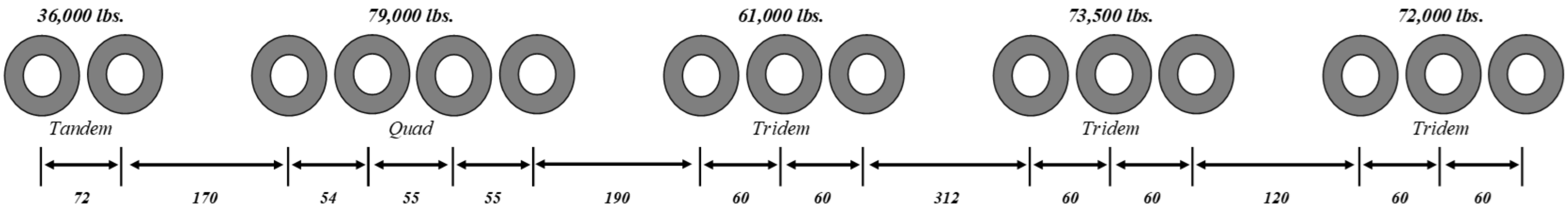

Figure 88: Schematic configuration for the Well Service Unit permit (Rank 5)

5.9 Final Remarks

In this section, a detailed analysis of the axle configurations of OW trucks, as recorded in the axle Report, was conducted. The analysis was based on data collected between 2018 and 2023. A total of 2,122,616 vehicles were assessed, resulting in 1,028 different vehicle configurations. Given the size of the dataset, to ensure that data exploration and analysis remained manageable, only vehicle configurations representing more than one percent of their respective permit type were considered. Additionally, when a significant number of configurations exceeded the one percent threshold, only the five most frequent configurations were selected as representative vehicles.

An exception was applied to those vehicles under the "General" permit type. Due to their broad GVW range, this permit was further divided into four subcategories based on four weight brackets. The most frequent vehicle configuration within each bracket was considered as the representative vehicle. A summary of all the representative vehicles is presented in Table 98.

Table 98: Summary of representative vehicle configurations by permit type

Permit Type (Number of Different Configurations)	Classification	Cum. (%)	GVW (lbs.)	lbs./axle
Crane Annual (51)	1-2	44.9	63,000	21,000
	1-3	64.5	65,950	16,488
	2-2	77.7	89,600	22,400
	2-3	82.9	89,906	17,981
	1-4	87.9	78,000	15,600
Crane SP Mileage (159)	1-4	17.9	121,500	24,300
	2-2	35.0	103,000	25,750
	1-2-2	42.5	133,500	26,700
	2-3	49.1	109,000	21,800
	1-2-2-3	54.0	162,000	20,250
General: 80,000–120,000 lbs. (273)	1-2-3	44.4	109,000	18,167
General: 120,001–160,000 lbs. (329)	1-3-4	34.3	150,000	18,750
General: 160,001–200,000 lbs. (421)	1-3-5	32.4	174,000	19,333
General: 200,000–254,300 lbs. (309)	1-3-3-3-3	40.7	250,000	19,231
Hubometer (132)	1-2-3	36.0	107,000	17,833
	2-3	53.4	116,600	23,320
	1-2-2	65.8	90,000	18,000
	2-2	73.4	99,000	24,750
	1-2	77.6	59,000	19,667
Implement Husbandry (29)	1-2-3	60.4	120,000	20,000
	1-2-2	83.1	105,000	21,000
	1-3-3	88.8	133,500	19,071
	1-2-1-1	91.5	100,000	20,000
	1-3-4	94.2	149,500	18,688
Rig-Up Truck (14)	1-2	53.5	59,000	19,667
	2-2	92.5	72,250	18,063
	1-1-2	96.9	84,000	21,000
Water Well Drilling Mach. & Equipment (21)	1-2	57.1	64,000	21,333
	1-3	65.8	78,350	19,588
	1-2-3	73.3	113,500	18,917
	2-3	79.0	92,500	18,500
	2-2	83.2	84,000	21,000
Well Service Unit (S/P Mileage) (210)	1-2-3	24.2	100,000	16,667
	2-3	33.2	109,640	21,928
	1-4-3-5-2	40.7	296,500	19,767
	1-2-2	47.4	90,880	18,176
	2-4-3-3-3	52.2	321,500	21,433

The representative vehicles for each permit type that accounted for at least 50 percent of the trucks in the database, except in the case of the General permit, where the most frequent vehicle configurations of each category represented a total of 38 percent of the permit's data. Based on the statistics obtained during data exploration, an additional variable (lbs/axle) was introduced. This variable is simply the ratio of GVW to the total number of axles, serving as a proxy for "load distribution" among the different permit types.

By treating each permit type as a factor, and the corresponding "lbs/axle" of each vehicle configuration as factor levels, an analysis of variance was conducted on this variable. The results, at a significance level of 0.05, indicate that the Crane SP Mileage permit has a significantly higher axle load compared to the other permits. This simple "axle-load variable" allows for a quick assessment of permits that could benefit from the addition of an extra axle group, helping them to distribute the load more effectively, thereby reducing the total damage caused to infrastructure (known to be exponentially related to the axle load).

It is noteworthy that, although the TxDMV has the "Super-heavy" permit for vehicles with a GVW exceeding 254,300 lbs., the third and fifth most common vehicle configurations under the Well Service Unit (S/P Mileage) were flagged with GVWs greater than the super-heavy threshold (loaded with 296,500 lbs. and 321,500 lbs., respectively). Nonetheless, this permit had the fourth-lowest average "lbs./axle" among the eight permit types analyzed, indicating an appropriate load distribution among the axle groups.

6. VEHICLE MILE TRAVELED

This section presents the methodology used to estimate the annual VMT for OW vehicles. In 2023, a total of 404,291 OW permits were issued across the following categories:

- Envelope and other Annual permits
- Hubometer (Quarterly)
- Self-propelled (SP): mileage based, and
- Single-trip

6.1 Envelope and other Annual permits

The above-mentioned permit categories were broken down into several subcategories to help correlate the permit type with a specific industry and vehicle class. Table 99 summarizes the 14,588 annual permits issued by subcategory.

Table 99: Annual Overweight Permits by Type

Permit Type	Permits Issued
Envelope Company Specific (Annual)	3,226
Envelope Truck Specific (Annual)	2,770
Subtotal Envelope (Annual)	**5,996**
Crane (Annual)	830
Implement of Husbandry (Annual)	1,033
Intermodal Shipping Container	401
Over-Axle	57,297
Ready-Mixed Concrete Truck (Annual)	5,346
Rig-Up Truck (Annual)	150
North Texas Intermodal (Annual)	2
Timber (Annual)	543
Water Well Drilling Machinery & Related Equipment (Annual)	121
Well Servicing Unit (Annual)	166
Total Annual Permits	**71,885**

The majority of the annual OW permits were "Envelope" permits. Envelope permits are issued either for a specific *truck* to operate for a one-year period or to a specific *company* to operate any truck owned or leased (one at a time) during a one-year period. Other annual permits are issued for specific industry or vehicle activities. To determine the average annual VMT for the Envelope permits, the project team used data from the Rider 36, along with newer industry data, to estimate average annual mileage by permit and industry type, as presented in Table 100.

Table 100: VMT Estimates by Industry

Industry	Annual Mileage Estimates
Aggregate	45,000
Agriculture	11,500
Concrete	16,000
Garbage and Recycling	20,000
Implement of Husbandry	700
Oil and Gas	30,000
Logging	35,000
Average across other industries	24,000

Using the mileage estimates from Table 100, the VMTs were calculated for each industry type, as shown in Tables 101 and 102).

Table 101: VMT for Annual Permits

Permits	No. Permits	VMT/permit	Total VMT
Crane	830	24,000	19,920,000
Implement of Husbandry	1,033	700	723,100
Intermodal Shipping Container	401	24,000	9,624,000
Over-Axle	57,297	24,000	1,375,128,000
Ready-Mixed Concrete Truck	5,346	16,000	85,536,000
Rig-Up Truck	150	24,000	3,600,000
North Texas Intermodal	2	24,000	48,000
Timber	543	35,000	19,005,000
Water Well Drilling Mach. & Equip.	121	24,000	2,904,000
Well Servicing Unit	166	24,000	3,984,000
Total	**8,592**		**1,676,496,100**

Table 102: VMT for Envelope Permits

Permits	Number Permits	VMT/permit	Total VMT
Aggregate & Minerals/ Mining	19	45,000	855,000
Agriculture	26	11,500	299,000
Air, Autos, Boats & Trailers	8	24,000	192,000
Construction and Equipment	2,784	24,000	66,816,000
Construction- Road	265	24,000	6,360,000
Hauling & Freight	46	24,000	1,104,000
House and other structure	6	24,000	144,000
Intermodal	1	24,000	24,000
Manufacturing	39	24,000	936,000
Machine	15	24,000	360,000
Oil & Gas	2,002	30,000	60,060,000
Other	394	24,000	9,456,000
Rail	55	24,000	1,320,000
Recycling	8	20,000	160,000
Steel, Metal & Plastic	9	24,000	216,000
Utility	202	24,000	4,848000
Water	108	24,000	2,592,000
Wind	3	24,000	72,000
Wood & Logging/Timber	6	24,000	210,000
Total	**5,996**		**156,024,000**

The total VMT for Annual permits is 1.68 billion miles.

6.2 Hubometer (Quarterly)

In 2023, a total of 31,817 Hubometer permits were issued. According to the TxDMV, these permits apply to the following vehicle types:

- Self-propelled oil well servicing units
- Unladen lift equipment motor vehicles
- Self-propelled concrete pumps
- Trailer-mounted oil well servicing units

- Coiled tubing units
- Swabbing units
- Self-propelled bundle extractors

The study team attributed 75 percent of these permits to the oil and gas industry and 25 percent to construction and equipment activities. To estimate their VMT, the average annual mileage (24,300) was divided by 12 to obtain an average monthly mileage (2,025). A conservative assumption of 25 percent roadway usage was applied, leading to 506 average monthly miles. Because Hubometer permits are issued *quarterly*, the monthly mileage was then multiplied by three, resulting in approximately 1,518 miles per permit. Multiplying this value by the total number of permits yielded an estimated annual VMT of approximately 48.3 million miles.

6.3 Single-Trip Permits

In 2023, a total of 278,883 routed single-trip General permits were issued. These permits are routed from origin to destination, and the reported mileage is provided by the TxDMV (through TxPROS). The remaining single-trip permits were classified individually by type, and their reported VMT are presented in Table 103.

Table 103: Single-Trip Permits

Permit Type	Number Issued	Reported VMT
General 80,000 to 120,000 lbs.	98,074	24,794,740
General 120,000 to 160,000 lbs.	119,873	18,024,364
General 160,000 to 200,000 lbs.	46,729	6,930,099
General 200,000 to 254,300 lbs.	14,207	3,827,262
Subtotal General	**278,883**	**53,576,465**
Housemove- General	1,417	49,267
Manufactured Housing	88,284	12,465,694
Portable Building	16,166	1,206,292
Self-Propelled Off-Road Equipment	14	1,487
Super Heavy	1,020	266,236
Subtotal Other	**106,851**	**13,988,976**
Total	**385,734**	**67,565,441**

The total VMT reported for the General permit was 53.6 million miles, resulting in an average of 188 miles per permit. Tables 104 and 105 presents the VMT for the single-trip permits by industry.

Table 104: Single-trip: General Permits

Industry	Permits	VMT
Aggregate & Minerals/ Mining	1,500	283,751
Agriculture	2,648	500,922
Air, Autos, Boats & Trailers	1,436	271,696
Concrete	23	4,266
Construction and Equipment	101,785	19,254,451
Construction- Road	17,789	3,365,138
Hauling & Freight	4,598	869,799
House and other structure	617	116,653
Intermodal	2	371
Manufacturing	9,132	1,727,543
Machine	449	84,940
Oil & Gas	113,394	21,450,461
Other	6,425	1,215,307
Rail	2,190	414,314
Recycling	41	828,643
Steel, Metal & Plastic	170	32,084
Utility	3,929	743,316
Water	3,189	603,295
Wind	9,566	1,809,515
Total	**278,883**	**53,576,456**

Table 105: Single-trip: Other Permits

Permits	Permits	VMT/Permit	VMT
Housemove (General)	1,417	35	49,267
Manufactured Housing	88,284	142	12,465,694
Portable Building	16,166	75	1,206,292
SP Off-Road Equipment	14	106	1,487
Super-Heavy	1,020	264	266,236
Total	**106,851**		**13,988,976**

The total annual VMT for the single-trip OW permits is 67.6 million miles.

6.4 Self-Propelled Mileage Permits

Self-Propelled (SP) mileage permits are single-trip permits issued for unladen lift equipment motor vehicles and well servicing units. These permits are valid for up to seven consecutive days, allow return travel, and are charged by mile. In 2023, the total reported SP mileage VMT was **2.8 million miles**.

6.5 On- and Off-System Mileage Split

This methodology estimated a total 2023 VMT of approximately **1.80 billion miles** attributable to OW permitted vehicles. The 2023 Roadway Inventory Report describes 75 percent of the centerline miles in the state as off-system and 25 percent as on-system roadways. However, 74 percent of the daily vehicle miles traveled statewide is reported as on-system travel, and 26 percent as off-system. For all trucks, 90 percent of travel is reported as on-system and 10 percent as off-system. The study team had to estimate the percentage of on- and off-system travel by each permit type. Based on roadway inventory data and truck travel patterns, the team estimated that 86 percent of this VMT occurred on-system and 14 percent occurred off-system. Subsequent tables detail these on-system and off-system VMTs by permit type and duration.

Table 106: Annual VMT estimate per system

Permit Type	VMT	On/Off (%)	On-System VMT	Off-System VMT
Annual Permits	1,676,496,100	86/14	1,446,924,670	229,571,430
Quarterly Hubometer	48,330,023	60/40	28,978,924	19,319,282
Single-Trip	67,565,441	86/14	58,032,947	9,532,494
S/P Mileage	2,806,163	39/61	1,097,768	1,708,395
Total	**1,795,197,727**	**86/14**	**1,535,053,399**	**260,144,328**

Table 107: Non-routed permits: VMT estimate per system

Permit Type	VMT	On-System %	Off-System %	On-System VMT	Off-System VMT
Crane	19,920,000	70%	30%	13,944,000	5,976,000
Implement of Husbandry	723,100	70%	30%	506,170	216,930
Intermodal Shipping Container	9,624,000	60%	40%	5,774,400	3,849,600
Over-Axle	1,375,128,000	90%	10%	1,237,615,200	137,512,800
Ready-Mixed Concrete Truck (RMCT)	85,536,000	40%	60%	34,214,400	51,321,600
Rig-Up Truck	3,600,000	60%	40%	2,160,000	1,440,000
North Texas Intermodal	48,000	100%	0%	48,000	-
Timber	19,005,000	90%	10%	17,104,500	1,900,500
Water Well Drilling Machinery & Equip.	2,904,000	60%	40%	1,742,400	1,161,600
Well Servicing Unit	3,984,000	30%	70%	1,195,200	2,788,800
Subtotal	**1,520,472,100**	**86%**	**14%**	**1,314,304,270**	**206,167,830**
Envelope Permits	156,024,000	85%	15%	132,620,400	23,403,600
Subtotal	**1,676,496,100**	**86%**	**14%**	**1,466,924,670**	**229,571,430**

Table 108: Hubometer: VMT estimate per system

Permit Type	VMT	On-System %	Off-System %	On-System VMT	Off-System VMT
Hubometer	**48,298,206**	60%	40%	**28,978,924**	**19,319,282**

Table 109: Single-trip: VMT estimate per system

Permit Type	Total VMT	On-System %	Off-System %	On-System VMT	Off-System VMT
General: 80,000 to 120,000 lbs.	24,794,740	90%	10%	22,315,266	2,479,474
General: 120,000 to 160,000 lbs.	18,024,364	90%	10%	16,221,928	1,802,436
General: 160,000 to 200,000 lbs.	6,930,099	90%	10%	6,237,089	693,010
General: 200,000 to 254,300 lbs.	3,827,262	90%	10%	3,444,536	382,726
Subtotal: General	**53,576,465**	**90%**	**10%**	**48,218,819**	**5,357,647**
Housemove (General)	49,267	60%	40%	29,560	19,707
Manufactured Housing	12,465,694	70%	30%	8,725,986	3,739,708
Portable Building	1,206,292	70%	30%	844,404	361,888
SP Off-Road Equip	1,487	80%	20%	1,190	297
Super-Heavy	266,236	80%	20%	212,989	53,247
Subtotal: Other	**13,988,976**	**70%**	**30%**	**9,814,129**	**4,174,847**
Total	**67,565,441**	**86%**	**14%**	**58,032,947**	**9,532,494**

Table 110: SP Mileage: VMT estimate per system

Permit Type	Total VMT	On-System %	Off-System %	On-System VMT	Off-System VMT
Crane (S/P Mileage)	639,798	70%	30%	447,859	191,939
Well Servicing Unit (S/P Mileage)	2,166,365	30%	70%	649,910	1,516,456
Total S/P Mileage	**2,806,163**	**39%**	**61%**	**1,097,768**	**1,708,395**

7. BRIDGE CONSUMPTION

The bridge analysis objective is to estimate the bridge consumption costs of representative OW permit configurations. The approach is neither a full-cost nor a cost allocation study; rather, it develops measures of bridge consumption costs per mile to support the revision of OW permit fees. The calculations estimate the effects of OW vehicle configurations on bridge consumption, treating each passage of the each vehicle as a fractional consumption of the bridge's design life. In this methodology, the study team did not consider other cost externalities such as the impacts of delays caused by work zones and detours to upgrade deficient bridges for proper operations. This analysis benefits from well documented bridge inventory, inspection and centerline mileage databases maintained by TxDOT.

7.1 Methodology Overview and Available Data

Bridge analysis for policy purposes must rely on readily available data. The Federal Highway Administration's National Bridge Inventory (NBI) (FHWA, 1995), with its own format in Texas maintained by TxDOT, is the only dataset that meets this objective. This bridge database includes, but is not restricted to, data describing the bridge length, support type, design type, and material. These data are adequate to compute live load bending moments.

This bridge inventory and appraisal data does not contain detailed data on individual bridge design elements, thus ruling out analysis of fatigue details such as stiffeners and connections, shear stresses, or other stresses that require a deeper level of analysis. This data limitation is primarily why previous studies of national truck size and weight policy issues (Moses, 1989) have either ignored fatigue effects (and other less critical stresses) or handled them in a very simplified manner.

Previous truck size and weight studies used bending moment stresses as a defensible surrogate for bridge stresses (Imbsen and Schomber, 1987; Weissmann and Harrison, 1992; Weissmann et al., 2002). The researchers for this project adopted the same approach used on HB 2223 (Section 2.10) that treats each passage of an OW load as consuming a dollar amount of the bridge asset value. This method uses a simplified fatigue calculation to evaluate bridge consumption due to the operation of permitted load configurations.

7.2 Centerline Mileage

TxDOT maintains a centerline mileage inventory termed RHINO. It includes both the on- and off-system roads, but the data is more detailed for the former. Moreover, there are very particular off-system characteristics that are not present on-system. For example, the off-system roads include several functional classes that are not traveled by permit loads (e.g., local streets). Therefore, two different approaches were required to estimate the centerline mileage for the on- and the off-system roads.

Table 111 summarizes the **on-system** mileage retrieved from RHINO, combined with the associated number of bridges. The bridge density per mile varies significantly among highway classes, as anticipated. For the Interstate highway (IH) system, the average bridge spacing was 3.6 miles, as expected, since the IH system includes urban areas with a significant number of overpasses. For the Farm to Market (FM) and Ranch to Market (RM) highway classes, this average spacing increased to 9 miles, which is also expected, because the bridge density per mile for these mostly rural roads is much lower than for the IH system. As discussed later, these bridge spacings have a significant effect on the permit configuration consumption per mile when the results are segregated by highway functional class.

Table 111: Summary of Mileage on Bridges: On-system

Highway Class	Number of Bridges	Miles	Miles/Bridge
FM/RM	4,699	42,069	9.0
IH	4,642	16,641	3.6
PR	37	292	7.9
SH	3,796	18,999	5.0
SL	1,003	2,391	2.4
US	4,674	20,866	4.5
Total	**18,851**	**101,257**	**5.4**

For the **off-system**, the mileage calculation is very challenging, due to the nature of the available road alignment data and the RHINO coding process, given the complexity on segregating the road alignment mileage by relevant road functional classification. Permit loads do not circulate on local streets or on some collectors, thereby limiting their routes primarily to County Roads, and possibly to some of the arterials in urban areas. For this reason, the study team segregated the County Roads in RHINO, and cross-referenced the centerline mileage with the off-system bridge inventory, after creating a temporary cross-referencing variable based on the "facility carried" field in the bridge database and the road name in the roadway alignment inventory. The results of this data cross-referencing were checked using a geo-referencing process in the ArcGIS system.

In addition, the bridge and roadway data were further segregated into specific counties that present higher bridge density for county roads. As expected, these were eastern counties located in areas with more rainfall and more rivers and creeks. To sum up, the basic difference between the on- and off-system consumption analyses was that, for the former, the permit consumption analysis includes the entire on-system mileage and bridges, while for the later the analysis was more akin to a sampling process and was restricted to high bridge density county roads.

Table 112 summaries present the distribution of mileage and bridges for the off-system counties selected for the bridge consumption analysis. These counties include 15,535 miles of county roads and 1,990 bridges with an average spacing of 7.8 miles between bridges.

Table 112: Bridge Statistics by County

County	Miles	Bridges	Miles/Bridge
Brazoria	668.6	122	5.5
Collin	585.9	84	7.0
Comanche	721.4	74	9.7
Cooke	692.3	95	7.3
Falls	741.3	91	8.1
Fannin	910.2	130	7.0
Grimes	457.8	79	5.8
Hill	965.4	124	7.8
Houston	703.4	83	8.5
Hunt	952.3	111	8.6
Johnson	621.2	75	8.3
Lamar	854.8	104	8.2
Lavaca	861.8	81	10.6
Limestone	869.6	130	6.7
Nacogdoches	139.2	94	1.5
Navarro	896.0	74	12.1
Rusk	952.4	104	9.2
Smith	746.8	87	8.6
Wharton	712.0	72	9.9
Williamson	756.1	92	8.2
Wise	726.9	84	8.7
Total	**15,535.4**	**1,990**	**7.8**

7.3 Consumption Calculation Methodology

Bridge consumption may be understood as a fatigue process in which each load passage over a given bridge consumes part of the bridge design life. The American Association of State Highway and Transportation Officials bridge design specifications (AASHTO, 1990) include fatigue curves that imply a certain number of stress cycles that define the bridge design life. Figure 89 depicts one of the fatigue curves included in the AASHTO bridge design specifications.

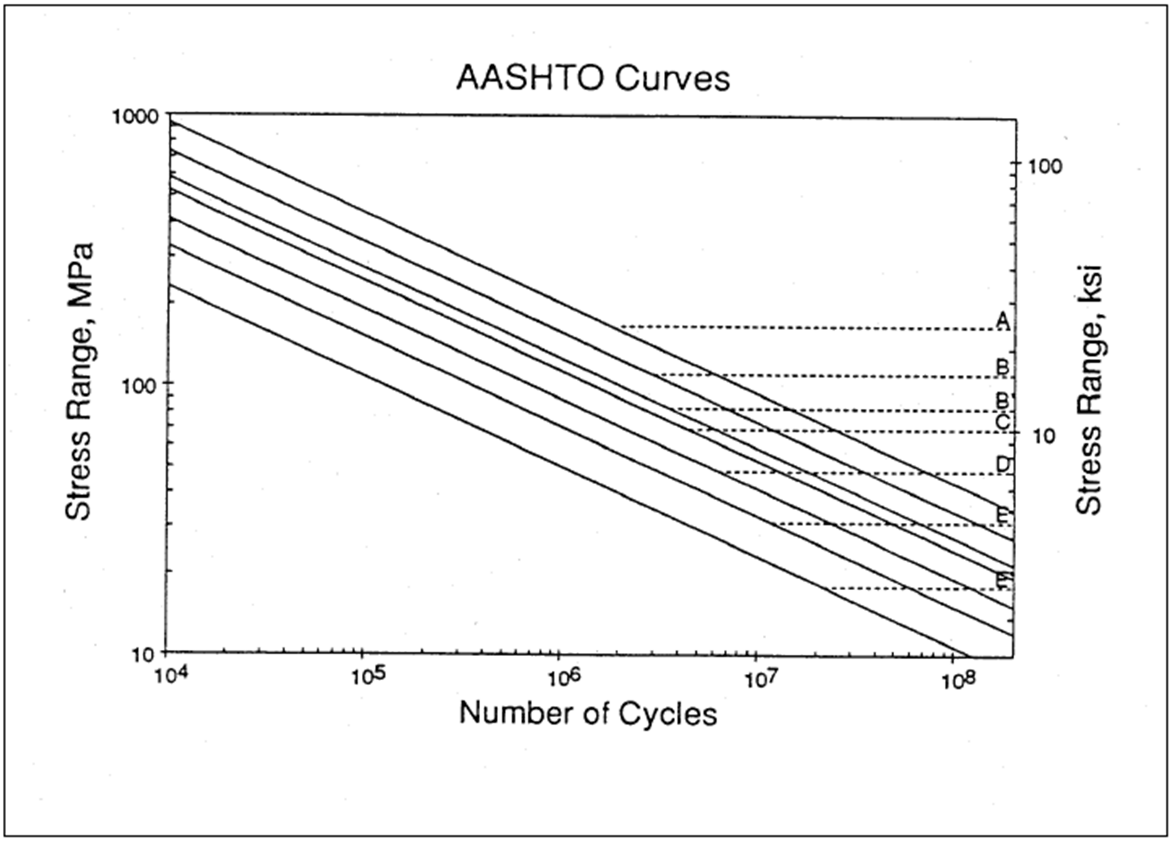

Figure 89: AASHTO Bridge Fatigue Curves

This set of curves is for steel bridge details and is in a logarithmic scale. As demonstrated by this set of curves, the wider the stress range, the lower the number of stress cycles to get to the end of the design life of a specific structural detail. Fatigue curves for other materials such as reinforced concrete and pre-stressed concrete follow this general shape but have different numerical parameters. Equation 7.1 presents the generic mathematical formulation of the bridge fatigue curves.

$$\log(N) = C - m \times \log(S) \tag{7.1}$$

Where N is the number of cycles (or load repetitions) to failure, S is the stress range, m is a material dependent constant, and C is a constant. AASHTO (1990) specifies a 75-year design life, or two million applications of the design load[9]. Inventory rating loads (recorded in the Bridge Inventory Data Base/NBI) induce stresses equivalent to design load stresses, but reflect the current load rating for a given bridge.

The data available in the TxDOT bridge database allows for the application of simplified methodologies to estimate bridge consumption for different load configurations at the policy level. By applying Equation 7.1 twice (once for the inventory rating load, and again for the OW permit load) and then subtracting one result from the other, it results in Equation 7.2.

$$\frac{N_{inventory}}{N_{OSOW}} = \left(\frac{S_{OSOW}}{S_{inventory}}\right)^m \tag{7.2}$$

Where $N_{inventory}$ is the number of load applications for the inventory rating load, N_{OW} is the number of load applications for the OW load, $S_{inventory}$ is the stress range for the inventory load, S_{OW} is the stress range for the OW load, and m is a material dependent constant.

At the policy level, it is not feasible to calculate actual stress ranges for bridge details. Digital descriptions of bridge cross sections and other characteristics are not available; even if they were, computational demands would make this task unfeasible within this project's time frame. An acceptable method, successfully used in aforementioned studies, involves using live *load bending moments* as surrogates for the stress range. This approach substitutes the stress ranges in Equation 7.2 with bending moments, defining the bridge consumption ratio (BCR) as presented in Equation 7.3.

$$BCR = \left(\frac{M_{OW}}{M_{inventory}}\right)^m \tag{7.3}$$

Where $M_{inventory}$ is the live load bending moment for the inventory rating load, and M_{OW} is the live load bending moment for theOW load. Simply put, Equation 7.3 states that the bridge consumption ratio induced by a bending moment of an inventory rating load passage on a given bridge is equal to 1. Loads inducing bending moments twice as large as the inventory rating bending moment lead to a bridge consumption ratio 2^m (two to the m-th power), where m is a function of the bridge material fatigue properties. Inventory ratings recorded in the bridge database are used to evaluate recurrent load applications such as annual permit loads. Operating ratings are considered for evaluation of one trip permits such as the ones for super-heavy loads. Table 113 presents m values recommended in the literature (Altry et al., 2003; Overman et al., 1984).

[9]Design loads are specified as specific load configurations with defined axle spacing and axle loads.

Table 113: Values of the Constant m for Bridge Fatigue Analysis

Structure Type	Code	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

The bridge consumption in dollars due to the passage of a given load is estimated by using Equation 7.3 combined with a consumable asset value for the bridge. Research developed in support of the Texas 2030 Committee established that the asset value of a bridge was \$190 per square foot of deck area, at that time (Texas 2030 Committee, 2009). These values were updated to 2025 using cost indices, resulting in \$309/sqft of deck as the consumable asset value of a bridge. Previous highway cost allocation studies established that the asset value of a bridge should be allocated with 11 percent of the bridge asset value attributable to loads that are over HS20-44[10] (FHWA, 2000).

With the help of computerized routines, Equation 7.4 was applied, on a bridge-by-bridge basis, to all bridges in the data previously described in this tech memo. Bridge asset consumption results for each bridge were summarized and aggregated to determine an overall cost for a given permit load, which was then divided by the mileage to obtain an average cost-per-mile for bridge consumption.

$$BC_{OSOW} = \frac{DA \times AV \times 0.11 \times \left(\frac{M_{OSOW}}{M_{inventory}}\right)^{m}}{2,000,000} \tag{7.4}$$

Where DA is the deck area, AV is the average asset value of \$309/sqft for a bridge

[10] HS20-44 is a standardized bridge design load, and the current bridge inventory ratings are usually represented as multiples of the HS20 design load when recorded in bridge inspection databases.

(in 2025-dollars), 0.11 is the bridge asset value responsibility for heavy trucks (FHWA, 2000), and $2,000,000$ is the number of allowable load cycles that define bridge design life according to AASHTO (1990).

7.4 Network-level Bridge Bending Moment Analysis

The computer program Moment Analysis of Structures (MOANSTR) was used to calculate live load moment ratios (required by Equation 7.4) for all bridges on the centerline mileage identified using the on- and off-system methodologies previously explained. The MOANSTR program's core is a finite differences routine that calculates lmoment envelopes and identifies the maximum value of positive and negative live load bending moments generated by OW vehicle configurations, as well as by the inventory rating loads. The MOANSTR routine incorporates previous research by Matlock and Taylor (1968) and others (Weissmann and Harrison, 1992; Weissmann et al., 2002).

To sum up, the following steps summarize the implementation of the previously discussed concepts:

1. Calculate the entire on-system centerline mileage from the RHINO road inventory data;

2. Summarize bridge and centerline mileage for the off-system county roads for the selected counties;

3. Characterize permit loads (axle weights and spacing);

4. Calculate bending moment envelopes using MOANSTR for the on- and off-system bridges, using the full on-system bridge inventory, and using the county road bridges for the selected counties for the off-system;

5. Calculate on- and off-system bridge consumption, using Equation 7.4, for each representative vehicle (from each permit type); and

6. Calculate the cumulative cost per bridge for on- and off-system, then combine it with centerline mileage to estimate bridge consumption per mile.

7.5 Bridge Consumptions Results

To exemplify the methodology, the calculations for the **General** (between 120,001 to 160,000 lbs.), for both on- and off-system, are presented in Table 114. For more information on this specific truck configuration, please refer to Section 5.

Table 114: On-System: Bridge Consumption per Mile for the General (120,001 to 160,000 lbs.)

Highway Class	Bridges	Permit Cost ($)	Miles	Cost/mile	Miles/Bridge
FM/RM	4,699	3,059	42,069	0.07	9.0
IH	4,642	11,408	16,641	0.69	3.6
PR	37	263	292	0.90	7.9
SH	3,796	5,771	18,999	0.30	5.0
SL	1,003	1,665	2,391	0.70	2.4
US	4,674	6,391	20,866	0.31	4.5
Total	**18,851**	**28,557**	**101,257**	**0.28**	**5.4**

The results are segregated by Highway Class to demonstrate the effect of the bridge spacing per mile on the average bridge consumption cost per mile. The relevant highway classes for this comparison are Interstate Highways (IH), US highways (US) State Highways (SH) and Farm and Ranch to Market roads (FM/RM). These classes comprise the bulk of the mileage in the on-system roads. The bridge spacing, the inverse of which is the bridge density, varies significantly for the different highway classes. The shortest space between bridges is observed in the IH class with a 3.6 miles average spacing. This is to be expected, since the analysis covers both rural and urban interstate highways including frontage roads, and interstate highways cannot have at-grade intersections. The average spacing between bridges is 9 miles for the FM/RM class. This, together with the deck area difference between IH and FM/RM roads, resulted in significant differences in bridge consumption costs between those systems. In addition, the FM/RM bridge density/spacing is significantly low for the western counties in Texas, which are generally flat and dry.

The bridge consumption costs per mile for the IH system are 0.69$/mile whereas they are only 0.07$/mile for the FM/RM classes. The overall average consumption cost considering the complete on-system for the General with GVW between 120,001 and 160,000 lbs. is 0.28$/mile. This discussion points to the importance of estimating and segregating the VMT of specific permits by highway functional class. It is also important to note that this General Permit exceeded operating rating moments for about 20 percent of all on-system bridges.

As previously discussed, the study team further segregated the bridge and roadway data into specific counties that present higher bridge density for county roads, as an attempt to assess the *off-system*. As expected, these are eastern counties located in the wet part of Texas. Table 115 summarizes the bridge consumption results using this approach, for the same General configuration presented for the on-system, but sorted alphabetically by County.

Table 115: Off-System: Bridge Consumption per Mile for the General (120,001 to 160,000 lbs.)

County	Bridge Count	Bridge Consumption ($)	Mileage	Bridge Consumption ($/mile)
Brazoria	122	25.63	668.6	0.038
Collin	84	19.35	585.9	0.033
Comanche	74	8.16	721.4	0.011
Cooke	95	14.09	692.3	0.02
Falls	91	11.46	741.3	0.015
Fannin	130	14.17	910.2	0.016
Grimes	79	5.03	457.8	0.011
Hill	124	19.26	965.4	0.02
Houston	83	8.49	703.4	0.012
Hunt	111	7.24	952.3	0.008
Johnson	75	7.25	621.2	0.012
Lamar	104	6.66	854.8	0.008
Lavaca	81	11.1	861.8	0.013
Limestone	130	14.08	869.6	0.016
Nacogdoche	94	6.12	139.2	0.044
Navarro	74	7.00	896.0	0.008
Rusk	104	7.95	952.4	0.008
Smith	87	9.63	746.8	0.013
Wharton	72	7.69	712.0	0.011
Williamson	92	23.30	756.1	0.031
Wise	84	10.50	726.9	0.014
Total	**1,990**	**244.16**	**15,535.4**	**0.016**

The overall bridge consumption per mile for these representative counties was only 2 cents per mile, reflecting the nature of the off-system bridges that have wider spacing between bridges, and are significantly smaller hence smaller deck areas. Again, this points to the need of segregating VMT between east and west counties. Western counties in Texas are mostly dry and present a far lower road mileage for county roads than the eastern counties used in the bridge analysis.

It is also important to note that this General Permit superseded operating rating moments for about 35 percent of the off-system bridges (in the sample used for county bridges). Finally, the bridge consumption results for the different OW permits for the entire state of Texas are presented in Table 116. These results will be combined with the VMT and the pavement consumption costs per mile to determine the overall consumption cost of these selected OW permits.

Table 116: Bridge Consumption by Permit Type and Representative Vehicle

Permit Type	Axle Config.	Consumption Cost per Mile On-System	Off-System
Crane Annual	1-2	0.055	0.007
	1-3	0.079	0.009
	2-2	0.133	0.013
	2-3	0.139	0.012
	1-4	0.089	0.009
Crane SP Mileage	1-4	0.427	0.041
	2-2	0.133	0.013
	1-2-2	0.543	0.049
	2-3	0.248	0.021
	1-2-2-3	0.600	0.036
General: 80,000 - 120,000 lbs.	1-2-3	0.132	0.009
General: 120,001 - 160,000 lbs.	1-3-4	0.280	0.016
General: 160,001 - 200,000 lbs.	1-3-5	0.450	0.026
General: 200,000 - 254,300 lbs.	1-3-3-3-3	0.800	0.020
Hubometer	1-2-3	0.160	0.01
	2-3	0.290	0.024
	1-2-2	0.090	0.005
	2-2	0.180	0.017
	1-2	0.050	0.005
Implement Husbandry	1-2-3	0.177	0.012
	1-2-2	0.106	0.008
	1-3-3	0.225	0.015
	1-2-1-1	0.089	0.006
	1-3-4	0.264	0.016
Rig-Up Truck	1-2	0.025	0.003
	2-2	0.053	0.005
	1-1-2	0.066	0.006
Water Well Drilling Mach. & Equipment	1-2	0.060	0.008
	1-3	0.236	0.012
Over-Axle (1547) Envelope	1-2-3	0.120	0.010
	2-3	0.174	0.017
	2-2	0.109	0.010
	1-2-2	0.060	0.004
	1-4-4	0.150	0.009
Ready-Mixed Concrete	1-2	0.110	0.011
Timber	1-2-2	0.072	0.006
Well Servicing Unit	1-2-3	0.046	0.003
	1-2-3	0.094	0.007
	2-3	0.236	0.020
	1-2-2	0.078	0.006

7.6 Conclusions and Recommendations

This section documented the bridge consumption methodology for both on- and off-systems. Figure 90 depicts a map with the segregation between East and West counties, used on previous bridge consumption analyses by the UTSA team, where two separate analyses were conducted: one for the eastern and the other for the western Texas regions. The bridge consumption costs were over 30 percent higher for eastern than western counties. In future projects, estimating the VMT separately for the eastern and western regions would improve the cost estimates and serve as a basis for a new fee structure that takes these regional differences into consideration.

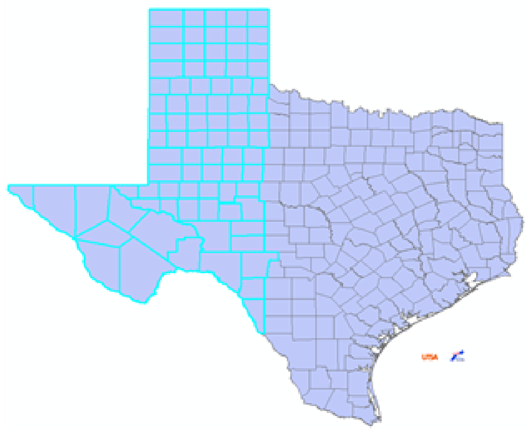

Figure 90: East and West Texas Regions Used in a Previous Bridge Consumption Project

The results documented in this technical memorandum also point to the need to improve the cross-correlation between the bridge data and road alignment data. It would be very useful to include the bridge ID numbers on the segments reported in the RHINO road inventory database. Finally, a harmonization between the coding of the highway functional class for the roadway and bridge databases (specially for the off-system) would improve the bridge consumption calculations. These recommendations would also be useful for any other type of project requiring correlations between bridges and roadways.

8. PAVEMENT CONSUMPTION

This section presents the methodology utilized for the pavement consumption analysis, based on the so-called Equivalent Consumption Factor (ECF). The ECF, also used during Rider 36 and HB 2223, was based on the work originally proposed by Prozzi and De Beer (1997) where the concepts of a comprehensive equivalent damage factor were introduced.

The ECF represents a comprehensive mechanistic-empirical modular approach for evaluating the effects of any vehicle (including OW trucks) on pavement performance. This method considers various axle configurations, pavement structures, different climate and environments aspects, and failure criteria; offering a rational framework to estimate the per-mile costs associated with OW vehicles and supporting the development of optimized permitting policies, contributing towards a more equitable operation of the transportation system.

8.1 Variables of Interest for Pavement Analysis

8.1.1 Pavement Performance

Before the AASHO Road Test (HRB, 1962), there was no quantifiable concept of pavement performance to determine whether a designed pavement was acceptable or not. In fact, the lack of a proper, continuously quantifiable failure criterion became evident even during the earlier WASHO Test Road (HRB, 1954).

The pavement serviceability index (PSI) was the first pavement performance indicator, based on the concept that highways are provided for the comfort of the traveling public, expected to be safe and smooth. This index relates the subjective opinion of users (i.e., how they perceive the highway conditions on a scale from 0 to 5), with characteristics that can be measured objectively (e.g., the amount of pavement distresses). The results from the AASHO Road Test laid the foundation for the AASHTO Guide for Design of Pavement Structures (AASHTO, 1993),

Many procedures are available for pavement design today, including those based on pavement mechanics, generally referred to as mechanistic-empirical methods. The attractiveness of these mechanistic-empirical methods lies in their ability to analyze the structural responses of layered systems and relate them to pavement performance using experimentally calibrated transfer functions. Since different pavement structures respond differently to loads and environmental conditions, it is expected that they would require specific failure criteria. The performance (or failure criterion) metrics utilized in this study for the pavement analysis are summarized in Table 117.

Table 117: Different pavement performance indicators for each pavement type

Pavement Type	Failure Criterion
Asphalt Concrete Pavement (ACP)	Rutting, Fatigue Cracking, Roughness
Surface Treatment Pavement (STP)	Rutting, Fatigue Cracking, Roughness
Continuously Reinforced Concrete Pavement (CRCP)	Punchouts, Roughness
Jointed Concrete Pavement (JCP)	Transverse Cracking, Faulting, Roughness

8.1.2 Traffic Loading and Simulations

In 1996, to establish a state-of-the-practice pavement design procedure, the AASHTO Joint Task Force on Pavements sponsored the development of a mechanistic-empirical design guide (currently known as AASHTOWare Pavement ME Design) for new and rehabilitated pavements through the National Cooperative Highway Research Program 1-37A Guide (Prozzi et al., 2012). The algorithms used in this guide have been approved by both AASHTO and the FHWA, making it a widely supported analysis tool, featuring performance functions calibrated at the national level. The guide enables the efficient computation of pavement distresses resulting from diverse traffic loads under a variety of environmental conditions. The AASHTOWare system also allows the user to define axle load distribution factors, which simply represent the percentage of the total axle applications within each load interval and axle groups (single, tandem, tridem, and quad).

The pavement analysis presented in this report used the AASHTOWare system. However, given the constraints of the system and the representative vehicle configurations presented in Section 5, only four axle-groups were considered during the analysis, and consequently the modeling process of the ECFs. Their load spectra are presented individually in Figure 91, and combined in Figure 92.

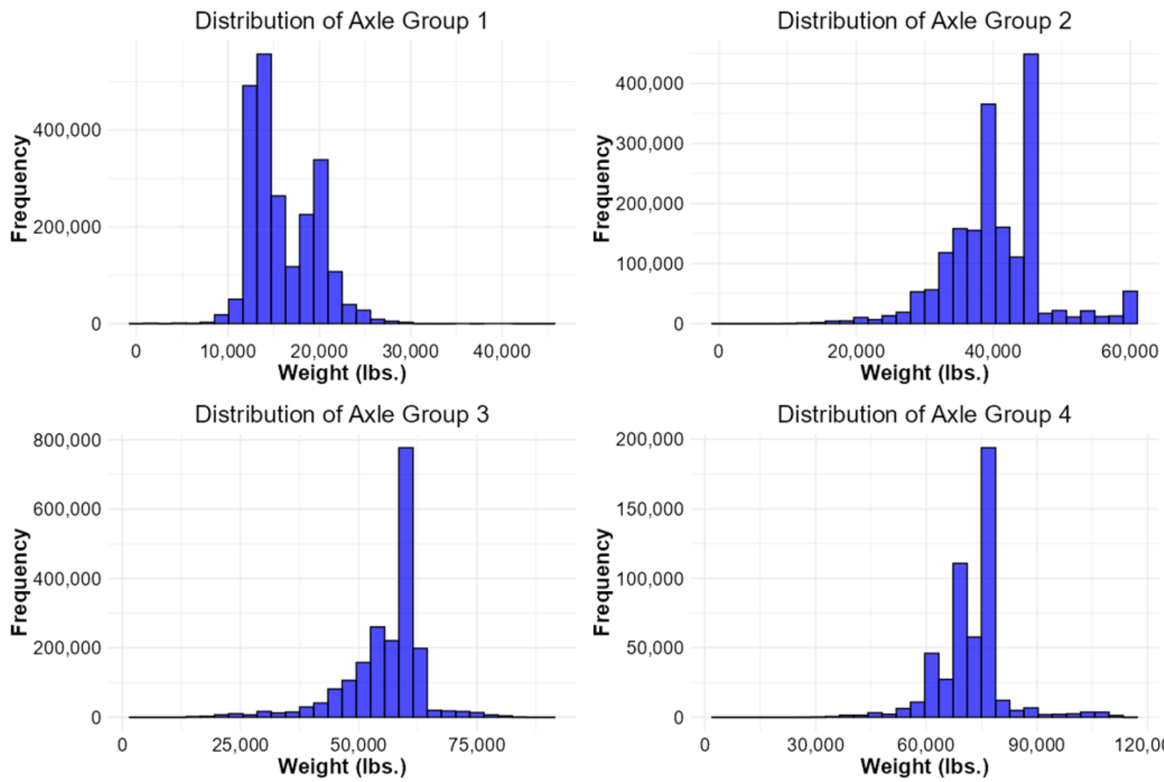

Figure 91: Load distribution per axle group

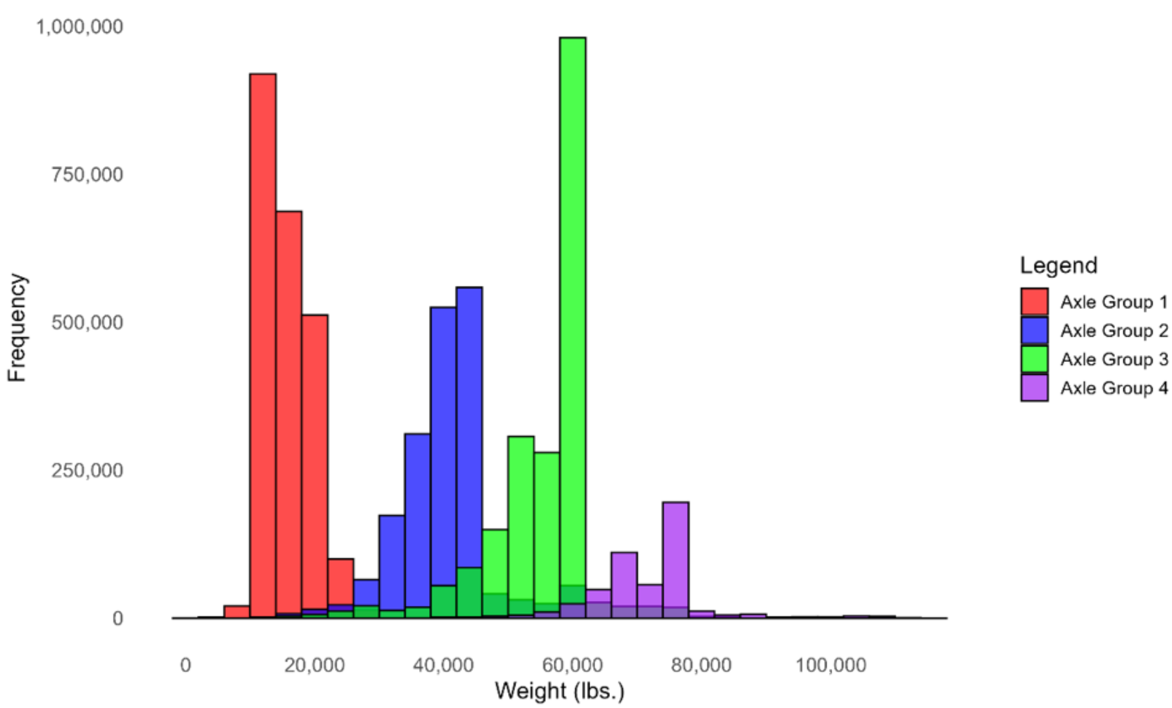

Figure 92: Load spectra of all axle-groups in the same scale

Where Axle Group 1 corresponds to single axles, Axle Group 2 to tandem, Axle Group 3 to tridem, and Axle Group 4 to quads. The main descriptive statistics for each axle group, across all the routed permit types analyzed, are presented in Table 118.

Table 118: Descriptive statistics per axle-group (lbs.)

Axle Group	**Mean**	**St. Dev.**	**25th Perc.**	**Median**	**75th Perc.**
1	16,076	3,927	13,200	15,000	19,000
2	40,984	7,398	36,500	40,000	46,000
3	55,876	8,172	53,000	60,000	60,000
4	72,073	9,236	68,300	74,000	75,900

The same statistics are also presented by permit type in Tables 119 to 122.

Table 119: Descriptive statistics for single axle

Permit Type	**Mean**	**St. Dev.**	**25th Perc.**	**Median**	**75th Perc.**
Crane (Annual)	19,150	2,794	17,782	20,000	21,000
Crane (S/P Mileage)	22,409	3,945	20,000	22,500	26,000
Hubometer (Quarterly)	15,490	5,007	12,000	13,000	19,000
General	15,944	3,343	14,000	15,000	19,000
Husbandry (Annual)	14,229	2,889	12,000	14,000	14,300
Rig-Up Truck (Annual)	23,503	2,716	23,400	25,000	25,000
Water Well Drilling Machinery	17,792	4,003	15,000	18,000	20,800
Well Servicing Unit (S/P Mileage)	15,911	3,646	13,000	15,000	19,000

It can be seen on Table 119 that, on average, all permits operate under the legal weight limits for single axles on trucks without a permit (20,000 lbs.), and at least 50 percent of all OW permits contained in the database have their single axle operating under the weight limits established for trucks with a permit (25,000 lbs.), An exception was observed for the Crane (S/P Mileage) permit, where at least 25 percent of the trucks operated beyond the weight limit for single axles.

Table 120: Descriptive statistics for tandem axle

Permit Type	**Mean**	**St. Dev.**	**25th Perc.**	**Median**	**75th Perc.**
Crane (Annual)	42,076	4,864	40,000	44,000	46,000
Crane (S/P Mileage)	45,393	7,720	40,000	46,000	52,800
Hubometer (Quarterly)	42,389	6,891	38,000	40,000	46,120
General	40,657	7,050	36,498	40,000	46,000
Husbandry (Annual)	43,722	3,802	40,200	46,000	46,000
Rig-Up Truck (Annual)	35,925	5,668	34,000	34,000	34,000
Water Well Drilling Machinery	42,080	5,870	40,000	46,000	46,000
Well Servicing Unit (S/P Mileage)	38,765	6,232	35,400	38,000	42,000

The results in Table 120 indicate that, on average, all overweight permits contained in the database were loaded beyond the legal weight limit for tandem axles without a permit (34,000 lbs.), but complied with the weight limit established for tandem axles with a permit (46,000 lbs.). An exception was observed for the Hubometer permit, where at least 25 percent of the trucks surpassed that weight limit threshold for permitted vehicles.

Table 121: Descriptive statistics for tridem axle

Permit Type	**Mean**	**St. Dev.**	**25th Perc.**	**Median**	**75th Perc.**
Crane (Annual)	51,541	7,283	45,426	51,700	58,750
Crane (S/P Mileage)	57,724	10,077	49,781	58,818	64,500
Hubometer (Quarterly)	59,720	9,136	54,000	60,000	66,000
General	55,235	7,732	53,000	59,000	60,000
Husbandry (Annual)	59,250	3,160	60,000	60,000	60,000
Rig-Up Truck (Annual)	41,055	9,257	34,000	39,000	52,500
Water Well Drilling Machinery	55,497	5,559	51,060	56,000	60,000
Well Servicing Unit (S/P Mileage)	61,011	9,868	54,000	60,000	68,000

From Table 121 it can be observed that, on average, seven out of eight permits complied with the tridem's legal weight limits for vehicles operating with a Texas permit (60,000 lbs.). The exception was the Well Servicing Unit (S/P Mileage) permit, which was also found to exceed the 254,300 lbs. GVW (threshold established for vehicles qualifying for a Super-heavy permit). Furthermore, the median axle weight for tridems under Well Servicing Unit (S/P Mileage) permit was found to be lower than the mean, indicating the presence of extremely heavy axle loads (i.e., positive skewness). The data indicates that at least 25 percent of the tridem axles mounted on these vehicles exceed the legal weight limit. A similar characteristic was observed for vehicles operating under the Crane (S/P Mileage) permit, although these vehicles, on average, remained within the legal weight limits.

Table 122: Descriptive statistics for quads

Permit Type	**Mean**	**St. Dev.**	**25th Perc.**	**Median**	**75th Perc.**
Crane (Annual)	61,769	6,646	58,090	60,080	64,000
Crane (S/P Mileage)	87,288	18,482	73,340	93,200	104,000
Hubometer (Quarterly)	91,489	15,736	80,000	96,000	105,600
General	70,553	6,730	68,000	72,000	75,900
Husbandry (Annual)	72,204	3,049	70,000	70,000	75,900
Rig-Up Truck (Annual)	68,200	16,158	50,500	80,000	80,000
Water Well Drilling Machinery	68,218	3,583	68,000	68,000	70,000
Well Servicing Unit (S/P Mileage)	77,380	10,242	72,000	80,000	83,400

Finally, Table 122 shows that, on average, less than half of the permits complied with the quad legal weight limit for trucks operating with a Texas permit. Due to the presence of extreme values in the axle load distribution, the median axle weight exceeded the legal threshold in five out of eight overweight permit categories. For vehicles operating under the Crane (S/P Mileage) and Hubometer permits, at least 25 percent of the fleet was found to have a quad-axle with more than 50 percent over load.

Overall, the Crane (S/P Mileage) permit was the most concerning category because its most frequent configuration does include a quad-axle setup. In contrast, the Hubometer permit primarily involves trucks with single and tandem axles, which are more likely to comply with the legal weight limits.

Based on the results, and to better represent the OW load spectra, the axle loads utilized during the pavement consumption analysis are presented in Table 123.

Table 123: Axle load spectra for consumption analysis

Single	Tandem	Tridem	Quad
12,000	34,000	56,000	64,000
14,000	38,000	59,000	73,000
18,000	42,000	62,000	82,000
22,000	46,000	65,000	91,000
26,000	50,000	68,000	100,000

8.1.3 Environmental Conditions

Pavement performance analysis must consider the prevailing environmental conditions, which directly impact pavement performance. For example, rutting is more critical in warm climates, while cracking is the dominant distress mechanism in colder regions. Texas has five distinct environmental regions: wet-warm (Southeast Texas), dry-warm (South Texas), wet-cold (Northeast Texas), dry-cold (Northwest Texas), and mixed (Central Texas). In this study, the effect of the soil and subgrade conditions was captured by using a sample of pavement structures from these different regions of Texas. The climate was accounted for by selecting climate stations according to each location under analysis.

Statewide values were determined by averaging the results obtained from these various regions. This approach was necessary due to the lack of accurate routed data (i.e., exact origin and destination of permitted trucks), which prevented a precise proportional assessment of regional effects on pavement performance.

8.1.4 Representative Pavement Structures

A sample of 33 pavement design projects from various locations of Texas, built between 2017 and 2021, was drawn from TxDOT's project library (Table 124). Information such as layer thickness, elastic modulus, and traffic (in terms of ESALs) was essential to establish a comprehensive range of representative structures.

Table 124: Sample with 30 projects from TxDOT library between 2017 and 2021

Project	District	County	Highway	Pavement Type	Design ESALs
1	Atlanta	Bowie	US 82, FM 989	JCP	1.63E+07
2	Atlanta	Bowie	US 82, FM 989	JCP	6.75E+06
3	Beaumont	Jefferson	US 69	CRCP	4.22E+06
4	Beaumont	Chambers	FM 1663	ACP	1.59E+05
5	Brownwood	Brown	FM 2632	STP	3.90E+05
6	Dallas	Dallas	IH 35	CRCP	2.34E+08
7	El Paso	El Paso	IH 10	ACP	3.05E+07
8	Fort Worth	Tarrant	US 287	CRCP	1.82E+06
9	Fort Worth	Johnson	FM 917	ACP	1.71E+06
10	Houston	Harris	Memorial Drive	JRCP	3.74E+06
11	Houston	Harris	FM 1960	CRCP	1.16E+07
12	Houston	Harris	FM 1960	JCP	2.56E+06
13	Laredo	Webb	IH 35	ACP	3.00E+06
14	Laredo	Kinney	US 277	ACP	7.63E+06
15	Lubbock	Parmer	US 70	ACP	9.55E+06
16	Lubbock	Crosby	SH 207	ACP	4.27E+05
17	Lufkin	Houston	SH 21	ACP	3.52E+06
18	Lufkin	Nacogdoches	FM 343	STP	2.21E+05
19	Paris	Grayson	US 75	ACP	6.37E+05
20	Paris	Grayson	US 75	CRCP	6.64E+06
21	Paris	Hopkins	FM 824	STP	1.49E+05
22	Pharr	Cameron	FM 506	ACP	3.02E+06
23	Pharr	Hidalgo	FM 1017	ACP	2.22E+06
24	San Antonio	Karnes	FM 99	ACP	2.00E+06
25	San Antonio	Bexar	IH 410	ACP	2.43E+07
26	San Antonio	Bexar	IH 410	ACP	4.66E+06
27	San Antonio	Bexar	IH 410	ACP	2.94E+06
28	San Antonio	Bexar	IH 410	ACP	2.43E+07
29	San Antonio	Bexar	IH 410	ACP	3.99E+06
30	Tyler	Henderson	US 175	ACP	5.05E+06

8.2 Equivalent Consumption Factor

The concept of pavement ECF is based on that of the Load Equivalency Factor (LEF), developed during the AASHO Road Test (HRB, 1962). The LEF represents the ratio between the repetitions of a given axle load and a standardized axle load (typically an 18-kip single axle) that produces the same loss of serviceability. This equivalency provides a convenient way to standardize a wide range of possible axle loads to a single reference value: the standard axle. However, the LEF has limited applicability outside the specific conditions of the road test where it was developed, especially concerning environmental factors, construction materials, and vehicle characteristics (Kawa et al., 1998). Additionally, since the development of LEF, more complex axle configurations became available, and advances in tire technology (such as radial versus bias-ply tires) took place. Vehicle suspensions and tire pressures also differ significantly nowadays.

To address the limitations of the LEF, the ECF concept was developed to incorporate the effects of different pavement structures (pavement type and environment), climate, current axle groups, and multiple failure criteria. The ECF is similar to the LEF in that it relates the relative impact of an axle load to a reference load, ensuring they achieve the same level of performance, but it addresses the impact in terms of *structural life consumption*. The ECF can be formulated as proposed in Equation 8.1 with is linearized form presented in Equation 8.2.

$$ECF = \frac{N_s}{N_i} = \left(\frac{W_i}{W_s \times \beta}\right)^{\alpha} \tag{8.1}$$

$$\log(ECF) = \alpha \times \log\left(\frac{W_i}{W_s \times \beta}\right) \tag{8.2}$$

Where N_i is the number of load repetitions of a given axle to reach a certain failure criterion; N_s is the number of repetitions of the standard axle to reach the same failure criterion; W_i is the weight of a given axle of interest in lbs.; W_s is the weight of the standard axle (18,000 lbs.); α is the exponential relationship between the different axle loads to reach the same failure criterion, governed by the structure behavior; and β is the coefficient that represents the effect of the group-axle to reach the same failure criterion as the single axle.

The AASHTOWare system was used to integrate all pavement analysis factors and compute the corresponding ESALs, as previously described. The AASHTOWare system computes pavement responses in a mechanistic-empirical analysis, assuming the pavement structure as a linear-elastic multi-layered system. Although this is not the case, the linearity assumption is reasonable at the low strain levels, typical of highway traffic. The critical pavement responses calculated by the system are correlated to field distresses using transfer functions (calibrated on field observations), and Miner's law is used to output the expected performance curves at a selected design life.

The basis for equivalency can be determined by either calculated (or measured) stress, strains, or deflections at various points in the pavement structure, or by equal conditions of distress or loss of serviceability. Therefore, it is expected that the coefficient α (Equation 8.2), hereinafter referred to as the Axle Load Factor (ALF), is related to the pavement structure. This implies that different structures will be affected by axle loads at different rates, which is reasonable and consistent with observations made over 70 years ago during the AASHO road test.

A well-documented and established empirical index used to convert multiple pavement layers with different properties into a common indicator is the Structural Number (SN). Although the SN does not fully account for the benefits of certain highway materials (e.g., inverted pavements, cement-treated layers, modified asphalt, etc.), it is still widely used by many pavement engineers and departments of transportation to characterize pavement structures.

Lastly, the coefficient β (Equation 8.2) represents the effect of the axle group, hereinafter referred to as the Group Equivalency Factor (GEF), that would cause the same structural consumption (damage or performance reduction) as of a single axle load. Thus, by definition, for single axles the GEF is equal to one. Notice that the GEF addresses only the effect of different axle groups using the number of axles (n) as a proxy for the variations in axle configurations (2 for tandem, 3 for tridem, and 4 for quad). We can then rewrite Equation 8.2 as:

$$\log(ECF) = ALF \times \log\left(\frac{W_i}{W_s \times GEF}\right) \tag{8.3}$$

To determine pavement performance over a specific analysis period, the set of different failure criteria defined earlier for each pavement type (Table 125) was used. The performance thresholds used in this study (Table 117) are the default values from the AASHTOWare software, but they were also aligned with TxDOT's requirements for pavement performance.

Table 125: Failure criteria adopted per pavement type

Pavement Type	Performance Thresholds
ACP and STP	Rutting of 0.5 inches Fatigue cracking (25% of area) IRI[1] of 172 in/mi
CRCP	IRI of 172 in/mi 10 punchouts per mile
JCP and JRCP	Faulting of 0.12 inches IRI of 172 in/mi Transverse cracking (1% of the area)

[1] International Roughness Index

Each pavement type has its own performance criteria and thresholds, designed to ensure that the pavement can withstand traffic and environmental conditions throughout a given design period (typically 20 to 30 years). However, due to inherent differences in failure mechanisms, it is impossible to simultaneously reach all performance threshold values at the end of the design period. Therefore, it is necessary to determine, for each failure criterion, the traffic volume that would result in a terminal distress value. The calculated terminal traffic volume depends on the distress mechanism considered. For instance, for ACP there is one traffic volume for rutting, one for cracking, and one for roughness, and typically the smallest of these determines the service life of the pavement. In this way, the concepts of ECF diverge from the traditional LEF because the second considers only one failure mechanism: the loss of PSI.

Once design traffic volumes are determined, the next step involves analyzing each pavement structure for a range of different axle loads and configurations and determining the equivalent traffic required to reach each failure criterion. Axles with an ECF of less than one will take longer than, for example, 20 years to reach failure criteria, while axles associated with an ECF of more than one will take less than 20 years to reach the same failure condition. Therefore, the ECF represents the relative pavement life for any given pavement structure under given environmental conditions, under an 18-kip single standard axle divided by the life of the same pavement under the same conditions for a given load and configuration. Notice that once ECFs are obtained for each pavement type and failure criteria, it is possible to create a weighted average ECF based on the most common distresses (and pavement type for each region), to properly address local conditions, such as the density of concrete pavements, for instance, around the Houston area compared to that in the Panhandle area.

8.3 ECF Stepwise Process

The first step in the ECF modeling is to estimate the rate of deterioration (ALF) from Equation 8.3 for each pavement type given the load spectra in Table 123. Notice that because each pavement has at least two failure mechanisms (Table 125), the ALF must be estimated for each failure criterion separately. The structure of Equation 8.3 suggests that it is possible to establish the ALF as the slope of the linear model between the ECF and the normalized load ($W_i/18,000$) on a log-log scale.

The second step assesses the GEF by applying different load combinations so that each pavement structure achieves the same performance as it would under the standard axle load (single axle). Notice that, for the same load, the greater the number of axles in a group, the better the axle-group distributes the loads over the pavement. Thus, to fail a given pavement at the same time, it is expected that larger axle groups (i.e., equipped with more axles) will require a greater number repetitions to reach the same terminal level. Given the range of loads between axle-groups, it was decided to estimate the GEF based on the point estimate of the median axle-load that leads the pavement to failure. The linear relationship between the number of axles and the normalized load result in the GEF.

The third and final step is combining both ALF and GEF calculated into the form of Equation 8.3. The next sections presents a step-by-step process to model the ECFs for each pavement type and failure criteria.

8.4 Asphalt Concrete Pavement (ACP)

Asphalt concrete pavements (ACP) were evaluated based on three distinct failure criteria: rutting, fatigue cracking, and roughness (measured in terms of IRI). Each failure mechanism yields a different ECF model. There are mainly two types of ACP structures: with a flexible base and with a cement-treated base (CTB). Although both feature an asphalt surface layer, their structural behavior under load differs significantly. The CTB structure possesses tensile strength that allows it to resist stress and strains differently from a flexible base. Consequently, fatigue cracking can initiate not only at the surface but also within the CTB layer itself. A histogram of all the ACP structures available in the sample of projects and their SN is presented in Figure 93.

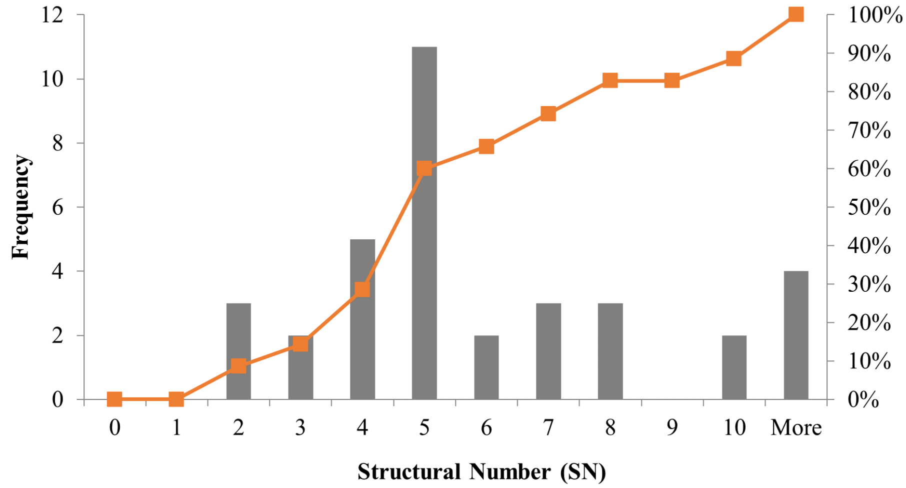

Figure 93: Histogram of the ACP structures based on their SN

8.4.1 Rutting

The estimation of an ECF model for rutting starts with designing ACP pavements to fail according to the performance thresholds presented in Table 125. By plotting the normalized load and ECF (Equation 8.1) repetitions to failure in a log-log scale, it is then possible to obtain the slope of the linear relationship between them, as exemplified in Figure 94.

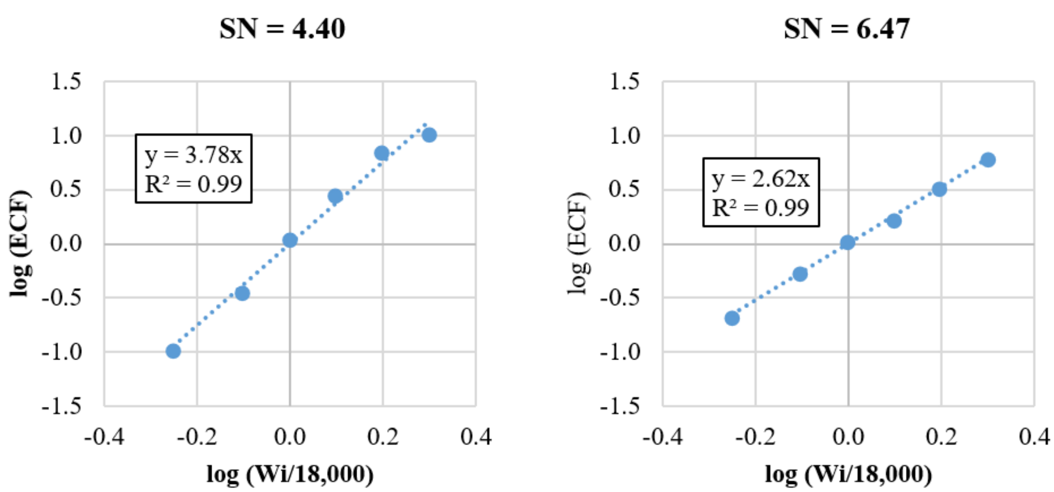

Figure 94: Difference in the ALF for distinct SNs

As noticed in Figure 94, the ALFs are a function of the SN. Hence, to better visualize the change in ALF according to each respective SN, they were both plotted as depicted in Figure 95.

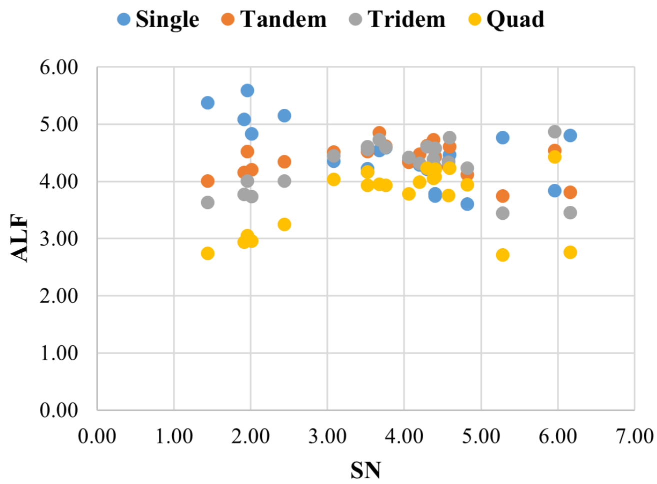

Figure 95: ALF variation across different SN

The results shown in Figure 95 demonstrate that ALFs vary significantly across different SN. Discernible trends can be visually identified in the scatter plot, but also there seems to be a different pattern for each type of axle configuration. To aid in interpretation, single-axles and quad-axles were isolated and presented in Figure 96.

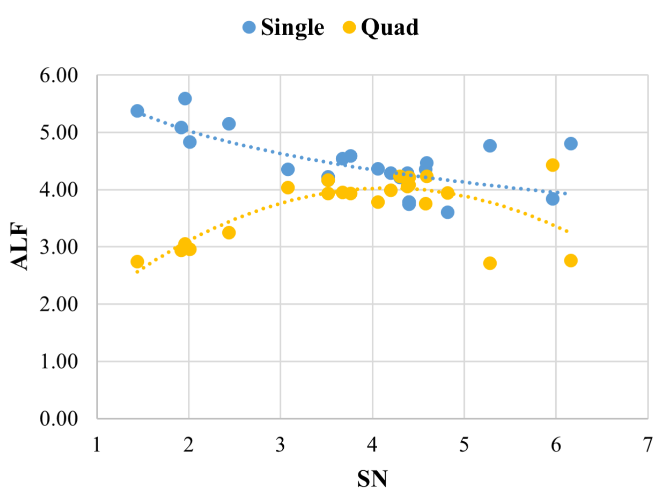

Figure 96: ALF variation for single and quads across different SN

Note in Figure 96 that while for single-axles, a clear monotonic decreasing trend is observed, for tandem, tridem and quads it seems that the ALF reaches a peak about a SN of 4. Hence to better capture the observed trends between ALF and SN, the rutting analysis was divided in two cases: monotonic decreasing (single-axles), and non-monotonic (for the rest). For the first case, the non-linear model presented in

Equation 8.4 was fitted by minimizing the sum of squared errors, as shown in Figure 97.

$$ALF_1 = \beta_1 \times SN^{\beta_2} \tag{8.4}$$

Where ALF_1 is the axle load factor for rutting of a single axle.

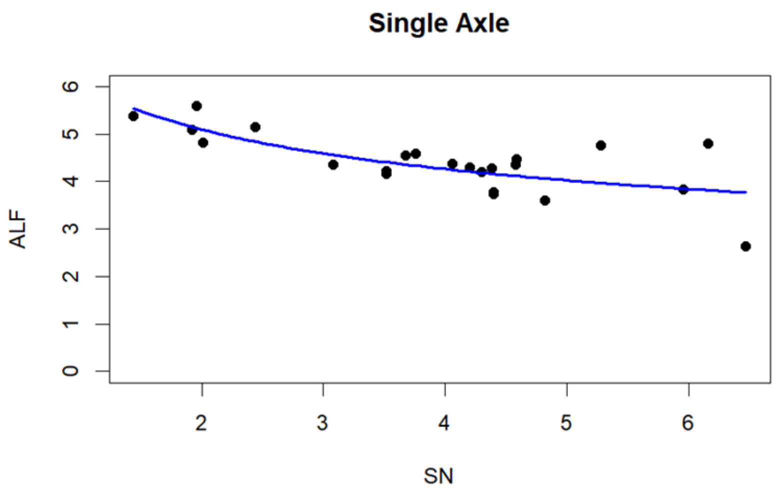

Figure 97: Monotonic decreasing ALF

The proposed model resulted in a $R^2 = 0.53$ and $RMSE = 0.45$, with the estimated parameters as presented in Table 126.

Table 126: Parameters for ALF_1

Parameter	Estimate	Std. Error	t-value
β_1	6.087	0.395	15.4
β_2	-0.257	0.050	-5.1

For the non-monotonic case, the non-linear model in Equation 8.5 was fitted, as shown in Figure 98.

$$ALF_{2,3,4} = \beta_1 + \beta_2 \times AXLE + SN^{\beta_3} \times \exp\left(-SN^{\beta_4}\right) \tag{8.5}$$

Where $ALF_{2,3,4}$ is the rutting axle load factor for tandem, tridem and quads; and $AXLE$ is the variable that adjusts the model's goodness-of-fit according to each of the axle configurations (tandem, tridem or quad).

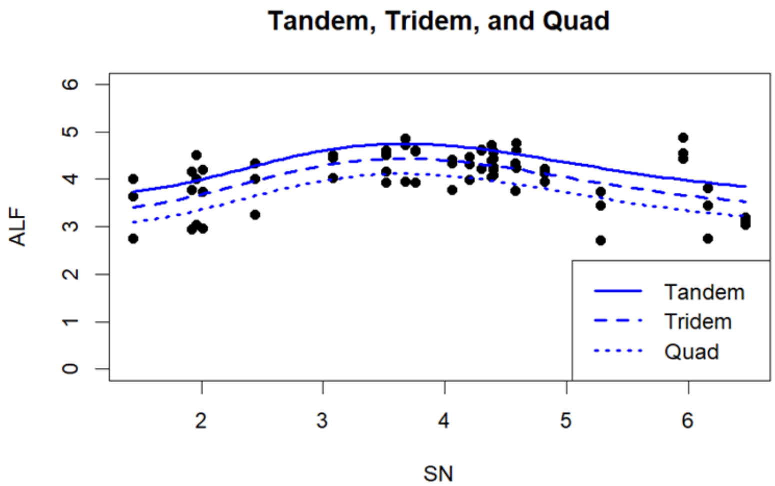

Figure 98: Non-monotonic ALF

The proposed model resulted in a $R^2 = 0.59$ and $RMSE = 0.36$, with the estimated parameters as presented in Table 127.

Table 127: Parameters for $ALF_{2,3,4}$

Parameter	Estimate	Std. Error	t-value
β_1	3.436	0.209	16.4
β_2	-0.317	0.052	-6.1
β_3	3.126	0.137	22.9
β_4	0.943	0.026	35.9

The GEF was found to have a wide range of values across the different axle configurations, with increasing variability according to the number of axles, as shown in Figure 99.

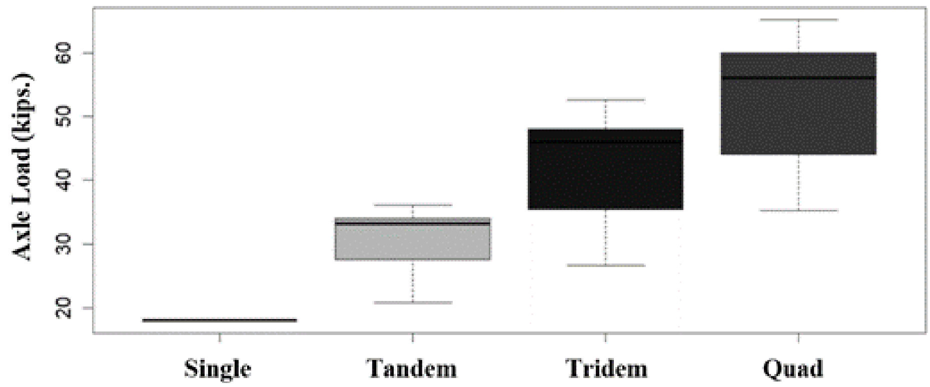

Figure 99: Effect of the different axle-group on load distribution

Note from Figure 99 that as the number of axles increase, heavier axle-loads are required to fail simultaneously to a single axle because of the load distribution. The GEF model for the different axle configuration is presented Figure 100.

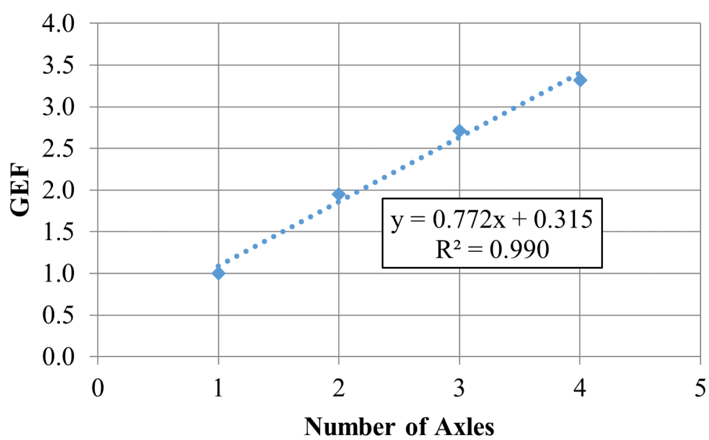

Figure 100: Relationship between GEF and axle-groups for rutting in the ACP

By combining the ALF and GEF models, we can finally write a final ECF model for rutting in the ACP, such that:

$$\log(ECF_1) = 6.087 \times SN^{-0.257} \times \log\left(\frac{W_L}{18}\right) \tag{8.6}$$

$$\begin{aligned} \log(ECF_{2,3,4}) = &\left(3.436 - 0.317 \times AXLE + SN^{3.126} \times \exp\left(-SN^{0.943}\right)\right) \\ &\times \log\left(\frac{W_L/18}{0.772 \times AXLE + 0.315}\right) \end{aligned} \tag{8.7}$$

Where ECF_1 is the equivalent consumption factor for single-axles; $ECF_{2,3,4}$ is the equivalent consumption factor for the remaining; $AXLE$ is a discrete variable for the number of axles within the axle-group (2, 3 or 4), W_L is the total axle-load in kips, and SN is the structural number.

8.4.2 Fatigue Cracking

The framework and procedure exemplified in Section 8.4.1 for "Rutting" was also employed for all the subsequent failure mechanisms. In contrast to the behavior observed for rutting, the ALF for fatigue cracking was less sensitive to variations on the SNs. Therefore, instead of establishing an ALF relationship as a function of the SN, the ALF values were simply estimated by axle group and averaged, as shown in Table 128.

Table 128: Mean ALF per axle-group for rutting in the ACP

Axle Group	Mean	Std. Error	Min.	Max.
Single	4.28	0.78	2.42	5.93
Tandem	4.10	0.95	1.66	6.80
Tridem	4.00	1.02	1.94	6.42
Quad	3.60	0.95	1.54	5.70

The results in Table 128 indicate that values for the ALF based on fatigue cracking were, on average, numerically higher than those for rutting. Furthermore, a decreasing trend was noticed between the ALF as a function of the axle-group, as presented in Figure 101.

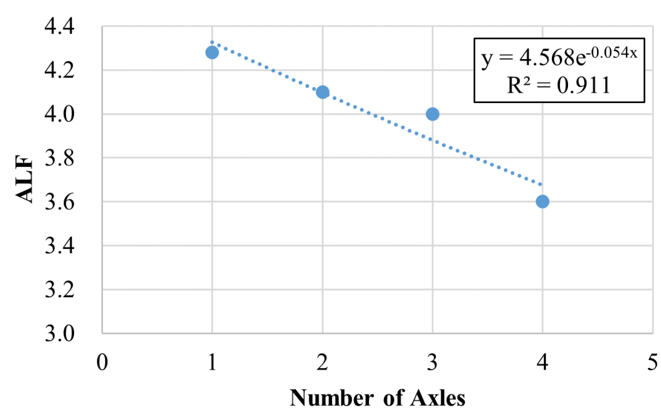

Figure 101: Relationship between ALF and axle-groups for fatigue cracking in ACP

By combining all this information, the final ALF specification is given by Equation 8.8.

$$\log(ALF) = 4.568 \times \exp(-0.054 \times AXLE) \tag{8.8}$$

The results for GEF are further presented in Figure 102.

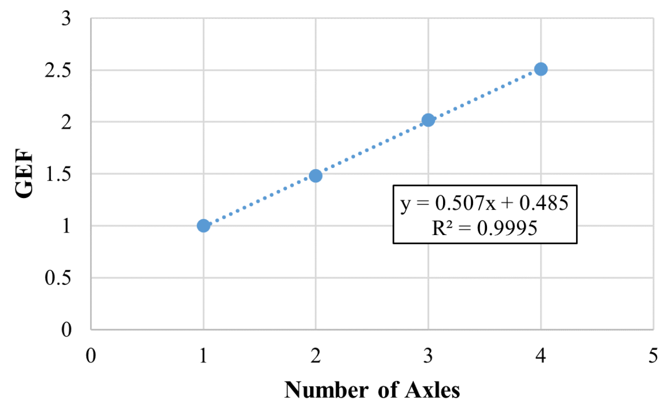

Figure 102: Relationship between GEF and axle-group for fatigue cracking in the ACP

After assembling both the ALF and GEF, the result is an ECF model for fatigue cracking in the ACP, given by Equation 8.9.

$$\log(ECF) = (4.568 \times \exp(-0.054 \times AXLE)) \times \log\left(\frac{W_L/18}{0.507 \times AXLE + 0.485}\right) \tag{8.9}$$

Where ECF is the equivalent consumption factor for rutting in the ACP; $AXLE$ is the discrete variable for the number of axles in each axle-group (1, 2, 3 or 4), and W_L is the total axle-load in kips.

8.4.3 Roughness

Roughness (a measure of ride quality in terms of IRI) increases as a result of a combination of failures, including but not limited to rutting and fatigue cracking. When evaluating the ALFs obtained, no systematic trends between the ALF and the SN were found, as shown in Table 129.

Table 129: Mean ALF per axle-group for roughness in the ACP

Axle Group	Mean	Std. Error	Min.	Max.
Single	3.66	0.97	1.70	6.04
Tandem	3.68	0.92	0.99	5.84
Tridem	4.44	0.97	1.93	6.51
Quad	4.35	0.84	2.35	6.27

Because the values obtained for the ALF were similar between singles and tandems, as well as between tridems and quads, the mean ALFs of 3.67 and 4.40 were utilized for the two groups, respectively, as shown in Equations 3.10 and 3.11

$$ALF_{1,2} = 3.67 \tag{8.10}$$

$$ALF_{3,4} = 4.40 \tag{8.11}$$

The results for GEF are presented in Figure 103.

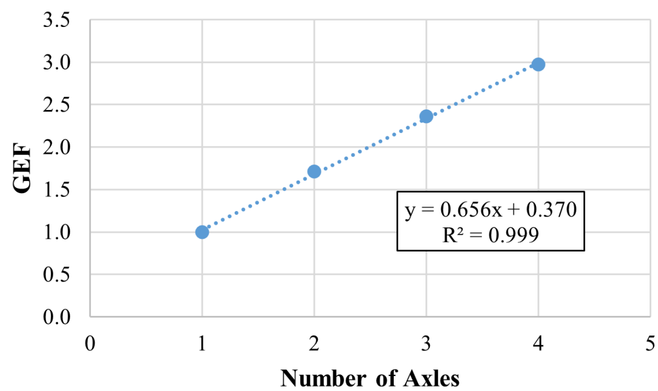

Figure 103: Relationship between GEF and axle-group for roughness in the ACP

The final ECF model for roughness in the ACP is given by Equation 8.12.

$$\log(ECF) = (3.67 + 0.73 \times 1_{AXLE=3,4}) \times \log\left(\frac{W_L/18}{0.656 \times AXLE + 0.370}\right) \tag{8.12}$$

Where ECF is the equivalent consumption factor for roughness in the ACP; $1_{AXLE=3,4}$ is an indicator function that assumes the value of one if the condition in the brackets is true and zero otherwise; and W_L is the total axle-load in kips.

8.5 Surface Treatment Pavement (STP)

Surface-treated pavements (STP) are characterized by an application of asphalt binder followed by an application of uniformly graded aggregate. Two or three such applications are possible and common. In Texas, surface treatments are used as surface courses in low-volume roads (e.g., farm-to-market, FM) in the form of either one- or multiple-course. STP is also used in maintenance interventions, reducing the rate of deterioration without adding structural capacity.

The failure mechanisms among STP are similar to those of ACP. However, the traditional definition of fatigue cracking, for instance, is less evident in the former, particularly in the case of chip-seals that are commonly stressed by shear and lack of tensile strength, as opposed to asphalt mixtures. Given the overall reduced structural capacity on STP, they are expected to yield relatively higher ALF values compared to those obtained during the ACP analysis.

8.5.1 Rutting

The ALFs for rutting in the STP are presented in Table 130.

Table 130: Mean ALF per axle-group for rutting in the STP

Axle Group	Mean	Std. Error	Min.	Max.
Single	5.82	0.71	3.73	7.11
Tandem	3.69	0.58	2.08	4.55
Tridem	3.62	0.65	2.11	5.20
Quad	3.79	0.67	2.01	5.36

The results in Table 130 indicate a relatively higher ALF value among single-axles, but similar slopes across tandem, tridem and quads. Therefore, the latter three axle-groups were clustered together and averaged. The final ALF relationship for rutting in the STP is presented in Equation 8.13.

$$ALF = 5.82 - 2.12 \times 1_{AXLE=2,3,4} \tag{8.13}$$

Where $1_{AXLE=2,3,4}$ is an indicator function that assumes the value of one if the condition in the brackets is true and zero otherwise. The results for GEF are presented in Figure 104.

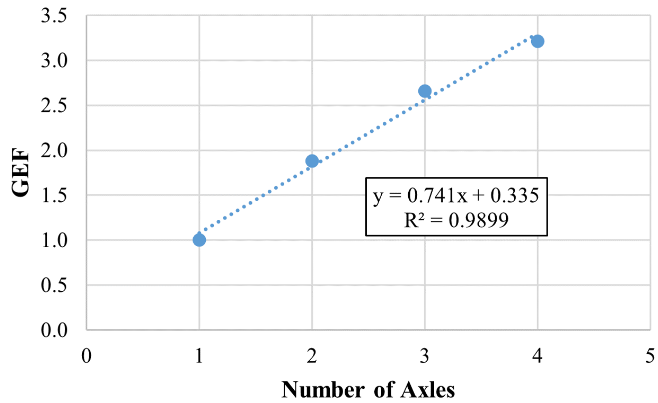

Figure 104: Relationship between GEF and axle-group for rutting in the STP

The final ECF model for rutting in the STP is shown in Equation 8.14.

$$\log(ECF) = (5.82 - 2.12 \times 1_{AXLE=2,3,4}) \times \log\left(\frac{W_L/18}{0.741 \times AXLE + 0.335}\right) \tag{8.14}$$

Where ECF is the equivalent consumption factor for rutting in the STP; $1_{AXLE=2,3,4}$ is an indicator function that assumes the value of 1.0 if the condition in the brackets is true and 0.0 otherwise; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.5.2 Cracking

The ALFs for cracking in the STP are presented in Table 131.

Table 131: Mean ALF per axle-group for cracking in the STP

Axle Group	Mean	Std. Error	Min.	Max.
Single	4.25	0.80	2.78	5.82
Tandem	4.60	0.98	2.64	7.34
Tridem	4.57	0.75	3.02	6.10
Quad	4.69	0.93	2.72	6.49

The results from Table 131 indicate that the ALF was consistent across all SNs and axle groups. Thus, the mean ALF (4.53) was utilized for cracking in the STP. The results for GEF are presented in Figure 105.

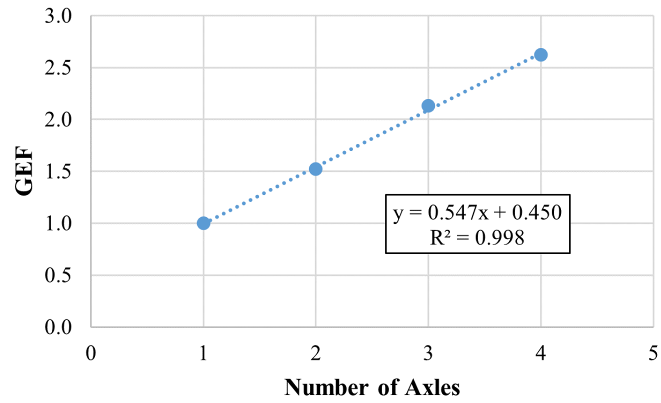

Figure 105: Relationship between GEF and axle-group for cracking in the STP

The final ECF model for cracking in the STP is shown in Equation 8.15.

$$\log(ECF) = 4.53 \times \log\left(\frac{W_L/18}{0.547 \times AXLE + 0.450}\right) \tag{8.15}$$

Where ECF is the equivalent consumption factor for cracking on STP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.5.3 Roughness

The ALFs for roughness for STP are presented in Table 132.

Table 132: Mean ALF per axle-group for roughness in the STP

Axle Group	Mean	Std. Error	Min.	Max.
Single	4.05	1.12	1.32	6.02
Tandem	4.28	1.34	1.82	6.91
Tridem	4.32	0.93	1.42	5.96
Quad	4.40	1.05	1.92	6.40

The results from Table 132 indicate that the ALF was consistent across all SNs and axle groups. Thus, the mean ALF (4.26) was utilized for roughness for STP. The results for GEF are presented in Figure 106.

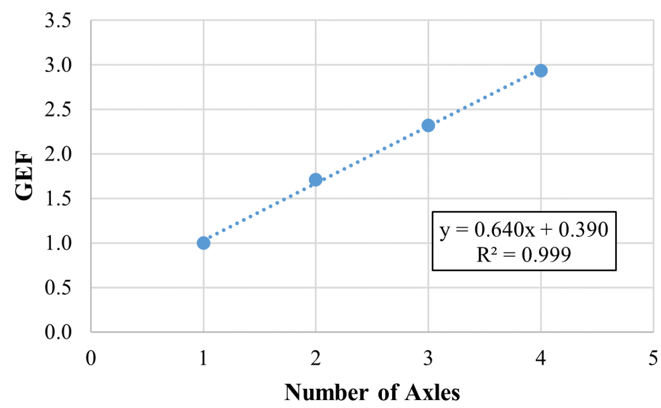

Figure 106: Relationship between GEF and axle-group for roughness in the STP

The final ECF model for roughness in the STP is shown in Equation 8.16.

$$\log(ECF) = 4.26 \times \log\left(\frac{W_L/18}{0.640 \times AXLE + 0.390}\right) \tag{8.16}$$

Where ECF is the equivalent consumption factor for roughness on STP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.6 Continuously Reinforced Concrete Pavement (CRCP)

Currently in Texas, the most common type of rigid pavement is the continuously reinforced concrete pavement (CRCP). The most frequent and severe distress affecting CRCP is the number of punchouts, which results from excessive wheel loads and inadequate structural capacity, such as insufficient slab thickness or subbase support. Punchouts are characterized by concrete blocks separated by depressed transverse and longitudinal cracks, often accompanied by ruptured longitudinal steel at the transverse cracks. Roughness is also a major concern in rigid pavements, as it directly affects ride quality, pavement performance, and vehicle operating costs. Hence, the ECF model for CRCP was based on the two failure mechanisms.

8.6.1 Punchouts

The ALFs for punchouts in the CRCP are presented in Table 133.

Table 133: Mean ALF per axle-group for punchouts in the CRCP

Axle Group	**Mean**	**Std. Error**	**Min.**	**Max.**
Single	1.75	0.49	0.82	3.19
Tandem	1.83	0.58	0.65	3.03
Tridem	1.86	0.41	1.15	2.64
Quad	1.89	0.51	1.10	2.34

The results from Table 133 indicate that the ALF was consistent across all slab thicknesses and axle groups. Thus, the mean ALF value of 1.82 was utilized for punchouts in the CRCP. The results for GEF are presented in Figure 107.

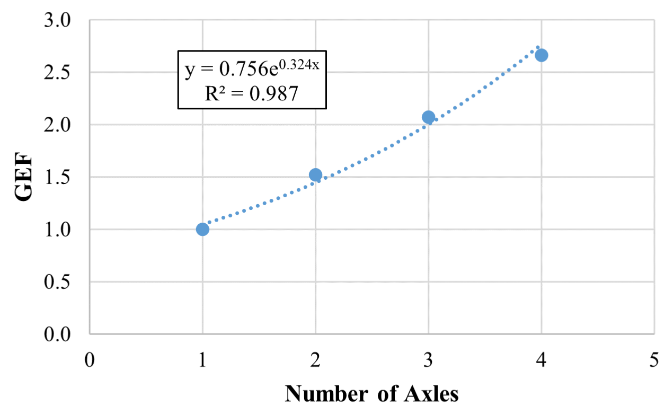

Figure 107: Relationship between GEF and axle-group for punchouts in CRCP

Note that the GEF was found to have an exponential relationship with the number of axles. This can be explained by the fact that, for rigid pavements under multi-axle configurations to fail at the same rate as under single-axle configurations, a significantly greater number of load repetitions would be required due to their relatively higher structural strength compared to flexible pavements. This effect is particularly evident for tridem and quad axle groups, which distribute loads more effectively. The final ECF model for punchouts in the CRCP is shown in Equation 8.17.

$$\log(ECF) = 1.82 \times \log\left(\frac{W_L/18}{0.756 \times \exp(0.324 \times AXLE)}\right) \tag{8.17}$$

Where ECF is the equivalent consumption factor for punchouts for CRCP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.6.2 Roughness

The ALFs for roughness for CRCP are presented in Table 134.

Table 134: Mean ALF per axle-group for roughness in the CRCP

Axle Group	**Mean**	**Std. Error**	**Min.**	**Max.**
Single	2.12	0.49	1.10	3.40
Tandem	2.20	0.51	1.38	3.17
Tridem	2.09	0.46	1.25	3.15
Quad	2.13	1.07	0.22	3.82

The results from Table 134 indicate that the ALF was consistent across all slab thicknesses and axle group. Thus, the mean ALF (2.14) was utilized for punchouts in the CRCP. The results for GEF are presented in Figure 108.

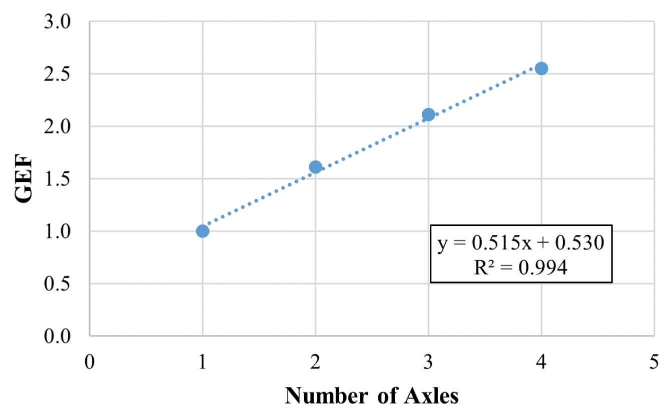

Figure 108: Relationship between GEF and axle-group for roughness in CRCP

The final ECF model for roughness for CRCP is shown in Equation 8.18.

$$\log(ECF) = 2.14 \times \log\left(\frac{W_L/18}{0.515 \times AXLE + 0.530}\right) \tag{8.18}$$

Where ECF is the equivalent consumption factor for punchouts for CRCP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.7 Jointed Concrete Pavement (JCP)

Jointed Concrete Pavements (JCP) use contraction joints to control cracking of the concrete slab. There are two types of JCP: plain and reinforced. The plain (or JPCP) has its transverse joint spacing selected so that temperature and moisture stresses do not produce intermediate cracking between joints, resulting in joints no longer than about 20 ft. a part (typically 15 ft.). The reinforced (JRCP) contains steel at mid-slab to hold cracks tightly together. In both cases, dowel bars are used at transverse joints to assist in load transfer, with tie bars at longitudinal joints. The AASHTOWare system only addresses JPCP, so only this type of pavement was assessed, hereinafter referred to as simply JCP.

8.7.1 Cracking

The ALFs for cracking for JCP are presented in Table 135.

Table 135: Mean ALF per axle-group for cracking in the JCP

Axle Group	Mean	Std. Error	Min.	Max.
Single	4.75	1.48	1.10	8.03
Tandem	6.91	1.29	4.32	9.11
Tridem	6.25	1.77	3.71	10.93
Quad	6.17	2.47	2.62	9.60

The results from Table 135 indicate that the ALF was consistent across all slab thicknesses and axle groups, except for single axles. Nevertheless, the mean ALF (6.14) was utilized for cracking for JCP. The results for GEF are presented in Figure 109.

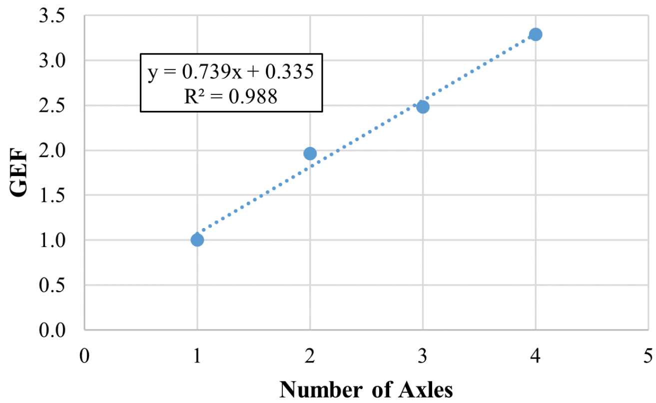

Figure 109: Relationship between GEF and axle-group for cracking in JCP

The final ECF model for cracking in JCP is shown in Equation 8.19.

$$\log(ECF) = 6.02 \times \log\left(\frac{W_L/18}{0.739 \times AXLE + 0.335}\right) \tag{8.19}$$

8.7.2 Faulting

The ALFs for faulting for JCP are presented in Table 136.

Table 136: Mean ALF per axle-group for faulting in the JCP

Axle Group	Mean	Std. Error	Min.	Max.
Single	1.52	0.20	1.08	1.96
Tandem	1.63	0.13	1.21	1.87
Tridem	1.45	0.25	1.01	2.17
Quad	1.50	0.31	1.22	2.64

The results from Table 136 indicate that the ALF was consistent across all slab thicknesses and axle groups. Thus, the mean ALF (1.53) was utilized for cracking for JCP. The results for GEF are presented in Figure 110.

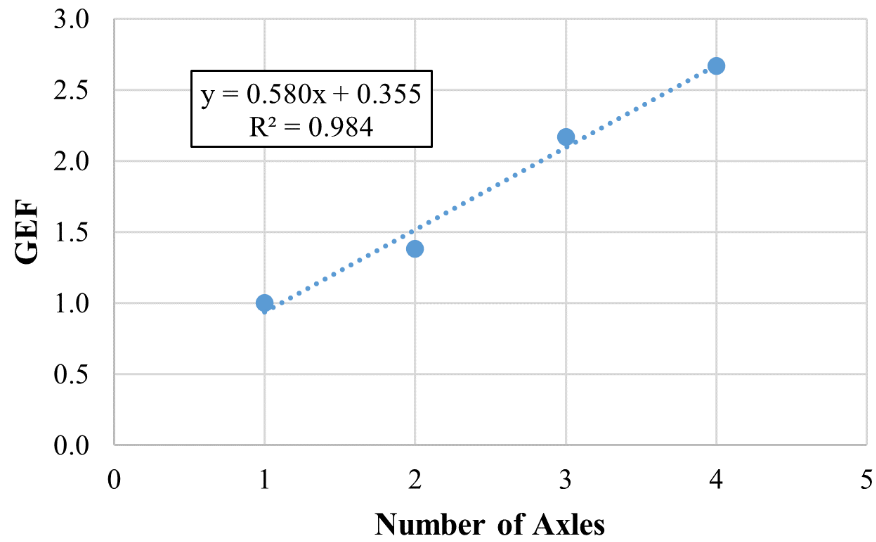

Figure 110: Relationship between GEF and axle-group for faulting in JCP

The final ECF model for faulting in JCP is shown in Equation 8.20.

$$\log(ECF) = 1.53 \times \log\left(\frac{W_L/18}{0.580 \times AXLE + 0.355}\right) \tag{8.20}$$

Where ECF is the equivalent consumption factor for faulting for JCP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.7.3 Roughness

The ALFs for roughness for JCP are presented in Table 137.

Table 137: Mean ALF per axle-group for roughness in the JCP

Axle Group	Mean	Std. Error	Min.	Max.
Single	2.18	0.64	0.71	3.22
Tandem	2.08	0.54	0.88	3.01
Tridem	2.10	0.59	1.03	3.08
Quad	2.24	0.61	1.07	3.20

The results from Table 137 indicate that the ALF was consistent across all slab thicknesses and axle groups. Thus, the mean ALF (2.15) was utilized for roughness for JCP.

The results for GEF are presented in Figure 111.

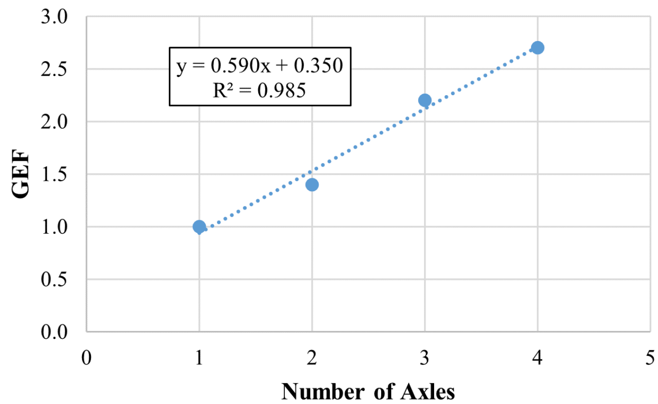

Figure 111: Relationship between GEF and axle-group for roughness in JCP

The final ECF model for roughness in JCP is shown in Equation 8.21.

$$\log(ECF) = 2.15 \times \log\left(\frac{W_L/18}{0.590 \times AXLE + 0.350}\right) \tag{8.21}$$

Where ECF is the equivalent consumption factor for roughness for JCP; $AXLE$ is the discrete variable for the number of axles within the axle-group (1, 2, 3 or 4); and W_L is the total axle-load in kips.

8.8 Summary and Final Remarks

In this section, the ECF models for each pavement type and their associated failure mechanisms are presented. A key objective during the modeling process – beyond what was pursued in previous studies (Prozzi et al., 2022c) – was to streamline the existing models. This update aimed to ensure that the proposed methodology could be readily extended beyond the scope of this project while still capturing the trends observed in the structural simulations and preserving the engineering relevance of the variables. The final models of the pavement consumption analysis are summarized in Table 138.

Table 138: Equivalent Consumption Factor Models

Pavement Type	Failure Criteria	Axle Group	Model
ACP	Rutting	1	Equation 8.6
		2, 3, 4	Equation 8.7
	Fatigue Cracking	1, 2, 3, 4	Equation 8.9
	Roughness	1, 2, 3, 4	Equation 8.12
STP	Rutting	1, 2, 3, 4	Equation 8.14
	Cracking	1, 2, 3, 4	Equation 8.15
	Roughness	1, 2, 3, 4	Equation 8.16
CRCP	Punchouts	1, 2, 3, 4	Equation 8.17
	Roughness	1, 2, 3, 4	Equation 8.18
JCP	Cracking	1, 2, 3, 4	Equation 8.19
	Faulting	1, 2, 3, 4	Equation 8.20
	Roughness	1, 2, 3, 4	Equation 8.21

The results in Table 138 indicate that the ECF models effectively captured the structural differences between pavement types. ALF represents the slope in the log-log relationship between axle load and pavement damage, capturing the sensitivity of a given pavement structure to increased wheel loads.

For rigid pavements, ALF values tend to be lower and more consistent across different failure criteria, reflecting the concrete's higher stiffness and the slab's ability to distribute loads over a wider area. These pavements exhibit lower sensitivity to increases in axle load, resulting is close-enough values across the different axle groups such that the mean of the observed ALF was sufficient for its formulation. However, for the CRCP punchout model, ALF was modeled as an exponential function of axle number, highlighting how localized failures from repeated flexural stresses can still be influenced heavily by axle load.

In contrast, flexible pavements (ACP and STP) showed higher and more variable ALF values across criteria and axle configurations. For ACP rutting, ALF was a function of structural number, revealing that damage sensitivity decreases as pavement strength increases. The fatigue and roughness models for both ACP and STP also exhibited ALF expressions that decay or shift depending on axle number, capturing how additional axles disproportionately increase damage in these more load-sensitive structures, possibly enhanced by the fact that these structures (flexible) are affected by shear stresses, rather than bending as rigid are.

The GEF scales the reference axle-load according to axle configuration and pavement type, to capture the influence of the number of axles on reaching the same performance level. Note that the punchout model for CRCP is unique for using an exponential axle effect, implying a rapidly increasing marginal damage caused by additional axles in the same group, which aligns with field observations where the failure strains for concrete under repeated loading was significantly greater than that under static loading (Strauss et al., 1977). Grouped axles also increase slab deflection, thus accelerating fatigue, which in turn reduces load transfer across cracks.

8.9 Estimating Pavement Consumption Costs

Highway costs are allocated to road users based on three key principles: marginality, completeness, and rationality. Marginality pertains to assigning costs to specific vehicle classes in a way that covers the expenses incurred by each class. Rationality ensures that the allocated costs for a vehicle class do not surpass what it would have paid on a privately owned facility. Completeness involves recovering all highway expenditures by distributing costs among participating vehicle classes. Various methods exist for assigning highway construction costs to the appropriate entities (AASHTO, 2020). In this study, a modified incremental method was utilized.

The regular incremental method involves constructing a pavement structure for the lightest vehicle class first and assigning the corresponding expenses to that group. This process is then repeated for progressively heavier vehicle classes, with pavement thickness and associated costs increasing accordingly for each category. However, the structural capacity of pavement increases exponentially with thickness, affecting how costs are distributed as heavier vehicles are added in sequence. Additionally, defining the lightest vehicle class can be subjective; a particular class may have a higher GVW but use more axles to distribute the load influences pavement distress differently. Pavement damage (as observed in the previous sections) is impacted by axle-loads, rather than just the gross vehicle weight.

In contrast, the modified incremental approach assigns highway costs to each individual vehicle category. After accounting for these costs, it then identifies and allocates highway expenses related to a coalition of multiple vehicle classes using a proportional measurement (e.g., VMT). Accurate cost estimation using this method depends on adequate construction expense estimates. In this study, such estimates were obtained through TxDOT's average low bid price portal. The cost allocation was done based on the construction cost of an additional asphalt overlay to compensate the effect of OW trucks to reach the same designed "structural life" (e.g., 20 years for flexible). This method can be visualized in Figure 112.

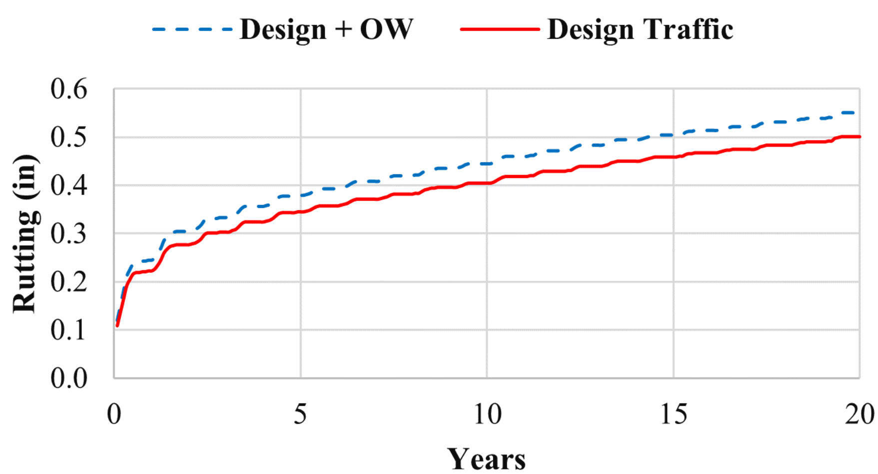

Figure 112: Effect of overweight trucks on rutting performance

As an example, note in Figure 112 that the pavement was designed for a maximum rutting of 0.5 in. for a given design-traffic. After accounting for the OW traffic, the pavement that was initially designed for 20 years experienced a faster deterioration rate and reached the same 0.5 in. of rutting at approximately 14 years. To compensate for the OW incremental damage, the same pavement structure would have to be redesigned with an asphalt overlay (i.e., a thicker asphalt layer) to ensure that the dashed curve (OW traffic plus design traffic) shifts towards the original performance level set as 0.5 in. at 20 years.

The pavement consumption costs use a modular structure that focuses on determining a representative set of ECFs for different OW permits, considering the distribution of the different pavement structures (ACP, STP, CRCP, JCP).

For determining the unit consumption costs (in dollars/ESAL.mile), the methodology developed for the Rider 36 Study and later applied in the HB-2223 Study was followed. The unit cost estimation was based on the assumptions that only commercial vehicles (i.e., designed traffic) contribute to structural pavement consumption, and that the cost of providing additional structure to support OW loads should be recovered through the maintenance and repair component of the permit fees. To that end, the study team considered the additional structure as an increase in the thickness of the primary structural layer and accounted for the total construction cost, not just materials.

The study team calculated an average statewide pavement consumption cost of 7.52 and 6.07 cents per ESAL per mile for flexible and rigid pavements, respectively. These unit costs were calculated in September 2025 dollars and, due to ongoing inflation, should be revisited and updated every two years using the indices provided in TxDOT's Highway Cost Index Report. A weighted average based on the distribution of flexible and rigid pavements at state level was then used, resulting in an average consumption cost of 7.40 cents per ESAL per mile for the on-system network and 7.45 cents per ESAL per mile for the off-system network. It should be noticed that the on-system means the TxDOT-managed highway system.

After determining the consumption cost per mile for each representative vehicle, a weighted sum (based on the number of permits issued for each representative vehicle) was used to calculate the overall "permit consumption cost" per mile. Using the VMT estimates from Section 6, the resulting pavement consumption costs are summarized in Table 139 and Table 140, for both on- and off-system roadways, respectively.

Table 139: Pavement Consumption Costs for On-System Roadways

Permit Type	ECF	VMT	COST (2025 dollars)
Crane Annual	6.47	11,952,000	5,715,632
Crane SP Mileage	15.40	383,879	437,199
General: 80,000–120,000 lbs.	7.20	22,315,266	11,883,882
General: 120,001–160,000 lbs.	10.13	16,221,928	12,156,849
General: 160,001–200,000 lbs.	12.27	6,237,089	5,659,212
General: 200,000–254,300 lbs.	18.14	3,444,536	4,622,593
Hubometer	9.89	28,978,924	21,199,202
Implement Husbandry	11.34	216,930	181,967
Rig-Up Truck	6.09	2,160,000	972,476
Water Well Drilling Machinery & Related Equipment	7.13	1,742,400	918,671
Over-Axle (1547)	5.42	1,113,853,680	446,169,220
Envelope (Truck & Company Specific)	3.81	124,819,200	35,180,806
Ready-Mixed Concrete Truck (Annual)	13.28	34,214,400	33,598,120
Timber (Annual)	3.66	5,701,500	1,543,645
Well Servicing Unit (Annual)	5.06	1,195,200	447,668
Well Service Unit (SP Mileage)	7.42	649,910	356,776
		Subtotal:	**581,043,918**

Table 140: Pavement Consumption costs for Off-System roadways

Permit Type	ECF	VMT	COST (2025 dollars)
Crane Annual	6.68	7,968,000	3,963,364
Crane SP Mileage	16.33	255,919	311,350
General: 80,000 - 120,000 lbs.	7.32	2,479,474	1,352,511
General: 120,001 - 160,000 lbs.	10.44	1,802,436	1,401,993
General: 160,001 - 200,000 lbs.	12.73	693,010	657,244
General: 200,000 - 254,300 lbs.	18.67	382,726	532,189
Hubometer	10.24	19,319,282	14,734,566
Implement Husbandry	11.70	506,170	441,225
Rig-Up Truck	6.41	1,440,000	687,020
Water Well Drilling Machinery & Related Equipment	7.37	1,161,600	637,719
Over-Axle (1547)	5.58	123,761,520	51,458,897
Envelope (Truck & Company Specific)	3.81	31,204,800	8,854,494
Ready-Mixed Concrete Truck (Annual)	14.14	52,185,600	54,056,360
Timber (Annual)	3.67	13,608,000	3,637,155
Well Servicing Unit (Annual)	5.10	167,328	1,060,170
Well Service Unit (SP Mileage)	7.78	1,516,456	878,975
		Subtotal:	**144,665,231**

9. PERMIT FEE ADJUSTMENTS

9.1 Introduction

Roadway assets, such as pavements and bridges, are essential components of the transportation system. They support the movement of people and goods and, in doing so, contribute directly to economic activity. When transportation costs are high, the cost of moving products increases, which can limit competitiveness in local markets and slow economic growth.

In Texas, transportation funds mainly come from the State Highway Fund (SHF), which includes motor fuel taxes, vehicle registration fees, OS/OW permit fees, oil and natural gas severance taxes, and sales taxes from general goods sales and motor vehicle sales and rentals (Prozzi et al., 2022c). The SHF is also incremented by Propositions 1 (oil and gas severance tax) and Proposition 7 (sales and use tax, vehicle sales and rental tax), the State Infrastructure Bank, regional subaccounts with toll, and concession revenue from comprehensive development agreements, which is an umbrella term for public-private partnerships (TxDOT, 2022).

Charges tied to vehicle usage, such as motor fuels tax revenue, vehicle registration fees, and truck permit fees, are commonly referred to as road user charges. While road user charges are expected to be economically efficient and equitable (each user pays according to their respective usage) most of the funding sources only partially meet these criteria (Queiroz, 2009). For example, taxes on vehicle fuel do not accurately reflect the proportional damage caused by heavy vehicles (despite consuming more fuel per mile traveled, they also consume a greater portion of the roadway assets' service life), vehicle license fees are not directly related to usage since their revenue remains the same regardless of VMT, and tolls can hinder economic benefits by causing traffic delays at tollbooths or diverting traffic to secondary roads, which in turn increases their maintenance costs and vehicle operation costs.

Previous studies on alternative funding sources for highway systems are commonly conducted by comparing transportation infrastructure cost responsibilities and revenue contributions among road users (Schank and Rudnick-Thorpe, 2011). When funding shortages are identified, alternative cost recovery scenarios typically consider improving user fees or adding new general revenue sources. However, this approach has been found to have a minor impact on improving *equity* across different road users, although it generates significant additional revenue (Hasnat and Bardaka, 2023).

This section summarizes the pavement and bridge consumption costs estimated on Sections 7 and 8, and, using the revenue estimates based on the permit fee framework, identifies funding gaps. Finally, the report proposes a cost-recovery fee per mile to inform permit fee adjustments that would more accurately compensate for effect of the OW fleet on Texas' highway network.

9.2 Addresing the Impact of Vehicles on Roadway Assets

It is well-established in the literature that motor vehicles produce several types of external costs to the society. For example, passenger cars affect congestion on the traffic streams and leverage emissions, while heavy trucks impact the roadway assets structural performance (Carey and Irick, 1960). A popular view between economists to address equity among road users is to charge motorists for each trip to directly cover their "marginal external cost", which depends on the distance traveled, the vehicle characteristics (weight and maintenance condition), and other factors such as the travel time (Luskin et al., 2001). Although this seems a straightforward task, in practice, feasible calculations of marginal external costs require some degree of averaging among road users' costs. As a result, taxes and charges on motorists, particularly passenger cars, often exceed the marginal external costs of their trips, while the revenue collected from heavy trucks (commercial and overweighted) generally falls short of their expected marginal external costs. Therefore, assessing charges on trucks is crucial for achieving economic efficiency and equity, as it helps to balance out the overcharges on other road users.

Previous research on equity among road users indicate that lightweight vehicles contribute substantially more to the revenue compared to their share of costs imposed to the infrastructure while single-unit trucks (with four or more axles) and multi-unit trucks underpay their costs responsibilities from 37 to 92 percent (Hasnat and Bardaka, 2023). However, if congestion and pollution were factored in, the appearance of underpricing could well be reduced (Luskin et al., 2001).

A study conducted by the North Carolina Department of Transportation suggested that a mile-based user fee could be a long-term solution towards equity among light and heavier vehicles (Hasnat and Bardaka, 2023). Other study by the Minnesota Department of Transportation showed that the load related expenditures could be brought closer to the estimated revenue, resulting in greater equity ratios if a weight-milage fee were to be considered (Gupta and Chen, 2012). Although policy choices in highway cost allocation are commonly made on the basis of revenue-cost comparisons by vehicle class, forecasting these values is always a complex task. Also, there is a constant need to determine where in the modeling effort (both on the cost and revenue sides) more accuracy would affect the outcomes. That is, from all the possible errors in estimation (e.g., VMT forecasts, pavement and bridge damage, fuel tax revenue per vehicle etc.), which would result in the most significant impact on the revenue and costs forecast such that it would affect policy choices? Efforts should be made to identify the errors that have a more critical impact on the revenue-cost analysis than on just improving its accuracy. Moreover, budget fluctuations also impact road user charges and should also be addressed for more accurate estimates (Zhang et al., 2011). Finally, most state DOT's revenues come from federal aid, motor fuel taxes, and vehicle license fees, the so called road user fees, which still provides most highway revenues (Varma and Sinha, 1997).

9.3 Revenue-Cost Analysis on Truck Permits

This report focuses on proposing a permit fee adjustment required to break even with the consumption costs attributable specifically to OW vehicles. The underlying assumption during the bridge and pavement consumption analysis was that roadway assets are designed to accommodate what is referred to as "design traffic". Therefore, the structural analysis during the consumption assessment concerned only with the marginal impact of OW vehicles, resulting in a certain cost that ought to be recovered through an appropriate permit fee structure.

9.3.1 Consumption Costs

The consumption cost analyses were conducted on a VMT basis. The total consumption costs for both pavements and bridges (in 2025 dollars) is summarized in Table 141.

Table 141: Total Overweight Consumption Costs

Permit Type	Permits	VMT	Pavement Cost	Bridge Cost	Total Cost
Crane (Annual)	830	19,920,000	9,555,046	1,014,725	10,569,771
Crane Self-Propelled (Mileage)	4,191	639,798	738,963	137,857	876,821
General: 80,000–120,000 lbs.	98,074	24,794,740	13,066,886	2,967,930	16,034,817
General: 120,001–160,000 lbs.	119,873	18,024,364	13,385,205	4,570,979	17,956,184
General: 160,001–200,000 lbs.	46,729	6,930,099	6,235,568	2,824,708	9,060,276
General: 200,001–254,300 lbs.	14,207	3,827,262	5,088,769	2,763,283	7,852,052
Hubometer (Quarterly)	31,791	48,298,206	35,473,596	4,955,835	40,429,432
Implement of Husbandry (Annual)	1,033	723,100	615,211	40,967	656,178
Rig-Up Truck (Annual)	150	3,600,000	1,638,245	90,285	1,728,530
Water Well Drilling Machinery & Equipment (Annual)	121	2,904,000	1,536,459	173,607	1,710,066
Over-Axle (1547) (Annual)	57,298	1,237,615,200	491,255,441	67,326,267	558,581,708
Envelope (Truck & Company Specific) (Annual)	5,996	156,024,000	43,471,380	19,003,723	62,475,103
Ready-Mixed Concrete Truck (Annual)	5,347	85,536,000	57,179,325	4,328,122	61,507,446
Timber (Annual)	543	19,005,000	5,114,453	490,329	5,604,782
Well Servicing Unit (Annual)	166	3,984,000	719,004	63,346	782,350
Well Servicing Unit Self-Propelled (Mileage)	17,942	2,166,365	2,052,678	383,864	2,436,542
	404,291	**1,636,990,469**	**687,126,231**	**111,135,827**	**798,262,058**

9.3.2 State Revenue Associated with Permitted Vehicles

The funds used for construction and maintenance of roads and bridges in Texas are sourced mainly from the SHF, which is further composed by many different funding sources categorized by their origin and the way they are expended. The major sources of revenue for the SHF include the motor fuels tax, vehicle registration fees, oil and gas severance taxes (Proposition 1), and sales and use taxes (Propositon 7), both from general goods and from motor vehicle sales and rentals (Inoue et al., 2025). Additionally, revenue from OS/OW permits also contributes to the SHF. In this report, the analysis focuses on the revenue directly associated with the bridge and pavement consumption of roadway assets due to OW vehicles.

9.3.3 Overweight Permit Fee Structure

The Texas Transportation Code (TTC) was enacted as part of the state's ongoing statutory revision program, initiated by the Texas Legislative Council in 1963. The TTC is the primary body of state law governing the movement of people and goods, encompassing topics ranging from basic rules of the road (such as speed regulations, turning maneuvers, traffic control devices, and right-of-way provisions in Chapters 544–545) to vehicle equipment requirements, size and weight limits, OS/OW permits (Chapters 621–623), motor carrier regulations, and even aviation and railroad provisions. Collectively, these statutes are designed to ensure the safe and orderly movement of traffic on public highways and waterways.

The structure of OW permits is defined within the Transportation Code (Tex. Transp. Code §623.001) under Title 7 "Vehicles and Traffic", Subtitle E "Vehicle Size and Weight", *Chapter 623 "Permits for Oversize and Overweight Vehicles"*. The TTC specifies both the components of the permit fee (e.g., administrative fees, baseline fees, mileage-based fees, and vehicle supervision fees) and the allocation of collected revenues, which can have five possible destinations: the General Revenue Fund (which may be used for purposes beyond transportation), the SHF, the Texas Department of Motor Vehicles (TxDMV), Counties and Municipalities. A summary of the OW permit fee structure, after accounting for all relevant provisions in the aforementioned statute, is provided in Table 142 and 143.

Table 142: Annual Permit Type Distribution

Annual Permit Type	Total	General Revenue Fund	State Highway Fund	TxDMV Fund	County	Municipal-ity
Envelope (Company & Truck Specific)	$4,000	$1,000	$2,700	$300	$0	$0
Crane	$100	$50	$45	$5	$0	$0
Implement of Husbandry	$270	$135	$121.50	$13.50	$0	$0
Over-Axle (1547) Base Fee	$90	$0	$0	$40	$50	$0
Over-Axle (1547) Add'l Fee (1–5 Counties)	$175	$0	$45	$5	$125	$0
Over-Axle (1547) Add'l Fee (6–20)	$250	$0	$112.50	$12.50	$125	$0
Over-Axle (1547) Add'l Fee (21–40)	$450	$0	$94.50	$10.50	$345	$0
Over-Axle (1547) Add'l Fee (41–60)	$625	$0	$54	$6	$565	$0
Over-Axle (1547) Add'l Fee (61–80)	$800	$0	$13.50	$1.50	$785	$0
Over-Axle (1547) Add'l Fee (81–100)	$900	$0	$0	$0	$900	$0
Over-Axle (1547) Add'l Fee (101–254)	$1,000	$0	$0	$0	$1,000	$0
Over-Axle (1547) Admin. Fee	$5	$0	$0	$5	$0	$0
Ready-Mixed Concrete Truck (RMCT)	$1,000	$500	$0	$0	$500	$0
Rig-Up Truck / Unladen Lift	$52	$0	$47	$5	$0	$0
Timber	$900	$450	$0	$0	$450	$0
Water Well Drilling Machinery & Related Equipment	$270	$135	$121.50	$13.50	$0	$0
Well Servicing Unit (Annual)	$52/axle	$0	90%	10%	$0	$0

Source: Texas Department of Motor Vehicles

Table 143: Single Trip and Other Permit Fee Distribution

Single-trip	Total	General Revenue Fund	State Highway Fund	TxDMV Fund	County	Municipal-ity
General (80,001 to 120,000 lbs.) Add'l Fee	$150	$0	90%	10%	$0	$0
General (120,001 to 160,000 lbs.) Add'l Fee	$225	$0	90%	10%	$0	$0
General (160,001 to 200,000 lbs.) Add'l Fee	$300	$0	90%	10%	$0	$0
General (200,001 to 254,300 lbs.) Add'l Fee	$410	$0	90%	10%	$0	$0
Self-propelled Mileage						
Crane (S/P Mileage)	Varies	$0	90%	10%	$0	$0
Well Servicing Unit (S/P Mileage)	Varies	$0	90%	10%	$0	$0
Quarterly						
Hubometer	Varies	$0	90%	10%	$0	$0

Source: Texas Department of Motor Vehicles

The total permit fee is shown to comprise three primary components: an administrative fee, a base fee, and a maintenance fee. The administrative fee covers costs associated with processing the permit, such as issuance and mailing. The base fee varies by permit type and is typically associated with the duration or nature of the authorization (e.g., single-trip, 30-day, or annual permits) and the type of permit (e.g., mileage-based have their fee starting at $31). The maintenance fee is an additional charge related to the expected impact of vehicle operations, which may be based on factors such as the number of counties through which the permitted vehicle will travel or the gross vehicle weight range applicable to the permit.

The mileage fee is determined by multiplying the number of miles traveled, the highway use factor, and the total rate per mile, and then adding the indirect cost share. The highway use factor for this permit type is 0.6. The total rate per mile reflects the combined mileage rates for width, height, and weight, and for trailer-mounted units it is based on the overall width, overall height, and all axle weights, including those of the truck-tractor. The mileage rate for width is 6 cents per mile for each foot or fraction of a foot above the legal width, and the mileage rate for height is 4 cents per mile for each foot or fraction of a foot above the legal height. Weight-related mileage rates vary by exceedance: for a single axle or any axle within a group weighing more than 20,000 lbs. but not more than 25,000 lbs., the rate is calculated by multiplying 4.5 cents by the number of pounds above the legal limit and dividing by 1,000; for axles or axle groups weighing more than 25,000 lbs. but not more than 30,000 lbs., the rate is calculated by multiplying 5.5 cents by the amount above the legal limit and dividing by 1,000.

9.4 Permit Fee Revenue in Texas

In the Calendar Year 2023, the TxDMV reported a total revenue of $149.5 million (approximately $163 million in 2025) dollars collected from overweight permits, as shown in Table 144.

Table 144: Overweight Permit Revenue by Permit Type (2023 dollars)

Permit Type	**Number of Permits**	**VMT**	**Revenue**
Crane (Annual)	830	19,920,000	84,942.74
Crane Self-Propelled (Mileage)	4,191	639,798	757,371.30
General: 80,000–120,000 lbs.	98,074	24,794,740	21,118,603.18
General: 120,001–160,000 lbs.	119,873	18,024,364	35,031,460.25
General: 160,001–200,000 lbs.	46,729	6,930,099	17,249,678.08
General: 200,001–254,300 lbs.	14,207	3,827,262	5,462,930.24
Hubometer (Quarterly)	31,791	48,298,206	12,109,015.79
Implement of Husbandry (Annual)	1,033	723,100	331,890.76
Rig-Up Truck (Annual)	150	3,600,000	8,005.92
Water Well Drilling Machinery & Equip. (Annual)	121	2,904,000	40,485.65
Over-Axle (1547) (Annual)	57,298	1,237,615,200	26,477,624.96
Envelope (Truck & Company Specific) (Annual)	5,996	156,024,000	22,430,953.78
Ready-Mixed Concrete Truck (Annual)	5,347	85,536,000	5,409,203.08
Timber (Annual)	543	19,005,000	493,191.69
Well Servicing Unit (Annual)	166	3,984,000	35,822.80
Well Servicing Unit Self-Propelled (Mileage)	17,942	2,166,365	2,826,589.32
	404,291		**149,867,769.54**

9.5 Permit Fee Structure of Peer States

Truck permit fee schedules from several states were reviewed to provide a baseline for comparison with the Texas permit structure. The analysis included California, Florida, Georgia, Illinois, Michigan, New York, and Ohio. In addition, permit fees from British Columbia (Canada) were evaluated as an international benchmark.

9.5.1 California

In California single trip permits cost $16 and annual permits cost $90. An additional $50 per hour fee is assessed for each hour expended directly on "engineering investigations, routing definitions, coordination, and control of permit movement for each individual load" that meets certain criteria (Cal. Code Regs., tit. 21, §1411.3). A summary of the permit fee framework in California is presented in Table 145.

Table 145: California Permit Fees

Permit Type	Description	Fee
Single-Trip (7-day)	loads greater than 8'-6" wide, 14'-0" high, and over 80,000 pounds	$16
Annual	loads up to 12'-0" wide, 14'-0" high, and Kingpin to Rear Axle (KPRA) 40'-0" maximum (except as specifically allowed per CVC). Travel on red routes prohibited.	$90
Repetitive (90-day)	Basically a single trip permit for the delivery of the same load over the same route on a repeated basis.	$90
Sea Container (Annual)	4-Axle tractor and 3-Axle trailer of maximum Overall Length (OAL) of 65'-0", and Kingpin to Rear Axle (KPRA) 40'-0" maximum, transporting intermodal cargo containers on state highways in the vicinity of the Port of Los Angeles and the Port of Long Beach.	$90
Variance	vehicles greater than 15'-0" wide, 17'-0" high, and 135'-0" long, or on special hauling equipment which exceeds the Department's standard method of weight classification.	$16
Motorsport (Single-trip)	vehicles going to an Automobile Competition Committee for the United States (ACCUS) sanctioned event at one of the locations currently authorized per vehicle code.	$16

9.5.2 Florida

Florida's Administrative Code (FAC 14-26.008) specifies the current fee structure for OS/OW permits, as summarized in Table 146.

Table 146: Florida Permit Fees

Overweight	**Trip Permit (10-day) $/Mile**	**Multi-Trip Permits (12 Month)**	**Multi-Trip Permits (3 Month)**
(a) Up to 95,000 pounds.	0.27	240	60
(b) Up to 112,000 pounds.	0.32	280	70
(c) Up to 122,000 pounds.	0.36	310	78
(d) Up to 132,000 pounds.	0.38	330	83
(e) Up to 142,000 pounds.	0.42	360	90
(f) Up to 152,000 pounds.	0.45	380	95
(g) Up to 162,000 pounds.	0.47	400	100
(h) Up to 199,000 pounds.	0.003 Per 1,000 Pounds	500	125
(i) Over 199,000 pounds.	0.003 Per 1,000 Pounds	Not Applicable	250
(j) Containerized Cargo Unit.	0.27	500	125
(k) Overall Wheel Base (Inner Bridge/External Bridge).	10	35	Not Applicable
(l) Implements of husbandry, farm equipment, agricultural trailers/products and forestry equipment (Local Moves Only).	5	17	Not Applicable

Note: 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.

9.5.3 Georgia

Georgia Department of Transportation (GDOT) provides a list of permits and their associated fees. Rules regarding these fees are described in Chapter 672 of the Rules and Regulations of the State of Georgia (Ga. Comp. R. & Regs. 672-2-0.1), as summarized in Table 147.

Table 147: Georgia Permit Fees

Permit Type	**Description**	**Fee**
Single-trip (Standard)	Weight limit of 150,000 lbs.	$30
Single-trip (Superload)	Weight limit of 150,001 to 180,000 lbs.	$125
Single-trip (Superload-plus)	Weight over 180,000 lbs.	$500
Annual (Standard)	Weight limit of 100,000 lbs.	$150
Annual (NHS)	Weight limit of 100,000 lbs. (NHS routes only)	$500
Annual (Wrecker Emergency)	Weight limit of 135,000 lbs. on 7 axles.	$500

9.5.4 Illinois

The Illinois Department of Transportation provides a detailed permit fee table for overweight loads by weight (in lbs.) and axle. These fees are listed in Tables 148 and 149. More information regarding these permits can be found in the Illinois Vehicle Code (625 Ill. Comp. Stat. 5/15-301). An additional fee is required by the Illinois Tollway for vehicles operating on the Tollway.

Table 148: Illinois Tollway Permit Fees based on axle-group and GVW

Fee	**2-Axles (4 to 8 ft.)**	**3-Axles (8 ft.)**	**3-Axles (9 ft.)**	**3-Axles (10 ft.)**	$\geq$ **5-Axles**
$35	34,001–44,200	42,001–54,600	42,501–55,250	43,501–56,550	80,001–104,000
$150	44,201–48,000	54,601–60,000	55,251–60,000	56,551–60,000	104,001–120,000

Super-loads have a fixed fee of $150.

Table 149: Illinois Permit Fees

Distance (mi.)	Gross Vehicle Weight (kips.)											
	48	**54**	**60**	**68**	**72**	**76**	**88**	**100**	**88**	**100**	**110**	**120**
	2-Axles		3+ Axles		4+ Axles		5-Axles		6+ Axles			
0–45	15.0	20.0	12.5	20.0	15.0	20.0	20.0	30.0	10.0	15.0	20.0	30.0
46–90	25.0	32.5	21.5	32.5	25.0	32.5	32.5	55.0	12.5	25.0	32.5	55.0
91–135	35.0	45.0	30.5	45.0	35.0	45.0	45.0	80.0	15.0	35.0	45.0	80.0
136–180	45.0	57.5	39.5	57.5	45.0	57.5	57.5	105.0	17.5	45.0	57.5	105.0
181–225	55.0	70.0	48.5	70.0	55.0	70.0	70.0	130.0	20.0	55.0	70.0	130.0
226–270	65.0	82.5	57.5	82.5	65.0	82.5	82.5	155.0	22.5	65.0	82.5	155.0
271–315	75.0	95.0	66.5	95.0	75.0	95.0	95.0	180.0	25.0	75.0	95.0	180.0
316–360	85.0	107.5	75.5	107.5	85.0	107.5	107.5	205.0	27.5	85.0	107.5	205.0
361–405	95.0	120.0	84.5	120.0	95.0	120.0	120.0	230.0	30.0	95.0	120.0	230.0
406–450	105.0	132.5	93.5	132.5	105.0	132.5	132.5	255.0	32.5	105.0	132.5	255.0
451–495	115.0	145.0	102.5	145.0	115.0	145.0	145.0	280.0	35.0	115.0	145.0	280.0

9.5.5 Michigan

The Michigan Vehicle Code Chapter 257.725 describes the permit fees for oversized and overweight vehicles (Mich. Comp. Laws §257.725), as shown in Table 150. Michigan offers single trip and annual permits, with a separate, less restricted permit for the movement of construction equipment.

Table 150: Michigan Permit Fees

Permit	**Description**	**Fee**
Single-trip	For a load that is over-dimension and/or over the legal axle weight.	$50
Annual	For each truck, each trailer, and each piece of equipment that, when loaded, is overweight and/or over-dimension. Prorated.	$100
Construction Equip. (Annual)	For the movement of construction equipment that exceeds the size, load, or combined size and load maximums specified for a power unit, without requiring a separate permit for each individual piece of equipment carried by that power unit.	$264

9.5.6 New York

The New York Department of Transportation provides a fee schedule for single trip, monthly, and annual special hauling permits. New York permits are governed under the New York Compilation of Codes (N.Y. Comp. Codes R. & Regs. Tit. 17 §§ 154-2.2). Table 151 lists the fees associated with single trip permits, Table 152 describes monthly permits, and Table 153 details annual permits.

Table 151: New York: Single-trip Permit Fees

Single-trip Permits	**Fee**
Single Trip	$40
Manufactured/Modular	$40
Superload	$40
Sealed Shipping Container	$40
Emergency Trip	$40

Table 152: New York: Monthly Permit Fees

Monthly Permits	Fee
Bulk Milk	$60
100 Mile Radius	$60
25 Mile Radius	$60
Statewide Blanket	$60
Farm Equipment—Dealer	$60
Steel Haulers / Special Vehicle Combination	$100
Sealed Shipping Container	$250

Table 153: New York: Annual Permit Fees

Annual Permits	Fee
Bulk Milk	$360
100 Mile Radius	$360
25 Mile Radius	$360
Statewide Blanket	$360
Emergency Blanket	$360 to $900
Steel Haulers / Special Vehicle Combination	$500
Sealed Shipping Container	$750

9.5.7 Ohio

The Ohio Department of Transportation publishes a Special Hauling Permit Fee Schedule per Ohio Administrative Code 5501:2-1-10. Separate permit fees are listed for one-way trips, and for return trips.

Table 154: Ohio Permit Fees

Permit	One-Way	Return
Single Trip OS/OW	$145	$210
Single Trip Steel/Aluminum Coil	$75	Not applicable
Single Trip Multi-State OS/OW	$145	Not applicable
Single Trip Emergency	$260	$375
90-Day OS/OW	$510	$760
90-Day Steel/Aluminum Coil	$135	Not applicable
90-Day Michigan Legal	$125	$125
90-Day International Sealed Container	$510	Not applicable
365-Day OS/OW	$1,980	$2,980
365-Day Steel/Aluminum Coil	$480	Not applicable
365-Day Michigan Legal	$470	$470
45-Day International Sealed Container	$260	Not applicable
Blanket 365-Day Boat	$100	Included
Blanket 365-Day Construction Equipment	$100	Included
Blanket 365-Day Farm Equipment	$100	Included
Blanket 365-Day Manufactured Building	$100	Included
Blanket 365-Day Marina	$100	Included
Superload Single Trip OS/OW	$145+TM	$210+TM
Superload 90-Day Michigan Legal	$165	$165
Superload 365-Day Michigan Legal	$630	$630

Note: TM = (GVW − 120,000) /2,000 × $0.04 per mile traveled.

9.5.8 British Columbia, Canada

The government of British Columbia sets the commercial transportation fees according to the Commercial Transport Act (B.C. Reg. 328/91). These fees are calculated using a mix of both overweight and VMT.

Table 155: British Columbia Single Trip Permit Fees

Overload (kg)	**Fee per 10 km**
Up to 2,000	$0.95
2,001–3,000	$1.15
3,001–4,000	$1.40
4,001–5,000	$1.60
5,001–6,000	$1.85
6,001–7,000	$2.15
7,001–8,000	$2.45
8,001–9,000	$2.95
9,001–10,000	$3.35
10,001–11,000	$3.75
11,001–12,000	$4.25
12,001–13,000	$4.95
13,001–14,000	$5.60
14,001–15,000	$6.25
15,001–16,000	$7.25
16,001–17,000	$8.25
17,001–18,000	$9.15
18,001–19,000	$10.10
19,001–20,000	$10.90
20,001–21,000	$11.85
21,001–22,000	$12.70
22,001–23,000	$13.95
23,001–24,000	$14.95
24,001–25,000	$16.10
25,001–26,000	$17.85
26,001–27,000	$19.85
27,001–28,000	$21.40

The minimum permit fee is $25. For vehicles exceeding 28,000 kg, the fee is $21.40 plus $1.85 for each additional 900 kg (or portion thereof) over 28,000 kg, per 10 km (or 6.2 mi) of operation.

9.6 Final Remarks on the Permit Fee Structure

Among the OW permits summarized in Tables 142 and 143, a concern arises for those permits that allocate a portion of the revenue to counties, such as Ready-Mix Concrete Truck (RMCT) and Timber permits. For these permit types, the revenue collected is distributed equally across all counties selected by the carrier during permit issuance. Consequently, the larger the number of counties chosen, the smaller the share allocated to each county, regardless of the number of miles actually traveled within a given jurisdiction. A carrier may select a permit allowing them to travel in 1-5 counties while their actual travel, and corresponding roadway consumption, may occur in only one or two of the counties chosen.

A similar concern applies to the Over-Axle 1547 permit. Although these permits include incremental fees that increase with the number of counties selected, the resulting revenue is deposited directly into the state's General Revenue Fund rather than distributed to counties directly, as occurs with RMCT and Timber permits.

Although routed permits prohibit travel on off-system roads, RMCT and Timber permits allow travel on county or municipally maintained roads. These annual permits typically authorize overweight divisible loads and permit unrestricted travel within the selected counties. However, interstate highways cannot be used for overweight divisible loads. Permits such as RMCT and Over-Axle 1547, are not valid on interstate facilities because they would jeopardize federal funding and are only valid on state-maintained roads unless explicitly authorized on county roads. Conversely, overweight non-divisible loads may travel on interstate highways with a routed permit.

A final consideration concerns the uncertainty in VMT associated with unrouted permits. Because the actual VMT for each annual permit is not reported, estimates must be inferred based on the permit type or the commodity being transported. In practice, industry characteristics, likely geographic regions of operation, and typical trip lengths are approximated using informed assumptions. In the absence of a specified route, both on-system and off-system travel distances must therefore be estimated. As observed in several of the states reviewed above, adopting a fee structure that explicitly incorporates mileage could substantially mitigate this source of uncertainty.

9.7 Proposed Permit Fee Adjustments

The study team proposes a cost-recovery rate per mile so that OW permit revenues meet the pavement and bridge consumption costs. From the previous discussion regarding the permit framework, it became evident that only a portion of the fee is actually allocated to roadway asset maintenance and rehabilitation. This share ranges from as little as 8 percent (for Over-Axle permits that travel across 101 to 254 counties, where most revenue is directed to the General Revenue Fund) to 100 percent (for RMCT permits). Nevertheless, the most practical cost-recovery approach (regardless of the revenue distribution among funds) is to match the total permit fee to the total consumption costs, rather than attempting to account for only the portion of the fee that is earmarked towards roadways assets maintenance. The total permit revenue collected in the CY 2023 (the same calendar year of the database utilized in the consumption) analysis was presented in Table 144. Before any further assessment, the permit fee revenues were converted into 2025 dollars, consistent with the year used for all consumption cost calculations. This was done through the Consumer Price Index (CPI), a measure released every month by the Bureau of Labor Statistics that reflects the average change over time in the prices paid by urban consumers for a representative market basket of goods and services. After adjusting for the CPI between 2023 and 2025, a revenue gap of $635 millions was identified.

Previous studies have proposed adjusting truck permit fees by distributing the total cost across permit types in proportion to each permit's share of the overall consumption cost by combining deterioration rates with VMT, which has been recognized as the most equitable approach to date (Prozzi et al., 2012, 2022c; Hasnat and Bardaka, 2023; Inoue et al., 2025). Following this rationale, a similar methodology was adopted as the recovery strategy. The results, in a per-mile basis, are presented in Table 156.

Table 156: OW Permit Analysis: Volume, Costs, and Fee per Mile (in 2025 dollars)

Permit Type	**Permits Issued**	**Total Consumption Cost**	**Fee per Mile**
Crane (Annual)	830	10,569,771	0.531
Crane Self-Propelled (Mileage)	4,191	876,821	1.370
General: 80,000–120,000 lbs.	98,074	16,034,817	0.647
General: 120,001–160,000 lbs.	119,873	17,956,184	0.996
General: 160,001–200,000 lbs.	46,729	9,060,276	1.307
General: 200,001–254,300 lbs.	14,207	7,852,052	2.052
Hubometer (Quarterly)	31,791	40,429,432	0.837
Implement of Husbandry (Annual)	1,033	656,178	0.907
Rig-Up Truck / Unladen Lift (Annual)	150	1,728,530	0.480
Water Well Drilling Machinery & Equipment (Annual)	121	1,710,066	0.589
Over-Axle (1547) (Annual)	57,298	558,581,708	0.451
Envelope (Truck & Company Specific) (Annual)	5,996	62,475,103	0.400
Ready-Mixed Concrete Truck (Annual)	5,347	61,507,446	0.719
Timber (Annual)	543	5,604,782	0.295
Well Servicing Unit (Annual)	166	782,350	0.196
Well Servicing Unit Self-Propelled (Mileage)	17,942	2,436,542	1.125

Note: Total consumption cost represents the aggregate pavement and bridge consumption costs for each permit type. Cost per mile values are derived from estimated vehicle miles traveled.

Based on the comparison between the fee collected and the consumption costs estimated, a fee adjustment is required for all annual permits and for the heaviest General single-trip permits (between 200,001 and 254,300 lbs.). Among the annual permits with the highest VMT (i.e., Over-Axle, RMCT, and Envelope) the estimated consumption costs were found to be three to nineteen times greater than the revenues currently collected.

In this study, only the load exceeding legal limits was considered in determining OW consumption rates. While this approach appears straightforward, the underlying process for accurately estimating marginal costs is complex. For single-trip permits, assessing consumption is relatively practical because key inputs, such as axle-load, spacing, and intended route are required at the time of purchase. However, TxPROS does not currently provide a mechanism for purchasers to obtain an annual permit that incorporates axle configuration information. Annual permits are typically assessed using either a flat rate or an incremental fee based on the number of counties selected, which (as previously discussed) does not ensure that collected revenue reflects the actual damage imposed on the county network. As a result, important vehicle configuration differences are not captured in the current annual permit fee structure. Trucks with additional axles may impose substantially lower pavement and bridge consumption, whereas heavier loads with shorter axle spacing generate significantly higher deterioration rates. These differences go unaccounted for under the existing framework.

The differences observed in the rate per mile presented are justified by the imbalanced consumption rates found during the pavement and bridge analysis, function of each representative vehicle configuration. Implementing a policy based solely on mileage, however, presents significant challenges, primarily due to the technical difficulties associated with tracking these vehicles. Although motor carriers have the biennial updates with the Federal Motor Carrier Safety Administration, an accurate VMT would only be possible through GPS tracking, leading to privacy implications as it raises ethical issues regarding the surveillance of individuals and organizations without their consent, collection of sensitive data, and potentially infringing on privacy rights (Apte et al., 2019). Hence, implementing such strategy would require significant administrative resources to manage the data, ensure compliance, and address disputes.

One possible strategy to obtain reliable VMT estimates (and truck configurations) for the unrouted or annual permits is to require carriers to obtain a single-trip (routed) permit for their first trip of the year before an "annual" permit is issued. This would generate an initial "routed and axle record" that could be used for future assessments.

10. FINAL REMARKS

This report compared the consumption costs attributable to OW vehicles with the revenues currently collected through permit fees. Two fee adjustment strategies are proposed: a cost-recovery fee based on the funding gap for each permit issued, and a flat mileage-based fee applied by permit type. Consumption costs for both pavements and bridges were estimated using a modified incremental approach, which assigns a monetary value to the additional deterioration caused by OW traffic beyond what is already accounted for in the design traffic.

The revenue–cost analysis demonstrated that current funding mechanisms are insufficient to offset the maintenance and rehabilitation needs generated by OW vehicles. The proposed cost-recovery scenarios provide pathways toward a more equitable allocation of roadway costs by aligning each permit type's fee with its relative consumption burden. Nevertheless, the following methodological limitations should be acknowledged and addressed in future research:

- **Exclusion of congestion-related costs**: This analysis does not include user delay costs arising from the earlier or more frequent maintenance interventions required due to accelerated deterioration from OW traffic. Because heavier trucks can trigger earlier pavement or bridge treatments (often necessitating lane closures or detours) the omission of these congestion impacts may underestimate the total societal cost associated with permitted OW operations.

- **Lack of Vehicle Configuration for Unrouted Permits**: Annual and Quarterly permits are not required to be routed and therefore do not need need to provide truck configuration (axle load and spacing) during the permit issuing process. The absence of such data prevents accurate evaluation of bridge and pavement consumption rates.

- **Challenges in implementing mileage-based fees**: The mileage-based scenario depends on accurate VMT data. In practice, collecting such data is difficult specially among the unrouted permits (annual and quarterly). As a result, implementation would likely require reliance on estimation rather than precise tracking.

- **System-level mismatch in cost and revenue allocation**: Although this study quantified consumption costs on both on-system and off-system roadways, the proposed permit fee adjustments are based on total permit revenues collected. As such, the adjustments do not guarantee alignment between where costs are incurred (state-maintained vs. local networks) and where revenues are ultimately allocated.

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