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The Impact of Specialized Hauling Vehicles on Pavement and Bridge Deterioration

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16. Abstract

This research study was performed to ensure that Texas complies with a Federal Highway Administration (FHWA) memo dated November 15, 2013, which requires each state to certify that it either does not permit operation of specialized hauling vehicles (SHV), or if so, it has conducted bridge load rating analyses. The research 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, according to type, configuration, number of axles and liftable axles (if any), route, and date of sighting. Based on the collected information, in addition to Department of Public Safety weight enforcement data and TxDOT weigh-in-motion data, the average and standard deviation gross vehicle weight (GVW), axle and axle group weights, number of axles, axle loads, axle types (fixed or liftable), and axle spacing were determined. Then, the research team developed representative SHV configurations, which were used to quantify SHV deterioration impacts to pavements in Texas compared to standard truck configurations with legal axle load limits and GVW and for trucks operating on roadways that are currently load posted. In addition, the SHV configurations were used to quantify impacts to bridges in Texas compared to HS20 or HL93 load configurations. Further, the researchers analyzed SHV safety performance in terms of crash history and operational characteristics; conducted an economic analysis of SHV operations in Texas; and prepared draft policy regarding SHV operations in Texas to minimize impacts on bridge and pavement load posting needs. Finally, load posting sign message designs were developed for potential use in the Texas Manual on Uniform Traffic Control Devices.

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- Alpha Paving

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List of Terms

AASHTO	American Association of State Highway and Transportation Officials
booster axle	A booster axle is a special type of lift axle that is mechanically attached to the rear of a truck. When deployed, the booster axle and tires fold downward to contact the pavement such that the tires positions several feet behind the rear of the truck. The booster axle thus increases the total length of the truck (and therefore the outer bridge length). A booster axle also carries a portion of the truck weight and incorporates a mechanism of steel beams and hydraulic or pneumatic pistons that are used to lower/lift the booster axle up and fold it against the rear of the truck. The stowed position of a booster axle is typically at the top of the rear most portion of the cargo compartment; thus increasing the height of the truck center of gravity.
BRINSAP	Bridge Inventory, Inspection and Appraisal Program
CDL	commercial driver's license
CIRCLY	CIRCular Loads – LaYered System
DOT	department of transportation
DPS–CVE	Commercial Vehicle Enforcement Service of TxDPS
ECF	equivalent consumption factor
FBF	Federal Bridge Formula
FHWA	Federal Highway Administration
GIS	geographic information system
GVW	gross vehicle weight
HMA	hot-mix asphalt (concrete)
IRI	International Roughness Index
kip	kilo-pound (1,000 pounds)
lift axle	A non-powered axle that can be raised using mechanical or pneumatic systems so that the tires are not in contact with the pavement and therefore no load is carried by the axle; or, can be lowered to be in contact with the pavement such that the axle carries a portion of the load based on the load control settings. Lift axles are also called 'variable load suspension axles', 'retractable axles' or, derisively, 'cheater axles' since the axle can be adjusted to be in contact with the pavement, but carry little load.
MBE	Manual for Bridge Evaluation
ME	mechanistic-empirical
MOANSTR	Moment Analysis of Structures
MUTCD	Manual on Uniform Traffic Control Devices
MVC	manual visual (traffic) counts

NBI	National Bridge Inventory
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Research Program
NHTSA	National Highway Traffic Safety Administration
NRMCA	National Ready Mixed Concrete Association
ODOT	Oregon DOT
OS/OW	oversize/overweight
pusher	A pusher axle is a liftable axle attached to the chassis of a truck at a position forward of the drive tandem axles of a truck. When in the retracted position, a pusher axle is lifted straight up and stowed directly under the truck chassis.
RF	rating factor
SAS	Statistical Analysis System
SHV	specialized hauling vehicle
SU	single-unit truck
SU3	single unit - three-axle truck with one liftable axle
SU4	single unit - four-axle truck with one liftable axle (different configurations)
SU5	single unit - five-axle truck with two liftable axles (different configurations)
SU6	single unit - six-axle truck with three liftable axles (different configurations)
SU7	single unit - seven-axle truck with four liftable axles (different configurations)
tag	A tag axle is a liftable axle attached to the chassis of a truck at a position, immediately behind the drive tandem axles of a truck. When in the retracted position, a tag axle is lifted straight up and stowed directly under the truck chassis.
TCPL	Truck Configuration Photographic Library
TP&P	TxDOT's Transportation Planning and Programming Division
TxDMV	Texas Department of Motor Vehicles
TxDMV-VTR	Texas Department of Motor Vehicles – Vehicle Titles and Registration Division
TxDOT	Texas Department of Transportation
TxDPS	Texas Department of Public Safety
VIUS	Vehicle Inventory and Use Survey
VMT	vehicles-miles traveled
WIM	weigh in motion

Executive Summary

This research study was performed to ensure that Texas complies with a Federal Highway Administration (FHWA) memo dated November 15, 2013. This memo requires each state to certify that it either does not permit operation of specialized hauling vehicles (SHV), or if so, it has conducted bridge force effects load rating analyses. These analyses must be consistent with the standard American Association of State Highway and Transportation Officials (AASHTO) HS20 or HL93 loads and applicable loads based on five SHV configurations.

A single-unit truck (SU) is designed with a steering and drive axles carried on the same chassis. An SHV is a modified SU with one to four additional liftable axles positioned either ahead or behind the drive axles or mounted on a hydraulic system that extends, when loaded, to lengthen the chassis. The SHV liftable axles are raised when the vehicle is empty or when the vehicle enters a construction or storage site to unload. Though most liftable axles are caster-steered and follow the track of the steering axle, exact tracking is not feasible due to design limitations. This design limitation can result in tire scrubbing during a turn, which can affect truck steering and stability. For this reason, drivers might lift part or all of the liftable axles during a turn, which significantly increases the steer and drive axle tire loads on the pavement. Though controls used to set the lift axle loads are usually located outside the truck cab, in Texas the axle lift controls are placed in the cab within the driver's reach.

Adding lift axles increases the allowable load by distributing the load across the axle groups and in the case of a various SHV configurations, most notably the SU7, adding a booster axle which extends the chassis length to meet the limits of the Federal Bridge Formula (FBF). SHVs are used in dump, construction, ready-mix, solid waste, and other enhanced SU truck operations.

Ten states have passed legislation requiring the lift axle load-pressure controls to be placed outside the driver's reach or outside the truck cab; seven states allow the axle lift controls to be inside the cab. Other states, including Texas, have no specific legislation or limited rules regarding SHVs, liftable axle controls, loads, or related applications. It is anticipated that states might pass legislation regarding SHVs and/or lift axles as studies are completed to ensure compliance with the FHWA memo.

Texas truck registration data identifies truck type in general terms such as dump, garbage, tanker, box van, etc., but contains no information about truck configuration (e.g., SU, SHV, or combination truck/tractor trailer) nor does registration data contain the number of axles fitted to a truck. The research team developed a study plan to determine the number and types of SHVs operating in Texas based on statistical sampling that included manual, visual field data collection along routes and at fixed sites. In addition, the Texas Department of Transportation (TxDOT) Transportation Planning and Programming Division's 24-hour video traffic count data were used to supplement the manual counts. Over 53,500 trucks were visually identified and recorded in spreadsheet databases, according to type, configuration, number of axles and liftable axles (if any), route, and date of sighting. A comprehensive truck type database was compiled from the individual route, site count, and video spreadsheets.

This information and TxDMV county-level truck registration data was used to develop a statistically based estimate of the number of SHVs operating in Texas by vehicle type, including rural and urban locations and roadway route types. Further, this data was combined with the Texas Department of Public Safety (TxDPS) weight enforcement data and TxDOT weigh-in-motion data to determine average and standard deviation gross vehicle weights (GVW), axle and axle group weights, number of axles, axle loads, axle types (fixed or liftable), and axle spacing.

The research team developed representative SHV configurations, which were used to quantify SHV deterioration impacts to pavements in Texas compared to standard truck configurations with legal axle load limits and GVW and for trucks operating on roadways that are currently load posted. In addition, the SHV configurations were used to quantify impacts to bridges in Texas compared to HS20 or HL93 load configurations.

Further, the researchers conducted a review of SHV safety performance in terms of crash history and operational characteristics; performed an economic analysis of SHV operations in Texas; and prepared draft policy regarding SHV operations in Texas to minimize impacts on bridge and pavement load posting needs. Finally, load posting sign message designs were developed for potential use in the Texas Manual on Uniform Traffic Control Devices (MUTCD).

Chapter 1. Introduction

1.1 Problem Statement

Specialized hauling vehicles (SHVs) were developed in recent years, and they play an important role in the trucking industry. Typically, SHVs are defined as single-unit (SU) vehicles with closely spaced multiple axles. These trucks are designed such that the engine, driver compartment and the cargo are carried on the same truck chassis. Therefore, SHVs can also be described as a modified SU truck with four or up to seven axles. The SHV is modified by adding from one to four liftable axles that can be raised once the cargo is delivered or, when the SHV is loaded, to make steering through an intersection easier though the potential for overturning might be increased. Even though SHVs meet the requirement under Federal Bridge Formula (FBF), these newer axle configurations were not considered in the original development of the FBF and American Association of State Highway and Transportation Officials (AASHTO) legal loads. As such, FBF does not adequately restrict SHVs and most likely overstress the bridges.

For this reason, the Federal Highway Administration (FHWA), by a memorandum dated November 15, 2013, requires a state to certify that it either does not permit operation of SHVs or has conducted bridge load rating analyses using the standard AASHTO HS20 or HL93 loads and applicable SHV load configurations. Texas does allow operation of SHVs, though information about the number and range of actual GVW, axle weights, axle configurations, and spacing was previously unknown and therefore one of the objectives of this study.

AASHTO has adopted one SHV notional load rating configuration for screening purposes and four SHV bridge load rating configurations (SU4, SU5, SU6, and SU7) that are now incorporated in the Manual for Bridge Evaluation. However, based on the specific types of SHVs operating within Texas, it may be necessary to supplement the AASHTO SHV load configurations with SHV configurations unique to Texas to ensure accurate bridge load rating practices are used. Moreover, it necessary to evaluate the SHVs' impact on pavements and safety.

For this reason, it is imperative for TxDOT to characterize SHV operations in Texas to quantify the impacts of SHVs on the Texas infrastructure, safety, and economics to enhance decision-making processes in infrastructure maintenance and operations. In this report, a detailed discussion of the procedure developed to gather, organize, and process various data sources is provided. This information was used to determine where SHVs operate in the Texas; the numbers and types of SHV configurations; and the axle loads, axle spacing, and gross vehicle weight (GVW). Furthermore, a systematic procedure to evaluate the deterioration (consumption) rates for pavements and bridges when all axles are on the ground is presented. These analyses will allow TxDOT to determine potential load posting requirements for SHV typical configurations in the State. Moreover, this report analyzes safety considerations by comparing the difference in SHV operating characteristics and crash history compared to traditional SU and tractor-semi trailer truck configurations in Texas. Finally, recommendations for draft policy and legislation to manage SHV operations and load posting sign layouts for the Texas Manual on Uniform Traffic Control Devices (MUTCD) are presented.

1.2 Research Statement

The goal of this research project is to characterize SHV operations in Texas to comply with FHWA requirements and enhance decision-making processes. The primary objective is to quantify the impact of SHVs on pavements and bridges to evaluate the load posting requirements in the state. To achieve this objective, the following tasks were performed:

1. A literature review of SHV regulations, configurations and operations in other states, Canada, and Mexico;
2. An estimate of the number of SHVs operating in Texas, including rural and urban locations and roadway route types;
3. Identification of SHV configurations used in Texas, including GVW, number of axles, axle loads, axle types (fixed or liftable), and axle spacing;
4. Determination of SHV deterioration impacts to bridges in Texas compared to HS20 or HL93 load configurations;
5. Assessment of SHV deterioration impacts to pavements in Texas compared to those of standard truck configurations with legal axle load limits and GVWs and for trucks operating on roadways that are currently load posted;
6. Assessment of SHV load effects on pavements and bridges and load posting recommendations to meet FHWA deadlines;
7. Review of SHV safety performance in terms of crash history and operational characteristics;
8. Drafting of policy and legislation regarding SHV operations in Texas to minimize impacts on bridge and pavement load posting needs; and
9. Proposal for load posting sign designs for use in the Texas MUTCD.

1.3 Organization of the Report

This chapter provides the problem statement and research objective of this study. The problem statement describes the FHWA requirements for state DOTs to analyze SHV operations in their respective states. Moreover, the research objective describes the goal of this study and an overall structure of the tasks developed to achieve it. The next chapters are organized as follows:

- Chapter 2 presents a comprehensive literature review on national and international research efforts that have been done regarding SHV operations and discuss the findings of interviews with subject matter experts and companies that operate SHVs. Moreover, it describes the stakeholder workshop with trucking industry associations, trade groups, companies that operate SHVs, and subject matter experts.
- Chapter 3 discusses the data collection effort to determine where SHVs operate in Texas; the numbers and types of SHV configurations; axle loads, axle spacing, tire designs, and GVW.
- Chapter 4 evaluates the pavement impacts due to SHV operations on the state-maintained highway system, including deterioration rates in terms of accelerated consumption and load posting requirements.
- Chapter 5 evaluates the force effect and consumption rates for Texas bridges due to SHV operations.

- Chapter 6 discusses safety considerations of SHV operations.
- Chapter 7 presents an economic analysis to evaluate the costs and benefits of SHVs in Texas.
- Chapter 8 drafts policies and legislative recommendations to minimize pavement and bridge deterioration (consumption) and load posting requirements
- Finally, Chapter 9 summarizes this research project's findings and recommendations.

Chapter 2. Information Gathering on SHVs

2.1 Review of Texas Law

2.1.1 Overview

This review of literature on SHVs and load posting is broken into six sections. Section 2.1 reviews Texas law, and Section 2.2 reviews U.S. laws and outlines current U.S. legislation on SHVs. Section 2.3 outlines interviews that the research team undertook. Section 2.4 reviews reports and journal articles. Section 2.5 outlines Canada and Mexico's laws and regulations on SHVs, and Section 2.6 describes a workshop held to obtain stakeholder input.

Government laws and regulations establish the maximum size and weight of vehicles that can operate on public roads to ensure that the roadways can safely carry routine vehicle sizes and weights without risk of accelerated consumption. Trucks carrying heavy loads are generally economical for trucking companies—if trucks carry heavier loads per trip, then they can deliver a certain amount of goods in fewer trips, which results in fuel, driver labor, and vehicle maintenance cost savings. However, these transportation cost savings need to be balanced with the need to preserve the pavement structure of roads and bridges as well as the pavement and bridge costs incurred by public agencies, and so certain weight restrictions need to be imposed. On a national level, the federal government allows a maximum of 80,000 lb GVW on interstate highways in the U.S. Likewise, in Texas, typically a maximum of 80,000 lb GVW is allowed on state-maintained roads (Harrison et al., 2000).

Moreover, certain sections of the road and bridge network in Texas have weight restrictions that are more limiting than the general weight restrictions. State highways or farm-to-market (FM) roads can be load zoned where "heavier maximum weight would rapidly deteriorate or destroy the road or a bridge or culvert along the road" (Texas Transportation Code, Sec. 621.102). As an example, the FM roads were originally constructed in Texas during the 1940s and 1950s to handle GVW of up to 58,420 lbs. Over 16,000 center-line miles of primarily FM road pavements are still load zoned at the 58,420 lb limit (TxDOT, 2017).

2.1.2 Data Availability and Needs for Further Data Collection

One objective of this research project is to determine where SHVs operate in Texas and the numbers and types of SHV configurations, including GVW, number of axles, axle loads, axle types (fixed or liftable), and axle spacing. This data will provide key inputs for the analysis of SHV deterioration impacts on bridges and pavements and for the SHV safety analysis. A thorough literature review was conducted to identify publicly available SHV-related data at both national and state levels, and to assess data limitations and determine gaps between available data and analysis needs.

National Cooperative Freight Research Program (NCFRP) Report 29 (2014) reviewed the current state of truck-activity data, evaluated data limitations and critical gaps, and provided potential innovative data-gathering strategies for overcoming current limitations. The research assessed and summarized quality, usability, and availability of existing truck-activity data. This report also identified key gaps in truck-activity data on vehicle-miles traveled (VMT), ton/ton-miles, value/value-miles, origin/destination flows, vehicle speeds, and transportation costs, as shown in Table 2.1. The authors concluded that key truck-activity data were lacking to answer key policy questions of how much freight is moved, what types of freight are moved, and how much truck traffic these movements generate. Based on the findings from the NCFRP, the research team further reviewed the following data sources that can potentially provide configuration and activity data for SHVs: weigh-in-motion (WIM) data, survey data, vehicle registration data, and weight enforcement data.

Table 2.1: Data availability and features

Dataset	Avail-ability	VMT	Tons	Ton-Miles	Commod-ities	Speed	Weight	O/D	Volume Counts
CFS	5 years	---	X	X	X	---	---	X	---
FAF	5 years[a]	---	X	X	X	---	---	X	X
VIUS	Dis-continued	---	X	X	X	---	X	---	X
Transearch[b]	Annual	---	---	---	---	---	---	---	---
HPMS	Monthly	---	---	---	---	---	---	---	X
WIM	> Monthly	---	---	---	---	---	X	---	X
Class Counts	> Monthly	---	---	---	---	---	---	---	X
FreightPerformance.org	> Monthly	---	---	---	---	X	---	---	---
GPS	> Monthly	---	---	---	---	X	---	X	---
IRP**	Monthly	---	---	---	---	---	---	---	---
Oversize/Weight	> Monthly	---	---	---	---	---	X	X	---
SAS	Annual	X	X	---	X	---	---	---	---
MCMIS	Annual	X	X	X	X	---	---	---	---

[a] FAF availability is 5-year benchmarks and annual estimates.

[b] The researchers were not able to obtain any samples of Transearch data so they used secondary sources to write about it.

National Cooperative Highway Research Program (NCHRP) Report 575 (2007) investigated SHV configurations and state legal loads and recommended SHV vehicle load posting configurations for evaluating bridges. The study used WIM data collected from 18 states (Ohio, Kansas, Nebraska, Rhode Island, Minnesota, Virginia, Connecticut, Alabama, Arkansas, Washington, Kentucky, Pennsylvania, California, Idaho, Missouri, Michigan, North Carolina, and Montana) to identify truck configurations and axle combinations for SHVs. Phase II of the study further collected WIM data with high-resolution time stamps at three WIM sites in Idaho Michigan Ohio to provide more accurate quantitative information on the occurrence of side-by-side truck loadings. The study stated that a 10 to 15% margin of error on axle weights is not uncommon in WIM data, and accuracy of axle spacing is generally better than for axle weights. The study considered the level of accuracy of the WIM data to be acceptable to extract information on number and spacing of axles, and was not used to measure axle loads.

The Vehicle Inventory and Use Survey (VIUS) was conducted by U.S. Census Bureau to provide data on national and state-level estimates of the total number of trucks and the physical and operational characteristics of the truck population. The survey was terminated in 2002. Although the survey contained information that can be potentially used to provide information on

SHVs (i.e., what is the total number of axles, including liftable axles, on this vehicle? how many axles are liftable axles? how many liftable axles are braking axles?), the data is considered not up-to-date to serve the research objective of this study.

The Texas Department of Public Safety's (TxDPS) Commercial Vehicle Enforcement (CVE) Service is responsible for weighing and checking commercial vehicle traffic to make sure these vehicles are compliant with laws regulating weight; motor carrier safety; registration; and transport of persons, hazardous material, and other property (TxDPS, n.d). They have a limited number of fixed weight stations located throughout the state. TxDPS weight enforcement officers also carry portable scales in the car and can pull over a vehicle for a weight check on the roadside. The enforcement officer will also observe the axle spacing of a truck; if they suspect inadequate axle or axle group spacing, they will measure the axle spacing of the truck and compare that with the bridge formula (Formula B) to judge if the truck is compliant.

TxDPS maintains data containing axle and total weight information obtained during fixed site and roadside truck weight checks that can serve as a valuable resource for this project. However, use of the TxDPS weight enforcement data presents two major issues when estimating the population characteristics of SHVs:

a. The sampling process is uncontrolled. Many trucks are pulled over and weighed by the roadside because the enforcement officer suspected a potential weight violation. So, the percentage of trucks violating the weight law among all the trucks weighed by the TxDPS is expected to be higher than the percentage of violators among all trucks.

b. It is unclear from the data if an axle is liftable or not. The database contains the number of axles, spacing between axles, and tire types (single/dual) of the weighed truck. However, there is no direct information indicating whether an axle is liftable. The research team will need to combine information on the types of tires and axle configurations to make best estimation of which vehicles are SHVs.

Due to these data limitations, the results obtained by analyzing the weight enforcement data needs to be further checked against other data sources.

The Texas Department of Motor Vehicles (TxDMV) maintains vehicle registration data. The data provides us the total number of vehicles of different truck types and their distribution over the state by county. This data can help ensure a statistically valid sample of each vehicle type when the researchers collect field data, as it provides us the population information of different truck types. Data limitations associated with this data resource include the following:

a) No axle information is recorded. When a vehicle is registered with TxDMV, the owner is not required to specify how many axles the vehicle has, nor if the truck has axles that are liftable or is a booster axle.

b) It is unclear from the data if a vehicle is an SU or not. For example, even though the TxDMV data has a specific body type labeled "Dump Trucks," it is unclear if a vehicle registered in this category is an SU truck or a truck tractor with a dump trailer. This project focuses on those SU trucks. Thus, the data collection effort will seek to obtain a statistically based sample of all truck configurations of each operational type to make statements about the number of registered trucks in each operational category.

c) Accurate definitions of different body types are not made clear to either the vehicle registrant or registration officers. The vehicle registrant reports their vehicle as the body type they think it should be. According to the information we obtained in our interview, the county registration clerk is not required to check the vehicle visually to verify that the reported body type is correct and matches with the definition. However, the researchers anticipate that certain operational types are relatively easy to correctly identify such as Dump, Concrete (ready-mix), Garbage, Flat bed, and Tanker as examples.

d) Some registration categories are too broad. For example, the vehicle category “Oil Field Equipment” has no subcategories to define more specifically what type of equipment it is. So, it may be a vacuum truck, a hot oil unit, or a winch truck—which are all very different in truck weight and size, axle spacing, and location of lift axles (if used). At present, fracking activity is at a low point in Texas and few oil field trucks were observed except during evaluation of 24-hour TxDOT traffic classification videos from the Midland-Odessa area.

Even though the above data resources provide valuable information, to accurately estimate the number, configuration, and other operating characteristics of SHVs operating in Texas, field data collection is necessary and important, especially considering the issues associated with those data resources discussed above. The detailed results obtained from the field data collection activities are reported in Chapter 3.

Field data collection activities comprise four major components:

a) Estimate the number of SHVs operating in Texas by counting the number of trucks observed at different types of sites.

i. Various sites, including quarries, ready-mix and hot-mix plants, construction material plants, and landfills, were visited in major urban areas (Austin, Houston, Dallas/Ft. Worth, and San Antonio) and numerous rural locations. By recording detailed body type, axle number, axle type, tire type, function, and additional information for each observed truck, a detailed sample of different types of trucks was established. Based on this sample, the number of SHVs and the percentage of different types of SHVs were estimated. A detailed discussion is provided in Chapter 3.

b) Estimate the number of SHVs operating in Texas by obtaining a sample of all trucks, with detailed descriptions operating on routes across Texas. The data will be collected for trucks operating within metro, urban, and rural areas and along routes between metro and urban areas and using individual identification and voice recordings transcribed to excel and TxDOT Vehicle Classification site 24-hour videos.

i. Detailed information regarding truck operational type, configuration (tractor-trailer or single-unit), number of axles, number of lift axles and positions, whether axles are lifted or not, for certain types of trucks, whether the truck is loaded or not and the cargo type.

c) Estimate the number of SHVs operating along a specific corridor in Texas by obtaining a sample of all trucks, with detailed descriptions.

i. Detailed information regarding truck operational type, configuration (tractor-trailer or single-unit), number of axles, number of lift axles and positions, whether axles are lifted or not, for certain types of trucks, whether the truck is loaded or not and the cargo type.

d) Identify SHV configurations operating in Texas by measuring the spacing and weight of a sample of SHV trucks.

i. Two HAENNI WL-101 portable scales that are identical to those TxDPS uses to weigh trucks on road side were purchased. Different project sites where SHVs are operating were visited under the coordination of TxDOT. At the project sites, the axle weights with liftable/booster (either up or down), axle spacing, and tire dimensions will be measured. The liftable/booster axle control mechanism and tire load rating will also be recorded. Based on the spacing and weight information collected from this sample of SHV trucks, the major types of SHV configurations operating in Texas can be characterized.

Interviews and communications with truck industries provided valuable information regarding SHVs' operating characteristics. This information was obtained by sending questionnaires to and interviewing truck industry representatives. A detailed discussion of the findings is discussed in Chapter 2.

2.1.3 Texas Weight Limits

Texas Transportation Code, Sec. 621.101 states the legal weight limits in the state of Texas. Typically, a maximum of 20,000 lb is allowed on a single axle; a maximum of 34,000 lb is allowed on a tandem axle (including all enforcement tolerances).

The maximum legal weight allowed on a group of two or more axles depends on the number and spacing of the axles in the axle group, and is determined using the FBF and rounding the result to the nearest 500 lbs.

The FBF was enacted by Congress in 1975 to protect bridges from excessive strain by restricting the weight of a vehicle based on its axle configuration (number of axles, and axle spacing). The formula is:

$$W = 500 \left[(LN/(N - 1)) + 12N + 36 \right] \quad (2\text{-}1)$$

where:
"W" is maximum allowed overall gross weight on the axle group;
"L" is distance in feet between the axles of the group that are the farthest apart; and
"N" is number of axles in the group

While the FBF limits are thought to be generally applicable for axle and axle group weights for long trucks, the bridge formula might underestimate bridge stresses for SHVs that have shorter wheelbases than tractor semi-trailer trucks. In effect, the NCHRP 575 study was initiated based on concerns about potential underestimation of bridge stresses due to SHVs and the need to develop new design load vehicles representing SHVs for use in bridge evaluation. This is because a long truck may span across two successive bridge column locations such that the entire weight of the truck is not carried by the one set of bridge beams that spans between the two column locations (referred to as *bents*). However, a shorter truck might fit between the two bents, thus applying its entire weight to one set of bridge beams.

In addition, in Texas the weight on a tire should not exceed the maximum tire load capacity specified and marked on the sidewall of the tire by the manufacturer. The maximum allowable legal GVW (which is equal to the sum of all axle weights) is 80,000 lbs (including all enforcement tolerances) regardless of tire ratings, and number and spacing of axles.

The Permissible Weight Table (Table 2.2) indicates the maximum legal weight for a group of two or more consecutive axles of a vehicle depending on the number and spacing of axles determined using the FBF. The number in the leftmost column, labeled "Distance in Feet," is the distance between the outermost axles of any group of two or more consecutive axles.

Table 2.2: Permissible Weight Table

Distance in Feet	Number of Axles					
	2	3	4	5	6	7
4	34,000					
5	34,000					
6	34,000					
7	34,000					
8	34,000	34,000				
8+ (These figures apply only to an axle spacing greater than 8 feet but less than 9 feet)	38,000	42,000				
9	39,000	42,500				
10	40,000	43,500				
11		44,500				
12		45,000	50,000			
13		45,500	50,500			
14		46,500	51,500			
15		47,500	52,000			
16		48,000	52,500	58,000		
17		48,500	53,500	58,500		
18		49,900	54,000	59,000		
19		51,400	54,500	60,000		
20		52,800	55,500	60,500	66,000	
21		54,000	56,000	61,000	66,500	
22		54,000	56,500	61,500	67,000	
23		54,000	57,500	62,500	68,000	
24		54,000	58,700*	63,000	68,500	74,000
25		54,500	59,650*	63,500	69,000	74,500
26		55,500	60,600*	64,000	69,500	75,000
27		56,000	61,550*	65,000	70,000	75,500
28		57,000	62,500*	65,500	71,000	76,500
29		57,500	63450*	66,000	71,500	77,000
30		58,500	64,000*	66,500	72,000	77,500
31		59,000	65,350*	67,500	72,500	78,000
32		60,000	66,300*	68,500	73,000	78,500
33			67,250*	68,500	74,000	79,000
34			68,200*	69,000	74,500	80,000
35			69,150*	70,000	75,000	
36			70,100*	70,500	75,500	
37			71,050*	71,050	76,000	

Distance in Feet	Number of Axles					
38			72,000*	72,000*	77,000	
39			72,000*	72,500	77,500	
40			72,000*	73,000	78,000	
41			72,000*	73,500	78,500	
42			72,000*	74,000	79,000	
43			72,000*	75,000	80,000	
44			72,000*	75,500		
45			72,000	76,000		
46			72,500	76,500		
47			73,500	77,500		
48			74,000	78,000		
49			74,500	78,500		
50			75,500	79,000		
51			76,000	80,000		

Source: TxDMV Website (Item 2123 Permissible Weight Table)

*These figures were carried forward from Article 6701d-11, Section 5(a)(4) when Senate Bill 89 of the 64th Texas Legislature amended it on December 16, 1974. The amendment provided that axle configurations and weights that were lawful as of that date would continue to be legal under the increased weight limits.

2.1.4 Oversize/Overweight (OS/OW) Permit

Vehicles that exceed the legal size and weight limits need to obtain an OS/OW permit and may also be required to obtain an approved route from TxDMV to operate on roads in Texas. General single trip and super heavy loads permits are examples of OS/OW permits that typically require routing. Other types of OS/OW permits for lower-weight vehicles are issued for annual operations and are typically not routed due to weight. As an example, permits for loads over GVW or over the axle weight tolerance are not routed, though state laws restrict operations on load zoned bridges.

Maximum Permit Weight Limits

Texas Administrative Code Chapter 219, Rule 219.11 “General Oversize/Overweight Permit Requirements and Procedures” states the maximum permit weight limits. Maximum permit weight for an axle or axle group is based on 650 lbs per square inch of tire tread width or the axle or axle group weights shown in Table 2.3, whichever is less. For load-restricted roads, the maximum allowed permit weight for an axle or axle group is reduced by 10%.

Table 2.3: Maximum legal and permit weights

Number of axles in axle group	Maximum legal weight (lbs)	General Maximum permit weight (lbs)	Maximum permit weight on load-zoned roads (lbs)
Single axle	20,000	25,000[1]	22,500
Two-axle group	34,000	46,000	41,400
Three-axle group	42,000	60,000	54,000
Four-axle group	50,000	70,000	63,000
Five-axle group	58,000	81,400	73,260
Note: Axle groups with six or more axles are not allowed unless the group has steerable or articulating axles or an engineering study of the equipment has been completed.			

Source: Texas Administrative Code, Chapter 219, and TxDMV, 2015

[1]Texas Administrative Code Chapter 219, Rule 219.43 which relates to Quarterly Hubmeter permits, allows a permitted, single axle weight up to 30,000 lbs or 850 lbs per inch of tire width whichever is less. In addition, steerable axles for permitted vehicles may have tires with up to 950 lbs per inch of tire width.

An axle group must have a minimum spacing of four feet, measured from center to center of axles, between each axle in the group to achieve the maximum permit weight for the group. Two opposing axle groups must have a minimum spacing of 12 feet, measured from the center of the last axle of the front group to the center of the first axle of the following group. For two or more consecutive axle groups having an axle spacing of less than 12 feet, measured from the center of the last axle of the preceding group to the center of the first axle of the following group, the maximum allowed permit weight will be reduced by 2.5% for each foot less than 12 feet.

In addition, each axle in a group of axles must equally share the weight of the group at all times, with no more than a 10% weight difference between any of the axles in the group, if the axles share suspension (TxDMV, 2015).

Moreover, the maximum permit weight for an axle group with spacing of five or more feet between each axle will be based on an engineering study of the equipment is conducted. An OW-permitted vehicle is not allowed to travel over a load-restricted bridge if its axle weight or gross weight exceeds the posted capacity of the bridge, unless the bridge is "land-locked" (a bridge located along the only route into or out of a community). Furthermore, a permitted vehicle is not allowed to exceed the manufacturer's rated tire load capacity.

Various types of OS/OW permits are available, such as the over-axle/over-GVW tolerance permit and non-divisible load permit, among others.

2.1.5 Over Axle/Over Gross Weight Tolerance Permit ("2060" or "1547" permit)

TxDMV issues an annual Over Axle/Over Gross Weight Tolerance Permit that allows a vehicle carrying divisible loads, such as crude oil and gravel, to operate above the legal weight limits on state-maintained roadways, and county roads (in the counties selected on the permit application) but not on the interstate highway system (TxDMV, 2016). This permit is also referred to as the "2060" or "1547" permit (named after the House Bills that authorized these permits). TxDMV's website also notes that the "2060" permit does not allow the permitted vehicle to exceed load-posted bridge weight restrictions unless the bridge is the only way to publicly access the origin or destination.

The “2060” permit allows a 10% axle weight tolerance for non-agricultural commodities, or a 12 percent axle weight tolerance for agricultural commodities above the maximum allowable axle weight. However, these axle weight tolerances are capped by a 5% GVW tolerance (84,000 lbs maximum for a five-axle tractor-trailer) such that the combined axles weights including tolerances cannot exceed this amount. Certain types of trucks are not eligible for the “2060” permit, based on the type of commodity they transport—such as solid waste trucks, trucks transporting recyclable materials, and processed milk, among others—as other special statutes apply to them (TxDMV, 2015).

The annual permit fee includes a base fee of $90, an administrative fee of $5, and a county fee based on the number of counties the applicant wants the permit to be valid in. Table 2.4 shows the amount of county fee based on the number of counties the permit will be valid in. In addition, a $15,000 bond or letter of credit is required to buy a permit as security against any road damage caused by operation of the permitted vehicle.

Table 2.4: “2060” permit costs

Number of Counties Designated	County Fee
1-5	$175
6-20	$250
21-40	$450
41-60	$625
61-80	$800
81-100	$900
101-254	$1,000

Source: TxDMV, 2015

Non-divisible Load Permit

Non-divisible load permits are issued by the state of Texas for vehicles carrying OW loads that cannot be easily dismantled (such as a large machine). ‘Easily dismantled’ means that the piece of equipment would require less than 1 working day to disassemble into components of legal size/weight or that dismantling would not negatively impact the value of the machine or item. These permits can be issued for a single trip, or can be valid for 30 or 90 days, or a year. The applicant needs to pay a fee to obtain these permits, and the permitted vehicle can travel only on the route approved by TxDOT. Depending on the type of permit, these non-divisible load permits can allow increases in width, or length, and/or GVW. For example, an annual permit can allow trucks up to 12’ wide, 14’ high, 110’ long, and a GVW of up to 120,000 lbs. These permits do not allow movement on non-state-maintained roads, and do not exempt vehicles from load-zoned road restrictions (Harrison et al., 2000).

Super Heavy Loads

A load is considered to be "super heavy" when one or more of the following holds true: the vehicle and load exceed 254,300 lbs gross weight; and/or the axle group weight exceed the weight limits shown in the Permissible Weight Table; and/or the vehicle and load have less than 95 feet of overall axle spacing and the weight exceeds 200,000 lbs but does not exceed 254,300 lbs. Super heavy permits are required to transport "super heavy" loads and these permits have specific requirements that must be met with before a permit can be issued (TxDMV, 2015).

Certain permits levy weight-related fees in addition to the permit fee. The weight-related fee includes the highway maintenance fee and vehicle supervision fee.

Highway Maintenance Fee

Vehicles with a GVW of more than 80,000 lbs need to pay a highway maintenance fee in addition to the permit fee. The highway maintenance fee amount depends on the GVW, as shown in Table 2.5.

Table 2.5: Highway maintenance fee

Gross Weight in Lbs	Highway Maintenance Fee
80,001-120,000	$150
120,001-160,000	$225
160,001-200,000	$300
200,001 and above	$375

Source: TxDMV, 2015

Vehicle Supervision Fee

Vehicles with a GVW of more than 200,000 lbs need to pay a vehicle supervision fee of $35 in addition to the regular permit fee and highway maintenance fee (TxDMV, 2015).

2.1.6 Texas Size Limits

Following are the legal size limits for vehicles operating on Texas highways without a permit:

- Maximum width – 8'6"
- Maximum height – 14'
- Maximum length is shown in Table 2.6.

Table 2.6: Truck lengths in Texas

Vehicle Type	Length Limit
Applicable to SHVs	
Truck or Single vehicle	45 feet
Truck-tractor	Unlimited
Truck-tractor combination	Overall length unlimited but the trailer is limited to 59 feet
Front overhang	3 feet
Rear overhang	4 feet
Applicable to other trucks	
Truck and trailer combination	65 feet
Semi-trailer single unit	59 feet
Semi double trailer	28.5 feet

Source: TxDMV, 2015

TxDMV notes that the width is measured from the outside points of the widest extremities, excluding safety devices such as mirrors. The height is measured from the roadbed to the highest point of the load or vehicle. The 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, and must include all overhangs.

Vehicles exceeding the legal size limits need to obtain an OS permit from TxDMV. The width, height, and length limits for vehicles with a permit that are allowed on Texas highways are shown in Table 2.7.

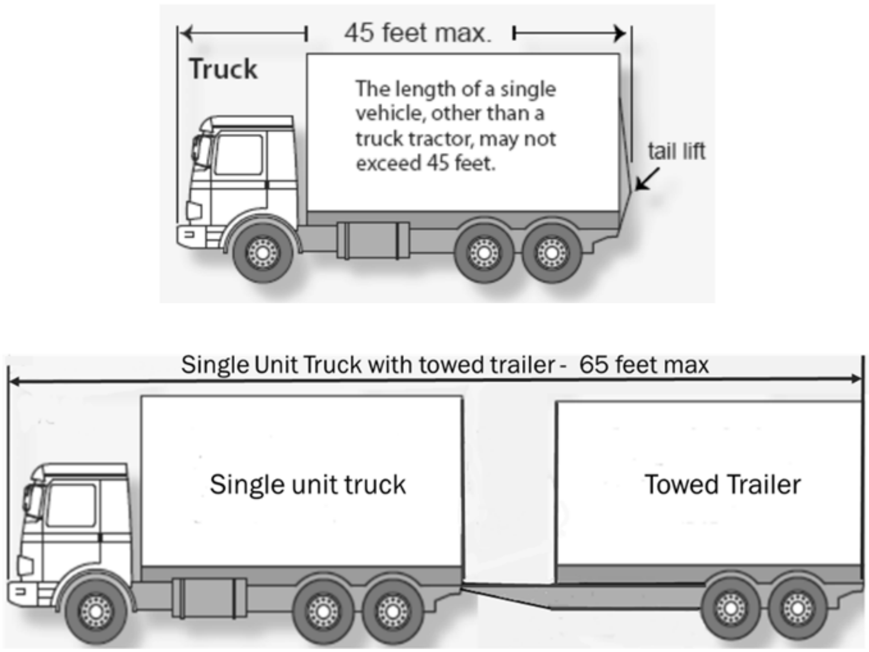
Table 2.7: Width limits with permits

Width Limits with a Permit	
Maximum width permitted on holidays	14 feet, except for manufactured housing
Maximum width permitted on controlled access highways (Interstate Highway System)	16 feet, except for manufactured housing
Maximum width permitted without a route inspection certification by applicant on file	20 feet
Maximum width permitted for new tanks	34 feet
Maximum width permitted for existing tanks	40 feet
Height Limits with a Permit	
Maximum height permitted on holidays	16 feet
Maximum height permitted without a route inspection certification by applicant on file	18 feet, 11 inches
Length Limits with a Permit	
Truck or single vehicle	75 feet
Front overhang	25 feet
Rear overhang	30 feet
Maximum length permitted without a route inspection certification by applicant on file	125 feet

Source: TxDMV, 2016a

2.1.7 Length Diagrams

Figure 2.1 shows the legal length limits for SU trucks, including SHVs and a SU truck towing a trailer.



Source: TxDMV, 2015 (SU Truck with towed trailer length based on text only, drawing not from citation)

Figure 2.1: Legal length limits for SU trucks and SU truck with towed trailer

2.1.8 Exceptions Based on the Type of Commodity

The state of Texas relaxes the legal size and/or weight limitations for trucks carrying certain type of goods on roads within the state (except for on the interstate highways).

Garbage Collection Vehicles

Texas Transportation Code, Sec. 621.206(b), allows a vehicle that collects garbage or recyclable materials and is equipped with front-end loading attachments and containers to carry a load that extends more than three feet beyond its front or more than four feet beyond its rear, which other vehicles are typically not allowed to exceed. No permit or bond or fee is required for this exemption.

Recyclable Materials or Solid Waste Trucks

Texas Transportation Code, Sec.622.131-136 (for recyclable materials truck) and Transportation Code, Sec.623.161-165 (for solid waste truck) allows a truck (single vehicle) used exclusively to transport recyclable materials or solid waste to operate without an OS/OW permit on state highways, excluding interstate and defense highways, with a single axle weight up to a maximum of 21,000 lbs, a tandem axle group weight up to a maximum of 44,000 lbs, and gross weight up to a maximum of 64,000 lbs. In addition, the statutes also state that owners of recyclable materials or solid waste trucks with a tandem axle weight exceeding 34,000 lbs are required to file a surety bond with TxDOT not to exceed $15,000 per vehicle as security against any road damages caused by operation of the truck.

Ready-mix Concrete Trucks

Texas Transportation Code, Sec.622.011, allows vehicles transporting ready-mix concrete, or a concrete pump truck to operate on state highways (without a permit) with a single-axle weight up to a maximum of 23,000 lbs, a tandem axle group weight up to a maximum of 46,000 lbs, and gross weight up to a maximum of 69,000 lbs. Ready-mix concrete trucks that do not operate under the provisions of a permit may be subject to additional county and municipality weight restrictions for operations on county and municipal roads, and are also subject to local bond requirements. Texas statute (Transportation Code, Sec. 622.015) states that a county or municipality government may require a ready-mix concrete truck owner to file a surety bond not exceeding $15,000 as security against any damages caused to a highway by the operation of a truck with a tandem axle weight of more than 34,000 lbs.

As per Texas Transportation Code, Sec.623.0171, a permit can be issued to ready-mix concrete trucks with three axles by the TxDMV that would allow these trucks to exceed the allowable single and tandem axle weights stated above by a tolerance of 10% provided the maximum GVW does not exceed 69,000 lbs. The annual permit fee is $1,000. The permit does not allow the ready-mix concrete trucks to exceed legal size limits. The permit allows operations of permitted vehicles on municipal roads, county roads (including load-zoned county roads), FM roads, Texas state highways, and U.S. highways in the counties listed on the permit for an unlimited number of moves during the time specified on the permit. However, this permit does not allow the vehicles to operate on interstate and defense highways (Texas Transportation Code; TxDMV, 2015; Prozzi et al., 2012).

2.2 Review of U.S. Laws

A review of the fifty states' regulations pertinent to SHVs was undertaken by the research team; Table 2.8 summarizes the findings.

Table 2.8: U.S. laws governing SHVs

State	What the Laws Say	Source
Alabama	Does not specifically mention SHVs, but has many exceptions added to the Motor Vehicle Code for different types of specialized vehicles (e.g., dump trucks, dump trailers, concrete mixing trucks, fuel oil, gasoline trucks, and trucks designated and constructed for special type work or use shall not be made to conform to the axle spacing requirements of paragraph (4)c of this section provided, that the vehicle shall be limited to a weight of 20,000 lbs per axle plus scale tolerances; and, provided further, that the maximum gross weight of the vehicles shall not exceed the maximum weight allowed by this section for the appropriate number of axles, irrespective of the distance between axles, plus allowable scale tolerances). Further exemptions exist for milk trucks and farm equipment.	The Code of Alabama 1975 Section 32-9
Alaska	A rotating drum transit mix concrete truck with a booster axle or a lift axle, or both, may operate on the state highway system for the movement of specialty manufactured products or other loads if the gross weight of the vehicle and the axle weights are not greater than the standards set out in 17 AAC 25.013 (Regular Limits). Weight adjustment controls for the booster axle and the lift axle must be located outside the driver's compartment and not within reach of the driver while the truck is in motion. The up-and-down position control that controls the booster axle and the lift axle must be a single control, and may be located in the cab of the vehicle. The lift axle must be in the down position and engaged to carry a minimum of 6,000 lbs to be counted as a tridem axle group. Similar to this, other exemptions exist for other specialized vehicles such as automobile carriers, boat transporters, and jeeps. There are also specific formulae for weights of trucks with lift axles. Lift axles or variable suspension axles are allowed in the drive axle group of the power vehicle, but may not be used for calculation of legal allowable vehicle gross weight	Alaska Admin Code (17 AAC 25.013 and .015)
Arizona	No information specific to liftable axle SHVs. However, Arizona has "Envelope Permits," which are special permits issued for a nonspecific and non-reducible vehicle or cargo load that does not exceed 250,000 lbs in gross weight, 14 feet in width, 16 feet in height or 120 feet in overall length and that has at least four axles. Also, the Legislation delineates some exceptions to height, width, length, and weight rules, such as for automobile carriers.	Arizona State Legislature - Title 28 - Article 18 and 19

State	What the Laws Say	Source
Arkansas	Highway OS/OW Permit Rules defines Lift Axles, but does not show up elsewhere in legislation. Legislation contains no information specific to liftable axle SHVs, but delineates exemptions in regular weight/size limits for special types of vehicles (e.g., forestry, farm equipment, etc.)	Arkansas Code 27-35-210
California	No information specific to liftable axle SHVs, but delineates exemptions in regular weight/size limits for special types of vehicles (e.g., dump trucks, garbage trucks, etc.)	California Vehicle Code, 15-5-1
Colorado	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Colorado Revised Statutes 42-4-510
Connecticut	No information specific to liftable axle SHVs, but delineates exemptions in regular weight/size limits for special types of vehicles (e.g., garbage trucks can carry more weight than normal, if operated off of the highway)	General Statutes of Connecticut, Title 14, Chapter 248, Sec 14-267
Delaware	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Delaware Code, Title 21, Chapter 45, 4504
District of Columbia	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	DCR 18-2512
Florida	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Florida Highway Patrol website
Georgia	No lift axle may be used in computing the maximum total gross weight authorized for any vehicle or load.	Georgia Code 32-6-26
Hawaii		
Idaho	Any vehicle which is equipped with variable load suspension axles (lift axles) transporting OW loads shall have all lift axles fully deployed.	Idaho Administrative Code 39-03-13
Illinois	Inspection procedures for lift axles are described.	Illinois Administrative Code 92-1-e-448-A
Indiana	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Indiana Administrative Code 105-10-4

State	What the Laws Say	Source
Iowa	A vehicle or combination of vehicles equipped with a retractable axle may raise the axle when necessary to negotiate a turn, provided that the retractable axle is lowered within one thousand feet following completion of the turn. Could not find any regulations in state laws regarding lift axles, but exemptions from weight limits were present for special vehicles such as milk tankers, garbage trucks, etc.	IOWADOT Truck Guide
Kansas	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Kansas Statute Chapter 8, Article 19
Kentucky	A lift axle that isn't always deployed shall not be used in computing the maximum total gross weight authorized for any vehicle or load.	Kentucky Statute Chapter 177
Louisiana	When "Variable Load Suspension" axles are equipped on a vehicle and are operational, they must provide for reasonable distribution of axle weight. In addition, the regulator that controls the pressure for these axles must be outside the cab. The only control that may be in the cab is that which is necessary to activate the mechanism. The suspension used by these axles may be either hydraulic, air or a combination thereof.	Louisiana Regulations for Trucks, Vehicles and Loads (DOT)
Maine	For all vehicles manufactured, modified or retrofitted with liftable or variable load suspension axles after October 30, 1991, liftable or variable load suspension axles are permitted only under the following conditions: only one liftable or variable load axle may be present on the truck tractor and only one liftable or variable load axle may be present on the semitrailer; liftable or variable load axles must be located on the vehicle so that they are legally part of the tandem axle group or tri-axle group as appropriate; and the axle weight rating of liftable or variable load axles must conform to the expected loading of the suspension and must be 20,000 lbs or more. When operating at a GVW exceeding 88,000 lbs, all liftable axles of the vehicle are in full contact with the ground at all times. Axles 2, 5 and 6 of a six-axle single-unit vehicle may be liftable axles. Axles 2 and 6 must be self-steering axles of a type that has been approved by the Department of Transportation.	Maine Revised Statutes 29-21-1-2354/2364/2365

State	What the Laws Say	Source
Maryland	Maryland currently only has lift axle regulations for four-axle-or-more trucks. Lift axle control shall allow only fully on or fully off. These controls may be in cab of vehicle, but air pressure adjustment control cannot be. There are specific rules about when the lift axles can be engaged and disengaged (such as when turning sharp curves). Also, weight limits and minimum lift axle loadings are specified, in relation to GVW.	Code of Maryland 11.15.27.05 and 07
Massachusetts	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Massachusetts General Laws I:XIV:90:19
Michigan	Michigan's OW laws are all related to individual axle loading, not GVW. Laws "imply" that lift axles are mainly to be used to negotiate turns/intersections. Axle loadings for OW determinations shall only be done with lift axles lowered.	Michigan Compiled Laws 257.724a
Minnesota	A vehicle or combination of vehicles equipped with one or more variable load axles shall have the pressure control preset so that the weight carried on the variable load axle may not be varied by the operator during transport of any load. The actuating control for the axle shall function only as an on-and-off switch. This doesn't apply to old farm trucks and general rear-loading refuse-compactor vehicles.	Minnesota Statutes 169.828
Mississippi	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Mississippi Code of 1972. 63:5:34
Missouri	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Missouri Revised Statutes. Section 304.180.1
Montana	If a motor vehicle is equipped with a retractable axle that is not fully extended and carrying its proportionate share of the load while the motor vehicle is operated upon the highways of this state, the weight penalties in subsection (1) apply to all weight over the legal maximum allowed by the fixed axles regardless of whether the axle is extended at the time of weighing. In addition to the penalties in subsection (1), the owner or operator shall be fined $100 for failure to have the retractable axle fully extended while the gross weight of the vehicle exceeds the legal maximum allowed by the fixed axles.	
Nebraska	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles. However, a survey conducted under the Maryland Study by Moffatt indicated that Nebraska requires lift axles to carry 8% of GVW or 8,000 lbs whichever is least.	Nebraska Revised Statute 60-6,298; Moffatt 2010

State	What the Laws Say	Source
Nevada	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Nevada Revised Statutes 484D.635
New Hampshire	SU4 vehicles shall drive on 2 rear axles, and the tridem may contain not more than one retractable axle.	New Hampshire Revised Statutes Title XXI: Chapter 266
New Jersey	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	New Jersey Statutes. 39:3-84.1
New Mexico	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	New Mexico Statutes. 66-7-413
New York	Lift axles must be steerable and trackable. Air pressure control valve must be beyond reach of driver while vehicle is in motion.	New York Code of Rules and Regulations. 154-2.4
North Carolina	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	North Carolina Statutes. 20-119
North Dakota	On all motor vehicles manufactured after July 31, 2005, the lock or pressure regulator valve for a lift axle shall be located outside the cab and inaccessible from the driver's compartment only if there is more than one lift axle. The control to lift and lower a retractable or variable load suspension axle may be accessible in the driver's compartment.	North Dakota Highway Patrol Weight/Size Guide
Ohio	If an axle is declared on the special hauling permit, it must be in the down position at all times, except if the permit (or permit attachment) states otherwise. There is no requirement regarding load equalization or suspension type so long as it is a load bearing axle and does not exceed the tire or axle load limit. Variable load suspension axles or groups of axles not having the same suspension type are not recognized in OW permit allowances. However, an airlift axle may be utilized and recognized if it is part of an air-ride suspension system and operates off of an equalizing valve common to all axles in the group, 16' 0" or less.	OHIO DEPARTMENT OF TRANSPORTATION Special Hauling Permit Section
Oklahoma	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Oklahoma Statutes. §47-14-101

State	What the Laws Say	Source
Oregon	The controls for the lift axle may be mounted inside the cab of the power unit provided that it limits the axle movement to the complete up or complete down position; The control for a variable load, or lift axle, which allows adjustment to increase or decrease loading on the vehicle must not be accessible from the cab; The lift or variable load axle must be deployed, and distribute the weight of the load, when failure to do so results in any tire, axle, tandem axle or group of axles exceeding the weight limits allowed; All single axles of triple trailer combinations must have four tires except for the steering axle of the power unit and lift axles which may have two tires; Raising a lift-axle is not considered a change in configuration (for tax purposes)	Oregon Administrative Rules 734-074-0010
Pennsylvania	Except when necessary for turning a truck that is operating under normal load conditions, the lift axle shall be in full contact with the highway under full pressure.	2010 Pennsylvania Code 49:4943
Rhode Island	Lifted liftable axles not allowed when using certain bridges in Rhode Island. No other laws found.	RHODE ISLAND TURNPIKE AND BRIDGE AUTHORITY
South Carolina	Considered legal as long as it is a full weight bearing axle. No other laws found.	South Carolina DOT
South Dakota	Unless specifically authorized by permit, a variable load axle may not be raised if, when it is raised, it causes any other axle to be overloaded. The control for adjusting pressure shall be mounted outside of the driver compartment and shall be preset so the weight carried on the variable load axle may not be varied by anyone in the vehicle. The control for raising and lowering the variable load axle may be accessible to the driver, but it may not also function as the pressure control device. Permits can be bought that allow lifting of axle when making turns. Lift axles and belly axles are not considered load-carrying axles and will not count when determining the vehicle's weight limits.	South Dakota Code SDCL 32-22-57.1 and South Dakota Motor Carrier Handbook Chapter 5
Tennessee	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Tenn. Code Ann. § 55-4-113

State	What the Laws Say	Source
Utah	Retractable or variable load suspension axles installed after January 1990 shall be self-steering on power units or when augmenting a tridem group on trailers; no axle in a group with a retractable or VLS axle shall exceed legal or bridge formula weight requirements, or the manufacturer's tire rating; controls for raising or lowering retractable or VLS axles may be located in the cab of the power unit. The pressure regulator valve shall be positioned outside of the cab and be inaccessible from the driver's compartment.	Utah Admin Code R909-2
Vermont	DMV has special instructions for inspection: If retractable axle equipped, check condition of lift mechanism. If air powered, check for leaks. But no statutes found.	Vermont Statutes 23:13:15:1392
Virginia	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	Code of Virginia. 46.2-1128
Washington	The axle must be self-steering. The simple "up/down" control may be in the driver's compartment; however, any variable control used to adjust axle loadings, by regulating air pressure or other means, must not be within reach of the driver's compartment. The self-steering requirement does not apply when: (a) The retractable axle, equipped with four tires, is used for the purpose of weight distribution on a truck or truck-tractor and gives the appearance of, but does not function as, a tandem axle drive configuration. The distance between the drive axle and the retractable axle must not exceed sixty inches. b) A retractable axle is used adjacent to a fixed axle on a trailing unit and distance between the two axles does not exceed sixty inches.	Washington Administrative Code WAC 468-38-280
West Virginia	No information specific to liftable axle SHVs, but delineates permits for irregular weight/size vehicles.	West Virginia Code. 17C-17-1
Wisconsin	The control valve that regulates the amount of pressure shall be mounted outside of the driver's compartment; The control valve that regulates the movement of the axle or axles so as to raise or lower the axle or axles may be in the driver's compartment. Lift axle must carry a minimum of 8% of gross load when used.	Wisconsin Administrative Code. Trans 305.49

State	What the Laws Say	Source
Wyoming	If any axle group containing a variable load suspension axle exceeds legal or allowable weight without using the variable load suspension axle, the variable load suspension axle shall be used to the extent that it assumes sufficient weight to keep the axle group with which it is used within legal weight for a divisible load or permissible weight for a non-divisible load. Vehicles equipped with a functional variable load suspension axle shall be required to put the axle into use if the vehicle is OW and the use of the axle will reduce the amount of OW on an axle group, inner bridge, or gross. In certain cases, the use of this type axle may reduce the allowable weights a vehicle may carry. If the allowable weight is reduced due to decreased bridge between axle groups, the use of the axle is not required. Lift axle must bear at least 8% of GVW. Wyoming Survey response NCHRP 575	WYDOT Rules, Motor Carrier Chapter 5; NCHRP 575 Survey results

2.3 Interviews

As part of the data availability and need, the research team conducted a series of interviews to gain information from the TxDMV and TxDPS. Interviews were conducted with the following individuals:

- Major Chris Nordloh, Director of TxDPS–CVE
- TxDPS Troopers
- Linda Kirksey, Director – Vehicle Titles and Registration (VTR), and Tammera Parr-Lamb at TxDMV

2.3.1 Summary of TxDPS Interview

Table 2.9 lists the TxDPS interview questions.

Table 2.9: Questions for TxDPS

Weight Enforcement
1. Based on the information provided by TxDMV – the Texas Weight Enforcement Plan goal is for DPS to conduct 110,000 scale truck weight measurements, 10,000 semi-portable scale and 10,000 portable scale truck weight measurements annually. a. Is this data retained in a database or other record source? b. Would it be possible for CTR to obtain this data if we sign a confidentiality agreement? 2. We are interested in learning how to correctly measure truck weights using portable scales and to observe professionals performing truck weight measurements. a. Would it be feasible for one of CTR's research staff and a student to ride along with a DPS weight enforcement team to observe the process used to measure truck weights using portable scales? b. Would it be feasible for us to observe the semi-portable weight data collection process? c. Would it be feasible for us to observe the fixed weight station data collection process? We have reviewed the list of 57 fixed weigh station sites—are these all in rural areas or are some located in urban areas? 3. Based on your interactions with law enforcement officers nationally do SHVs (multi-axle dump trucks, ready-mix trucks or other types) present any issues in terms of OW axle or GVW operations or other issues? a. Can you suggest other state contacts that can advise about SHV operations? b. Does DPS have any specific reports or other information about SHV operations in Texas? c. Are you aware of any other states (law enforcement or DOTs) that have specific programs or studies under way regarding SHVs?
Safety
4. Was DPS aware that the Federal Highway Administration is requiring state DOTs to study SHV operations in their state to determine impacts to bridges and pavements? a. Has this topic been discussed during state, regional or national meetings of law enforcement officials? If so can you advise the location / dates of conferences? b. Has DPS considered SHV operations in Texas to be a focus area for enforcement issues? Have there been any meetings with trucking groups regarding these issues? c. Are you aware if any state agency has made special efforts to record the numbers of SHVs in operation? d. If it was found necessary to load post additional bridges or pavements due to SHV operations what impact would this have on DPS if any? 5. Has DPS observed any specific safety issues regarding SHV operations? a. Steering, braking or turning movements? b. Issues maintaining lane position in horizontal curves?

c. Is there a specific type of crash that is more common—such as truck over turning? 6. Can you provide any comments regarding the frequency or severity of SHV crashes? a. Is there a city or region in Texas that SHV crashes occur more frequently? b. Is there a particular trucking industry segment (dump trucks, ready-mix trucks, agriculture, oil field, etc.) that has a higher number of SHV crashes compared to other industry segments? c. Can you suggest other law enforcement contacts in Texas or nationally that are specifically knowledgeable about SHVs or SHV operations? 7. Are you aware if SHV drivers receive any special training prior to operating a multi-axle SU truck? a. Maxi dump trucks—also called Super 18s b. Multi-axle ready-mix trucks c. Does DPS specifically work with certain trucking industry groups / companies regarding SHV operational safety?
Operations
8. Regarding weight enforcement violations: a. Is it more common for an SHV to have all tires on the ground but one or more tires/axles is over loaded, or to have the lift axles up so that the fixed axles are over loaded? b. What types of truck maintenance problems has DPS seen with SHV trucks? Do SHVs appear to have any more frequent violations than typical three-axle trucks of the same type? c. When measuring the tire weight using a portable or other type scale, we understand that a violation occurs if the measured weight exceeds the tire load capacity rating printed on the side of the tire. d. Is there any allowance (% or number of lbs) given when making the decision to issue a citation? e. If there is an allowance, what is the basis—variations in equipment readings or other factors? 9. We have compiled a list of vehicle types that operate with additional lift axles or booster axles; these include: ▪ Dump trucks ➢ Sand, gravel stone ➢ Hot mix asphalt concrete ▪ Ready-mix trucks ▪ Garbage / recycling trucks ▪ Grain and other agricultural trucks ▪ Oil field trucks such as winch or vacuum trucks ▪ Sewer vacuum trucks ▪ Heavy duty wreckers ▪ Fuel / lube trucks Based on your experience are their other types of operations/companies that use trucks with liftable/booster axles? 10. Do you have any additional comments or suggestions for us?

Question 1:

TxDPS enforces the Bridge Formula by checking the different bridges (distance between different axles or axle groups). TxDPS checks every different combination of axle groups to ensure that the vehicle complies with the Bridge Formula. There are lift axle systems that do measure load and automatically deploy the axle; the HEB grocery store chain operates trucks with axles of this type, as do other industries (used for oilfield trucks, heavy equipment haulers, timber haulers, etc.).

TxDPS maintains a database of the weight enforcement records and have seven years of data on file. About 50,000 vehicles are weighed at roadside or fixed weigh stations each year; a weight enforcement officer uses a standard form to record the inspection results. TxDPS wanted to redact the name of the enforcement officer but could provide the research team with five years of data, which is approximately 250,000 records. This data set is comprised of vehicles of all types, including tractor-trailer rigs, three-axle dumps, ready-mix trucks, and SHVs. The TxDPS data set includes both TxDPS weight records and those of local law enforcement; however, TxDPS conducts the majority of the weight measurements. The data is public record.

The inspection report includes a diagram that the officer uses to designate the steering axle and load bearing axles. The single wheels are designated with an ‘X’, dual wheels with an ‘O’. The diagram will include the number and configuration of axles, and various dimensions (the criteria used for inspection includes tire ratings, axle spacings, the Federal bridge law, and whether the truck has a permit).

TxDPS did not know the type of weighing device that was used by local law enforcement to weigh trucks. Speculation was that most local law enforcement weight officers are using portable scales, but TxDPS does not know the type. Starting in 2017, the type of scales—including calibration and other measures—are available as the legislature deemed TxDPS responsible for oversight of all weight enforcement programs statewide, whether managed by local law enforcement or TxDPS. However, a data dictionary or manual is unavailable because the database system was developed internally. Data that was provided includes:

- **Location:** County, highway route (e.g., FM 2222)
- **Location 2:** Roadside or fixed scale
- **Vehicle Make:** Mack, Freightliner, Kenworth, etc.
- **Vehicle Year:** 2010, 1991, etc.
- **Gross Vehicle Weight Rating:** GVWR
- **Registered Gross Vehicle Weight:** GVW
- **Vehicle Configuration**: number and spacing of axles, tire weights/ratings, axle spacings expressed in bridge lengths
- **Vehicle Commodity:** gravel, ready-mix, etc.
- **License Plate Number:** for use in CRIS crash records search
- **VIN #:** for use in obtaining additional vehicle configuration data
- **Vehicle-Taken-Out-of-Service and Reason:** Major Nordloh indicated a vehicle would be taken out of service if the weight of a wheel exceeded the tire rating. In addition, if the enforcement officer believed the truck presented safety-related concerns (e.g., problems with brakes, load frame/bracket, etc.), the truck could be taken out of service.
- **Vehicle Trip Origin and Destination:** for use in determining the routes/areas of vehicle travel.
- **Comment Field:** The officer might provide additional information regarding the vehicle that does not fit an existing data cell.
- TxDPS does not record tire size, but they will record the tire rating if the tire is overloaded.

Question 2:

TxDPS offered to let the research team observe a TxDPS weight enforcement team as they measured truck weights using portable scales in the Austin area. TxDPS also offered to let the research team view the fixed weight station on IH 35 in New Waverly, which is a NAFTA weigh station open 40 hours a week that employs WIM technology. A visit to the Ysleta Border Safety Inspection Facility in El Paso, which sees about 500,000 commercial vehicle crossings a year and is a 24-hour state-of-the-art inspection facility was arranged. Eventually, a visit was made by research team members to the DPS weigh station on IH 10 at Kingsbury/Sequin in Guadalupe County.

Major Nordloh noted that the troopers who use the Haenni scales employ a 'blank,' which is a metal plate or a piece of plywood sheet the same size and thickness of the Haenni scale. The officers place the plate or plywood sheet under the tires on the opposite side of the axle when doing a weight measure to ensure the axles are at the same height.

Question 3:

Major Nordloh noted that SHVs are not a major topic for law enforcement, and they do not focus on SHVs specifically. He did not note any other state contacts regarding SHVs.

Question 4:

TxDPS was not aware that the Federal Highway Administration is requiring state DOTs to study SHV operations in their state to determine impacts to bridges and pavements. It has not been discussed at any state, regional, or national meetings of law enforcement officials, nor with trucking groups. TxDPS did not know of any state agencies that had made special efforts to record SHV operations. They do not have a specific vehicle code for SHVs, nor do they track or count them. There were no specific concerns about SHVs in particular. TxDPS is most concerned about the accuracy of the measurement of weight data.

Question 5

SHV-involved crashes are not a major concern as they are rare. In about 80% of the crashes that involve a commercial motor vehicle, it was the passenger vehicle that caused the crash. When the crash is due to the commercial motor vehicle, it is almost always attributed to driver errors (i.e., distracted, on a cell phone, eating while driving, fatigued, aggressive, impaired, etc.). The heavier a truck is, the longer it will take to stop. No issues regarding maintaining lane position in horizontal curves have arisen or no specific type of crash was identified as more common.

Question 6

In reviewing the frequency and severity of SHV crashes, Major Nordloh noted that crashes happen where you have high traffic volumes with cars and trucks operating together. An example is IH 35—with high volumes of both trucks and cars as well as stop-and-go operations, crashes are going to happen. Other locations include areas where oil field traffic operates, such as the Permian Basin and the Eagle Ford Shale region. Metropolitan areas in general present more opportunities for crashes, such as in the Texas Triangle (the route between Houston, Dallas/Ft. Worth, and Austin/San Antonio. This is where most of the traffic operates and most of the crashes occur. The IH-10/IH-20 interchange in West Texas at Pecos has always been a hot spot, Major Nordloh reported.

TxDPS has only 500 weight enforcement officers for the 254 counties in Texas. TxDPS has been directed to focus resources along the Texas-Mexico border, which further complicates covering the entire state. Other issues they face are difficulties in posting officers to areas lacking housing or jobs for spouses. One example is Ochiltree County in the Panhandle: TxDPS has a difficult time posting officers there because there is no housing available or jobs for spouses. It might be two weeks before a trucker sees a TxDPS trooper in that area of the state.

To address this issue TxDPS conducts several task force initiatives a year, during which they send several officers to counties where they cannot post officers full-time and spend a few weeks weighing trucks. They often have to place up to 50% of trucks out of service due to maintenance issues or other violations. During the cotton harvest in south Texas, it is not uncommon to weigh trucks that are 4,000 lbs to 6,000 lbs over the weight limit.

Question 7:

Major Nordloh noted that the oil field sector has been a focus due to high numbers of heavy trucks mixed with cars. He could not think of any specific operational types for SHVs. SHV drivers typically obtain a commercial driver's license (CDL) Type B. There is no special training required for SHV operators by the state.

> **Note:** TxDPS Commercial Driver's Handbook (page i) provides definitions for three types of CDL licenses in Texas:
>
> - **Type A:** Combination Vehicles with a GVW rating (GVWR) of 26,001 lbs or more or towing a vehicle with a weight rating that exceeds 10,000 lbs.
> - **Type B:** Single Vehicles with a GVWR of 26,001 lbs or more or any one of those vehicles towing a vehicle that exceeds 10,000 lbs; busses under 26,001 lbs unless a skills test is taken.
> - **Type C:** Any type of vehicle or combination of vehicles that are not in Class A or B and if the vehicle is designed to transport 16–23 passengers (including the driver), or transports hazardous waste.

Question 8:

Major Nordloh noted that certain violations—e.g., the lift axle was up—sometimes occur because the driver had forgotten to lift/lower the axle. Major Nordloh thought that if an SHV is operating with its lift axles in the air and is OW, the enforcement officer will draw the vehicle configuration, including the lift axles that were up. He noted that the research team could look for this when we examined the data. He suggested we look to the comments section of the inspection report to see if this was notated.

Maintenance problems with SHVs did not fall into any specific categories. Major Nordloh noted that trucks that operate on rough roads have more maintenance problems. As an example, logging trucks have wires that come loose so that not all lights are working when they are pulled over—the same is true for truckers working in the oil patch. A rough road can shake a hose clamp loose. There is also a correlation between maintenance problems and the fleet size of a carrier. For example, a truck driven by an owner-operator is likely to have more maintenance problems than a truck owned and maintained by a large trucking company not because of its size, but because of the investment large companies commit to their safety program(s).

In measuring the tire weight using a portable or other type scale, the research team believed that a violation occurs if the measured weight exceeds the tire load capacity rating printed on the side of the tire. We asked if there was an allowance (whether a percentage or number of lbs) given when making the decision to issue a citation. Major Nordloh stated that "Our goal is not to be ‘right;’ our goal is to be ‘accurate’ with our weight measurements. We do not want to issue a citation if a trucker is operating within legal limits.”

A follow-up question to this was if there is an allowance, what is the basis—variations in equipment readings or other factors? Major Nordloh noted it was at the enforcement officer’s discretion, but TxDPS uses a 1,000 lb weight tolerance. There are different laws or rules that are taken into consideration. If a truck has a tire load that exceeds the manufacturer’s rating, the truck is taken out of service. If the axle is above the legal limit, the 1,000 lb tolerance will be applied—as it will for GVW.

Question 9:

Finally, Major Nordloh noted that we had named most types of trucks that operate with lift axles. The only other truck types TxDPS sees are heavy haul trucks/permitted trucks that often have lift axles (though not a type of SHV); cranes are another type of vehicle that may have liftable axles.

2.3.2 Summary of TxDMV Interviews

Table 2.10 lists the general TxDMV interview questions.

Table 2.10: Question for TxDMV

Commercial Vehicles – Registration Information
1. We need vehicle registration data to estimate the number of dump trucks, ready-mix trucks and other types of SU and tractor trailer units that are registered in Texas and in each county. This data is necessary to help ensure we have a statistically valid sample of each vehicle type when we conduct field data collection activities to know the number of SHVs operating in Texas. a. We want to request this Commercial Motor Vehicle registration data from TxDMV. How should we proceed? b. Does TxDMV require a CMV registrant to specify the number of axles that a vehicle has? c. Does TxDMV require a registrant to specify the number of liftable or boost axles that a vehicle has when registering a vehicle? 2. Based on data obtained in 2010 during the Rider 36 Study, we are unsure of the types of vehicles included in some categories: a. Does the registration category 'dump trucks' include both SU (straight) trucks and dump trailers? If so, is it possible to separate these two types of vehicles in the registration data set? b. Does TxDMV use sub-categories for Oil Field Equipment when registering the vehicle (such as Vacuum truck, Hot Oil Unit, Winch Truck etc.)? If so, is it possible to separate these different vehicles in the registration data set? c. Who makes the determination if a truck is oil field equipment or not when it is being registered? d. What is considered to be a Soil Conservation Vehicle? e. VTR-52B is an application for out of state residents to move agricultural products. Would it be possible to obtain a data set of the non-confidential data contained in the forms including the origin / destination and/or routes used? f. What is the purpose of the form 'Application for Seasonal Agricultural Registration' VTR 626'? g. Can a farm vehicle be registered in excess of the manufacturer's gross vehicle weight rating during the harvest? h. Is there information of silos location were agricultural trucks collect the products? i. Is there information on whether they take the products to the final destination or to the nearest freight train? j. TxDMV provides a fee chart for vehicle registration based on weight: → 10,001-18,000 lbs. $110.00 → 18,001-25,999 lbs. $205.00 → 26,000-40,000 lbs. $340.00 → 40,001-54,999 lbs. $535.00 → 55,000-70,000 lbs. $740.00 → 70,001-80,000 lbs. $840.00 → Over 80,000 lbs. Varies Would it be possible to obtain a data set of the number of registered vehicles in each of these categories for each county in Texas?
Oversize/Overweight Permits
3. We would like to request OS/OW permit data from 2011 to 2015. This data will be examined to identify SHVs operating with a permit. a. What steps should be taken to request this OS/OW data? b. We have reviewed a selection of OS/OW data from 2009 and found that it may possible to use the vehicle type (e.g., truck crane), the axle weights, spacings, and tire information to identify SHVs. Does TxDMV require a permit purchaser to identify liftable or booster axles when purchasing a permit?

c. When considering the allowable gross vehicle weight for an axle group based on the Federal Bridge Formula, does TxDMV differentiate between a fixed axle group and an axle group that combines fixed and liftable axles? d. What advantage do OS/OW SU trucks gain by operating with liftable or booster axles? e. Can you suggest vehicle types we might not yet have identified that operate with liftable or booster axles? f. Is it permissible / legal for a SU truck with additional liftable or booster axles to operate loaded on the Interstate due to increased numbers of axles in the axle group, or larger outer bridge length?
Commercial Motor Vehicle Enforcement
4. Has TxDMV conducted investigations of companies that operate SHVs specifically because of OW citations for SHVs? a. Repeated failures to lower liftable or booster axles when loaded. b. Inoperable liftable or booster axles. 5. If so, is it possible for us to request a copy of the investigation reports if we sign a confidentiality agreement with TxDMV? 6. Do you think SHVs are more likely to operate in large metropolitan areas than in smaller urban or rural areas? 7. Other issues that you have observed or identified?
Proposed / Future Legislation regarding truck size and weight
8. During the last legislative session House Bill 2592 addressed increased allowable gross vehicle weights for ready-mix trucks: (1) 69,000 lbs if the truck has three axles; (2) 70,100 lbs if the truck has four axles; (3) 70,500 lbs if the truck has five axles; (4) 75,500 lbs if the truck has six axles; or (5) 80,000 lbs if the truck has more than six axles. Though this bill did not move forward for a vote, it is anticipated that the bill be reintroduced during the next legislative session. Based on our review of ready-mix trucks for sale in Texas, the mixer drum capacity of three-axle trucks typically ranges from 10 CY, 10.5 CY and 11 CY. The mixer drum capacity of an SHV ready-mix truck is typically 11 CY and rarely 12 CY. Since there does not appear to be a productivity gain through increased product carrying capacity, can you comment why you think this bill is desirable to the ready-mix industry? a. House Bill 2060 proposed a new type of permit for Oil Well Servicing Vehicles that would have allowed a permit for an unescorted vehicle to travel statewide with loads up to 135,000 lbs GVW. b. New and used Oil Well Servicing Units in this weight class operate with liftable axles. Can you comment about why this permit would be of interest to the oil industry? c. Are you aware of other types of commodities or truck operational types that operate with liftable or booster axles that may lobby the legislature for new draft / proposed legislation? d. Are you aware of any specific locations or routes that have been discussed with regard to this draft legislation?

The research team met with TxDMV in December 2015. TxDMV personnel in attendance included Noemi Harvell (Texas OW management plan), Tracy Stafford (Enforcement Division – transportation investigator), Philip Pettit (Enforcement Division – section director), Kristy Schultz (MCO – program specialist), Scott McKee (OS/OW permit section director), and Linda Poole (program specialist).

Question 1:

TxDMV noted that the research team should contact Vehicle Title and Registration Division (VTR) to request data. TxDMV stated that they cannot identify vehicle type based on registration data. Axle numbers are not included in the registration data. The vehicle types of interest to this project probably will fall into one registration category: “Truck.” TxDMV does not require a commercial vehicle registrant to specify the number of axles, including any liftable or boost axles that a vehicle has.

Question 2:

The research team noted that they were unsure of the types of vehicles included in some categories; TxDMV commented that based on the numbers provided, the data obtained so far for the project was based on the bond data.

The registration category “Dump Trucks” does not separate out the two types of dump trucks. In addition, TxDMV does not use subcategories for oil field equipment when registering the vehicle (such as vacuum truck, hot oil unit, winch truck, etc.). They collect data only on weight, not on number of axles.

For agricultural trucks, TxDMV noted that they do not have data on where the trucks run, as these are mostly on a 1547 permit, which is non-routed.

Question 3:

Data requests on OS and OW permits require an open records request.

Question 4 and 5:

TxDMV conducts investigations of companies operating SHVs that have OW citations. They do not, however, have data on the ‘extra’ axles. If the research team wanted to request copies of the investigation reports, we’d have to identify companies. In conducting investigations, TxDMV noted that many carriers are retrofitting the drop axles (waste haulers, specifically). In many instances, for a fleet running on manufacturer specifications, it is hard for TxDMV to conduct enforcement and gather data. They are working with the TxDPS list, which is based on a stop conducted by a trooper, and so this is not a ‘statistically’ driven set of data. They noted that the trucks may not run with boosters down to save tread, and for other reasons. These trucks may have a permit but may not be running legally. Much of TxDMV’s business involves “taking people at their word.” For the concrete industry, if they follow standards, they are essentially OW automatically, so it’s hard for them to actually be legal.

Question 6:

TxDMV agreed with the research team’s supposition that SHVs are more likely to operate in large metropolitan areas than in smaller urban or rural areas. They again noted that no records of number of axles are kept.

Question 7:

Other issues that TxDMV have observed or identified included:

- TxDMV works with companies that are out of compliance to develop a plan and measures for a company to get back into compliance. However, it is the company's responsibility to implement the plan and become compliant – though the majority of trucking companies are cooperative, some do not cooperate in developing a plan or becoming compliant.
- The wider the track (axle gage) width, the heavier the weight a truck is permitted to carry. The impact is not significant compared with the influence by the number of axles or axle spacing. The formula for calculating allowable axle load based on gage width is contained in
- TxDMV noted that they expected some of the bills that were introduced in the last legislative session could be reintroduced again.

Table 2.11 lists the interview questions for an interview with TxDMV's Linda Kirksey.

Table 2.11: Questions for TxDMV's Linda Kirksey

Commercial Vehicles – Registration Information

1. We need vehicle registration data to estimate the number of dump trucks, ready-mix trucks and other types of SU and tractor trailer units that are registered in Texas and in each county. This data is necessary to help ensure we have a statistically valid sample of each vehicle type when we conduct field data collection activities to know the number of SHVs operating in Texas.
    a. We want to request this Commercial Motor Vehicle registration data from TxDMV. How should we proceed?
    b. Does TxDMV require a CMV registrant to specify the number of axles that a vehicle has?
    c. Does TxDMV require a registrant to specify the number of liftable or boost axles that a vehicle has when registering a vehicle?
2. Based on data obtained in 2010 during the Rider 36 Study, we are unsure of the types of vehicles included in some categories:
    a. Does the registration category 'dump trucks' include both SU (straight) trucks and dump trailers? If so, is it possible to separate these two types of vehicles in the registration data set?
    b. Does TxDMV use sub-categories for Oil Field Equipment when registering the vehicle (such as Vacuum truck, Hot Oil Unit, Winch Truck etc.)? If so, is it possible to separate these different vehicles in the registration data set?
    c. Who makes the determination if a truck is oil field equipment or not when it is being registered?
    d. What is considered to be a Soil Conservation Vehicle?
    e. VTR-52B is an application for out of state residents to move agricultural products. Would it be possible to obtain a data set of the non-confidential data contained in the forms including the origin / destination and/or routes used?
    f. What is the purpose of the form 'Application for Seasonal Agricultural Registration' VTR 626'?
    g. Can a farm vehicle be registered in excess of the manufacturer's gross vehicle weight rating during the harvest?
    h. Is there information of silos location were agricultural trucks collect the products?
    i. Is there information on whether they take the products to the final destination or to the nearest freight train?
    j. TxDMV provides a fee chart for vehicle registration based on weight:
        i. 10,001-18,000 lbs. $110.00
        ii. 18,001-25,999 lbs. $205.00
        iii. 26,000-40,000 lbs. $340.00
        iv. 40,001-54,999 lbs. $535.00
        v. 55,000-70,000 lbs. $740.00
        vi. 70,001-80,000 lbs. $840.00
        vii. Over 80,000 lbs. Varies
3. Would it be possible to obtain a data set of the number of registered vehicles in each of these categories for each county in Texas?

Oversize/Overweight Permits

4. We would like to request OS/OW permit data from 2011 to 2015. This data will be examined to identify SHVs operating with a permit.
    a. What steps should be taken to request this OS/OW data?

b. We have reviewed a selection of OS/OW data from 2009 and found that it may possible to use the vehicle type (e.g., truck crane), the axle weights, spacings and tire information to identify SHVs. Does TxDMV require a permit purchaser to identify liftable or booster axles when purchasing a permit?
c. When considering the allowable gross vehicle weight for an axle group based on the Federal Bridge Formula, does TxDMV differentiate between a fixed axle group and an axle group that combines fixed and liftable axles?
d. What advantage do OS/OW SU trucks gain by operating with liftable or booster axles?
e. Can you suggest vehicle types we might not yet have identified that operate with liftable or booster axles?
f. Is it permissible / legal for a SU truck with additional liftable or booster axles to operate loaded on the Interstate due to increased numbers of axles in the axle group, or larger outer bridge length?

Commercial Motor Vehicle Enforcement

5. Has TxDMV conducted investigations of companies that operate SHVs specifically because of OW citations for SHVs?
   a. Repeated failures to lower liftable or booster axles when loaded.
   b. Inoperable liftable or booster axles.
6. If so, is it possible for us to request a copy of the investigation reports if we sign a confidentiality agreement with TxDMV?
7. Do you think SHVs are more likely to operate in large metropolitan areas than in smaller urban or rural areas?
8. Other issues that you have observed or identified?

Proposed / Future Legislation regarding truck size and weight

9. During the last legislative session House Bill 2592 addressed increased allowable gross vehicle weights for ready-mix trucks:
   (1) 69,000 lbs if the truck has three axles;
   (2) 70,100 lbs if the truck has four axles;
   (3) 70,500 lbs if the truck has five axles;
   (4) 75,500 lbs if the truck has six axles; or
   (5) 80,000 lbs if the truck has more than six axles.

   Though this bill did not move forward for a vote, it is anticipated that the bill be reintroduced during the next legislative session. Based on our review of ready-mix trucks for sale in Texas, the mixer drum capacity of three-axle trucks typically ranges from 10 CY, 10.5 CY and 11 CY. The mixer drum capacity of an SHV ready-mix truck is typically 11 CY and rarely 12 CY. Since there does not appear to be a productivity gain through increased product carrying capacity, can you comment why you think this bill is desirable to the ready-mix industry?
   a. House Bill 2060 proposed a new type of permit for Oil Well Servicing Vehicles that would have allowed a permit for an unescorted vehicle to travel statewide with loads up to 135,000 lbs GVW. New and used Oil Well Servicing Units in this weight class operate with liftable axles. Can you comment about why this permit would be of interest to the oil industry?
      b. Are you aware of other types of commodities or truck operational types that operate with liftable or booster axles that may lobby the legislature for new draft / proposed legislation?
      c. Are you aware of any specific locations or routes that have been discussed with regard to this draft legislation?

TxDMV VTR agreed to provide the research team with vehicle registration data by body style by county dated December 2015. However, vehicles are classified according to weight. Axle specifications are typically not available. The Motor Carrier Division might provide more information. TxDMV does not require a registrant to specify the number of liftable or boost axles that a vehicle has when registering a vehicle.

Dump trucks would likely be SU dump trucks, according to TxDMV. TxDMV does not use subcategories for oil field equipment when registering the vehicle (such as vacuum truck, hot oil unit, winch truck etc.). TxDMV classifies trucks only in general categories (e.g., Oil Field). The determination of the truck use is based on the information provided by applicants. TxDMV does not verify the information.

The form "Application for Seasonal Agricultural Registration" (VTR-626), submitted for trucks that will "transport a seasonal agricultural product," includes any transportation activity necessary for the production, harvest, or delivery of an agricultural product that is produced seasonally. A special permit plate will not be issued. Qualifying vehicles will display standard license plates.

The research team asked that whether a farm vehicle can be registered in excess of the manufacturer's GVWR during the harvest. TxDMV noted that more research would need to be done to obtain this information.

TxDMV would provide a data set on the number of registered vehicles by the weight chart. However, the research team would need to specify the body styles of interest. We will estimate the time that is needed to extract the information.

These follow-up questions were emailed after the initial interview:

a) We see that the data is dated as of December 2015. We wanted to clarify if this means that the data is a record of all vehicles registered in Texas, of the types listed, as of December 2015?
Yes, this represents the total number of vehicles for each body style.

b) Is this truck registration data (by body style type) available for each month of 2015? We would like to determine how the numbers of registered trucks of a specific type might vary over the year.
This would require ad hoc programming and a fee to be assessed. Before I move forward with the estimate I want you to be aware of not only a cost for the report, but it would have to be prioritized with other requests and could take several weeks. Please advise if you would like for me to get the level of effort and cost for this request.

c) Are the numbers of grain trucks listed only for Texas trucks registered in Texas or do they also include out-of-state trucks that obtain a temporary registration to operate in Texas during the harvest?
The number in the report only includes those registered in Texas.

d) Is data available for temporary truck registration in Texas? If yes, we would like to request that data for agricultural trucks.
This would require ad hoc programming and a fee to be assessed. Before I move forward with the estimate I want you to be aware of not only a cost for the report, but it would have to be prioritized with other requests and could take several weeks. Please advise if you would like for me to get the level of effort and cost for this request.

e) Does TxDMV issue temporary truck registrations by county?

Not certain I understand this question. Are you referring to Seasonal Ag Registration? Non-Resident Ag Permit?
Both types mentioned are issued by a county tax office; however, operation is not limited to a particular county. Please clarify the question to ensure we provide an accurate response.

f) Does TxDMV have a database of registration requests to temporarily increase the allowable GVWR from, say, 60,000 lbs to 80,000 lbs? If yes, we would like to request this temporary GVWR increase registration data to have a better idea of how many grain and other types of agricultural trucks operate in Texas during the harvest.
This is a huge request and may not be possible. However, if it is possible this would require ad hoc programming and a fee to be assessed. Before I move forward with the estimate I want you to be aware of not only a cost for the report, but it would have to be prioritized with other requests and could take several weeks. Please advise if you would like for me to get the level of effort and cost for this request.

2.3.3 Summary of Field Trip to the TxDPS Kingsbury/Seguin Weight Enforcement Scale Site

A team of CTR researchers visited the TxDPS Kingsbury/Seguin Scale Site in Guadalupe County (IH 10, Mile Marker 621) on February 12, 2016, to gain experience in using portable scales to measure the weight of trucks. At the site, the research team met with TxDPS officers Sergeant Oscar Garza and Trooper Jeff Sones; two other officers were present as well. The team got firsthand experience in using portable scales (Haenni scales) to weigh trucks, and observed how TxDPS officers conduct commercial vehicle weight enforcement operations at a scale site. The team prepared a set of questions for the TxDPS officers regarding truck weight measurement, and the team was able to gain valuable insights from the TxDPS officers' responses to those questions. In addition, Sergeant Oscar Garza gave the CTR team a presentation on weight laws in Texas; the presentation contained information on the maximum allowable weights, and associated penalties or fines. Table 2.12 lists the interview questions for the TxDPS officers.

Table 2.12: Questions for TxDPS officers

Collection of truck weight data
1. How long have you been involved in collecting truck weight data using portable scales? 2. How long did it take (days, weeks, months) or (how many trucks did you have to weigh) before you felt proficient collecting truck weight data? 3. What type of formal training did you receive in performing truck weight measurements using portable scales? 4. Can you advise what types of truck features you look for when choosing to weigh a truck or not? (e.g., tire bulge, flatbed trailer sways downward, fender to top of tire gap etc.) 5. What weight tolerance do you use when weighing a truck before you say a tire or axle is overloaded? a) How (and why) was this tolerance determined? b) How often are DPS portable scales calibrated? Who performs the calibration? 6. Is there any error associated with taking truck weight measurements using portable scales that you are aware of? If yes, what are the potential causes of this error?
Truck axle configuration and truck maintenance conditions data
7. Besides truck tire and axle weight information, what type of information (if any) do you collect on truck axle configuration and spacing? 8. How do you determine if axles are part of a group or split? (For example, an SU4 SHV could be described as X--XOO, X----OO, or X----O—O) Do you use some threshold axle spacing to make that distinction? (Literature suggests an 8 ft spacing) 9. What type of information (if any) do you collect on truck maintenance conditions when a truck is pulled over for a weight enforcement check?
Pavement conditions
10. What specific pavement site conditions do you look for when selecting a site to weigh a truck? (This question has to do with weight accuracy, not safety). 11. Are there pavement site conditions you would not use to weigh a truck? (This question has to do with weight accuracy, not safety). 12. Do you collect other types of data to help you determine if the pavement site might have an effect on the truck weight?
Specific types of trucks (such as trucks with liftable axles)
13. Are there specific types of trucks you think are more likely to be OW? (dump trucks, ready-mix, garbage, oil field trucks, flat beds, box vans etc.). 14. Do you pay any particular attention to trucks that have liftable axles when selecting trucks to weigh? 15. When you take weight measurements of a truck with liftable axles, and the axles were up when you pulled the truck over, do you collect weight measurements with the axles up and with the axles down to determine if the truck would have been legal if the axles were down? 16. If the truck with liftable axles is overloaded and the axles were up, do you ask the driver why he did not have the axles down?
Oversize and overweight permits
17. Do you ask to see OS/OW permit(s) the trucker might have purchased? If the truck has one or more permits, do you record this in the weight enforcement record?

Following are their responses to the interview questions.

Question 1: Trooper Jeff Sones had worked for TxDPS for 41 years and been with DPS-CVE for 15 years. Sergeant Oscar Garza has worked for DPS-CVE for about 20 years.

Question 2: TxDPS requires formal training before any trooper can work on site.

Question 3: TxDPS officers undergo CVE training, which takes about 6 weeks.

Question 4: Troopers noted they look for items mainly based on experience—this includes the location of the hump of the materials in a dump truck and water leaking out of a truck, which can indicate that the driver loaded too much water.

Question 5: A 1000-lb tolerance is used. Weight readings are rounded off to the nearest 10 or 50 lbs. Readings from weight scales fixed in the pavement are rounded off to the nearest 10 lb. Readings from portable scales are rounded off to the nearest 50 lb. Readings are always rounded down. In addition, when both fixed and portable scales are used to weigh the same truck, the lower weight reading among the two is used to judge if the truck is OW. The portable scales are annually calibrated by TxDPS officers who are in change of scale calibration.

Question 6: The troopers report what is read from the scales. When TxDPS weighs trucks, a level surface is chosen. One criteria for choosing the pavement surface to weight trucks is that the surface should not damage the portable scales. For example, a gravel surface would not be used to weigh trucks using portable scales as excessive bending due to unbound pavement can damage the portable scales. For trucks carrying liquids, officers wait for the weight on each axle to stabilize on the scale. Officers ensure that the tires whose weight is to be measured are on the scales.

Question 7: The officer observes the truck and if they notice a short axle spacing, they measure the axle group spacing and compare that with the bridge formula to judge if the truck violates the weight limits based on the formula.

Question 8: The officer noted that they use "X(10240)--O(25380)--OO(31020)" to indicate the weight of the axle or axle group.

Question 9: Officers check the brakes of the truck, among other conditions.

Question 10: A level surface is chosen. One criteria is that the surface should not damage the portable scales. A hard surface is chosen.

Question 11: Sites with a large slope would not be used. Also, a surface with too many aggregates, such as gravel, is not used to weigh trucks using portable scales because materials such as gravel could damage the scales.

Question 12: not answered

Question 13: They do not use truck type as a criterion to make judgments if a truck is OW or not.

Question 14: No. Selection of trucks is based on prior experience, and visible signs of overloaded material in the truck.

Question 15: TxDPS weighs the truck in the state that it is in when it drives into the weighing station site (with lift axles up or down).

Question 16: Yes. Even if the driver says that he forgot to put the liftable axles down, the driver would still get a ticket if his truck is OW because he may have been driving with the axles up for a long distance and that would have already caused damage to the pavement surface.

Question 17. Yes. Typically, the drivers are supposed to have the OS/OW permits (if they have any) displayed in the windshields of their trucks.

2.4 Review of Reports and Journal Articles

Table 2.13 and Table 2.14 list the reports and journal articles studied in this research project. Appendix A and B summarize the major findings and conclusion from each individual report and journal article.

Table 2.13: Summary of reports

Report		Author	Year
1	Guide for Maximum Dimensions and Weights of Motor Vehicles and for the Operation of Non-Divisible Load Oversize and Overweight Vehicles	AASHTO	1987
2	Manual for Condition Evaluation of Bridges (MCE)	AASHTO	1994
3	An Evaluation of the Lift Axle Regulation in Washington	Washington State Transportation Center	1994
4	NCHRP Report 368: Calibration of LRFD Bridge Design Cod	Nowak, A.S.	1999
5	Truck Characteristics Analysis	FHWA	1999
6	Comprehensive Truck Size and Weight Study, Volumes I-III.	USDOT	2000
7	NCHRP Report 454: Moses, F. Calibration of Load Factors for LRFR Bridge evaluation	Moses, F.	2001
8	Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges	AASHTO	2003
9	NCHRP Report 495: Effect of Truck Weight on Bridge Network Costs	Fu, G.	2003
10	NCHRP 575: Legal truck loads and AASHTO legal loads for posting	Sivakumar, B.	2007
11	Examine Impact to Highways/Structures–Vehicles Equipped with Lift Axles (No. MD-11-SP009B4K)	Fu, C and Moffatt, T.A.	2011
12	NCHRP 683: Protocols for collecting and using traffic data in bridge design	Sivakumar, B., Ghosn, M. and Moses, F.	2011
13	NCHRP 700: A comparison of AASHTO bridge load rating methods.	Mlynarski, M., Wagdy G. Wassef, W.G. and Nowak, A. S.	2011
14	Review of Load Rating and Posting Procedures and Requirements	Bowman, M.D. and Chou, R.N.	2014
15	Side by Side Probability for Bridge Design and Analysis (RC-1601)	Eamon, C.D., Kamjoo, V. and Shinki, K.	2014

Table 2.14: Summary of journal articles

Journal Article: Authors, Title, Journal, Year, Page	
1	Sebaaly, Peter E., and Nader Tabatabaee. “Effect of tire parameters on pavement damage and load-equivalency factors.” Journal of Transportation Engineering 118.6 (1992): 805-819
2	Nowak, Andrzej S. “Live load model for highway bridges.” Structural safety13.1 (1993): 53-66.
3	Gillespie, Thomas D. Effects of heavy-vehicle characteristics on pavement response and performance. No. 353. Transportation Research Board, 1993
4	Nowak, Andrzej S. “Load model for bridge design code.” Canadian Journal of Civil Engineering 21.1 (1994): 36-49
5	1.4.1 Hewitt, Julie, et al. “Infrastructure and economic impacts of changes in truck weight regulations in Montana.” Transportation Research Record: Journal of the Transportation Research Board 1653 (1999): 42-51
6	Laman, Jeffrey, and John Ashbaugh. “Highway network bridge fatigue damage potential of special truck configurations.” Transportation Research Record: Journal of the Transportation Research Board 1696 (2000): 81-92
7	Hajek, Jerry, and John Billing. “Trucking trends and changes that affect pavements.” Transportation Research Record: Journal of the Transportation Research Board 1816 (2002): 96-103.
8	Salama, Hassan K., Karim Chatti, and Richard W. Lyles. “Effect of heavy multiple axle trucks on asphalt pavement damage.” Proc., 8th Int. Symp. on Heavy Vehicle Weights and Dimensions. 2004.
9	Chatti, Karim, and Chadi El Mohtar. “Effect of different axle configurations on fatigue life of asphalt concrete mixture.” Transportation Research Record: Journal of the Transportation Research Board 1891 (2004): 121-130
10	Al-Qadi, Imad L., et al. “Effects of tire configurations on pavement damage. Journal of the Association of Asphalt Paving Technologists 74.1 (2005): 921-961
11	Salama, Hassan K., Karim Chatti, and Richard W. Lyles. “Effect of heavy multiple axle trucks on flexible pavement damage using in-service pavement performance data.” Journal of Transportation Engineering 132.10 (2006): 763-770
12	Fortowsky, J., and Jennifer Humphreys. “Estimating traffic changes and pavement impacts from freight truck diversion following changes in interstate truck weight limits.” Transportation Research Record: Journal of the Transportation Research Board 1966 (2006): 71-79
13	Salama, Hassan, and Karim Chatti. “Evaluating flexible pavement rut damage caused by multiple axle and truck configurations.” Proceedings 9th International Symposium on Heavy Vehicle Weights and Dimensions. Pennsylvania, 2006.
14	Guzda, Mark, Baidurya Bhattacharya, and Dennis R. Mertz. “Probabilistic characterization of live load using visual counts and in-service strain monitoring.” Journal of Bridge Engineering 12.1 (2007): 130-134
15	Oh, Jeongho, E. G. Fernando, and R. L. Lytton. “Evaluation of damage potential for pavements due to overweight truck traffic.” Journal of transportation engineering 133.5 (2007): 308-317
16	Haider, Syed Waqar, and Ronald S. Harichandran. “Relating axle load spectra to truck gross vehicle weights and volumes.” Journal of transportation engineering 133.12 (2007): 696-705
17	1.4.2 Chatti, Karim, Anshu Manik, and Nicholas Brake. “Effect of axle configurations on fatigue and faulting of concrete pavements.” 10th International Symposium on Heavy Vehicle Transport Technology. Paris, Francia. 2008
18	1.4.3 Tirado, Cesar, et al. “Process to estimate permit costs for movement of heavy trucks on flexible pavements.” Transportation Research Record: Journal of the Transportation Research Board 2154 (2010): 187-196
19	Zhao, Jian, and Habib Tabatabai. “Evaluation of a permit vehicle model using weigh-in-motion truck records.” Journal of Bridge Engineering 17.2 (2011): 389-392

20	Obrien, Eugene J., Bernard Enright, and Cathal Leahy. "The effect of truck permitting policy on US bridge loading." (2013)
21	Muthumani, Anburaj, and Xianming Shi. "Impacts of Specialized Hauling Vehicles on Highway Infrastructure, the Economy, and Safety: Renewed Perspective." Environmental Sustainability in Transportation Infrastructure@ Selected Papers from the International Symposium on Systematic Approaches to Environmental Sustainability in Transportation. ASCE, 2015

2.5 Review of Canadian and Mexico Statutes and Laws

Canada and Mexico both allow for heavier trucks, as well as long combination vehicles. However, their statutes and regulations are different compared to those of the U.S.

2.5.1 Mexico

A review of Mexico's laws and regulations revealed no references to liftable axles, or the types of trucks that have these axles. Mexico allows trucks to run heavier and longer than the U.S. They have identified all routes in their network and categorized these, and allow certain routes to be used by heavier vehicles.

2.5.2 Canada

Canada, like Mexico, allows for heavier and longer vehicles to run on their network, and they also have a series of identified heavy haul corridors. Vehicle size and weight statutes of Canadian provinces were reviewed. As Table 2.15 shows, there are very few references in the provinces' statutes to liftable axles. The research team's review found that SHV type trucks are not readily identifiable as a 'managed' type of vehicle in the statutes, regulations, and truck size and weight manuals of the Ministry of Transportation. In addition, British Columbia has a different bridge formula. Another major difference with Canada's permitting system and OS/OW truck routing is the major role that the freeze-thaw cycle plays in defining specific routes for trucks.

Table 2.15: Canada's provincial statutes and regulations

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
British Columbia	"Has specific language in Division in 7.11 regarding lift axles. These cannot be operated by a person(i) without a permit unless the control locks or (a) the control locks or unlocks a sliding fifth wheel coupler, (b) the vehicle is a ready mix concrete truck and the control is manually operated and located outside the driver compartment and immediately adjacent to the axle or group of axles being affected, or (c) the control is an automatic axle lift device that i) was installed on the trailer by (A) the original trailer manufacturer, or (B) an installer working under the supervision of, and according to an installation plan developed by, a professional engineer, and (ii) is equipped with tamper-resistant features to prevent unintended field adjustments, and the trailer on which it is installed (iii) has affixed on each side, near the affected axles, a unique logo indicating that an automatic axle lift device is installed on the trailer, and (iv) is equipped with an on/off control to operate the automatic axle lift device and with a status light visible from the cab to indicate to the driver when the device is activated. (2) A person must not, without a permit, drive or operate a vehicle or vehicle combination with lift axles in contact with the ground if the vehicle is (a) not also equipped with an automatic lift axle that meets the requirements set out in subsection (1) (c) (i) and (ii), or (b) a pole trailer. In addition, Division 7.12 requires that a person cannot without a permit drive or operate a vehicle with a self-steering axle if the tires of the self-steering are in contact with the ground unless the vehicle is a tandem drive ready mix concrete truck equipped with a self-steering booster axle, or is a jeep, and A or C converter dolly or full trailer, and the steering axle is in the front axle group. Legal weight, according to the Heavy Haul Overweight Guidelines and Permits chapter of the Commercial Transport Procedures Manual, for a single axle (other than steering axle and jeeps and boosters) is 9100 kg. Permitted heavy haul loads allow up to 28,000 kg for a tridem booster axle with axle spacing between 2.4 m to 3.1 m for a tridem lowbed). A Tridem trailer is allowed at 28,000 kg with 2.4 m to 3.7 m axle	30 x Wheelbase (cm) + 18,000 = maximum permissible weight in kilograms	Commercial Transport Regulations B.C. Reg. 30/78. O.C. 27/78 Commercial Transport Procedures Manual: Chapter 6 Heavy Haul Overweight Guidelines and Permits, Extraordinary Loads Manual	http://www.bclaws.ca/civix/document/id/complete/statreg/30_78#section7.12 http://www.th.gov.bc.ca/cvse/ctpm/Chapter_6.pdf http://www.th.gov.bc.ca/cvse/ctpm/Chapter_5.pdf http://www.th.gov.bc.ca/NewWestPartnership/index.html	New West Partnership: British Columbia, Alberta and Saskatchewan

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
	spread with tandem or tridem booster, or 29,000kg with 2.4m to 3.7m axle spread with no booster or single booster.				
Alberta	No specific mention of SHVs in the regulations or in manuals. In a notice on attached conditions for tandem drive trucks modified in December 2011 the drive axles specifications do not allow liftable axles within the tridem group.		Commercial Vehicle Dimension and Weight Regulation. Alberta Regulation 315/2002	http://www.qp.alberta.ca/1266.cfm?page=2002_315.cfm&leg_type=Regs&isbncln=9780779734542 http://www.transportation.alberta.ca/Content/docType276/Production/tridrivefleet.pdf	New West Partnership: British Columbia, Alberta and Saskatchewan
Saskatchewan	Under Part II Section 7, a vehicle cannot be operated equipped with lift axle tires if the axle is in contact with the ground unless the lift axle is on a vehicle other than a semi-trailer and the person has a permit to operate the vehicle with the lift axle tires in contact with the ground. The subsection does not apply if the control switch is located so that the vehicle operator is unable to raise the axles off the surface of the highway from inside of the cab. Subsection (1) does not apply if: (a) the lift axle is on a semi-trailer; (b) the lift axle was installed on or after November 1, 2010; c) the lift axle system meets all of the following requirements: (i) the lift axle system is designed so that the axles can be raised only when the semi-trailer is unladen; (ii) the lift axle system is designed so that, on an unladen semi-trailer, the lift axle system can maintain an axle in the raised position once the axle is raised; (iii) the lift axle system is designed so that, when the semi-trailer is carrying a load: (A) all of the axles in the axle group are on the ground; (B) none of the axles in the axle group can be raised by the lift axle; and (C) the weight on the axle group is equally distributed; (iv) the lift axle system is designed so that whether the axles are in the raised or lowered position, the trailer wheelbase and effective overhang conform to the limits set by these regulations; and (d) the person has a permit issued pursuant to section 36 of the Act authorizing the person to use the lift axle system. For tandem & tandem End Dump Trailers the following combined axle group weights apply: <5m- 3.4m 32 000 kg 35 000 kg WinterWeight <3.4m- 3m 30 000 kg <5m- 4.5m 32 000 kg 35 000 kg WinterWeight		The Vehicle Weight and Dimension Regulations 2010. Chapter H-3.01 Reg 8, November 12, 2010: Part II Section 7	http://www.qp.gov.sk.ca/documents/English/Regulations/Regulations/H3-01R8.pdf http://www.highways.gov.sk.ca/truckersguide	New West Partnership: British Columbia, Alberta and Saskatchewan Manitoba and Saskatchewan MOU: Harmonization of Regulations and Cooperation on Transportation Issues, February 2011

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
	<4.5m- 3m 30 000 kg Maximum allowable weight for axle units may depend on the following minimum distance requirements between axles. • For two single axles 3.0 metres (9'10") • For a single axle and a tandem axle group, 3.0 metres (9'10") • For a single axle and a tridem axle group 3.0 metres • For two tandem axle groups, 5.0 metres (16'4") • For a tandem axle group and a tridem axle group, 5.5m • For two tridem axle groups, 6.0 metres (19'6") • For a multiple axle group and a single, tandem or tridem axle group 5.5m (18'1") If inter-axle spacing is less than the minimum spacing the combined axle weight is reduced by 500 kg for every 10 cm less than the above listed minimum distance requirement				
Manitoba	Part 7 Axles and Tires Section 22 (1) Lift Axles notes that no one can operate a vehicle or combination of vehicles manufactured after December 31, 1988 where control is provided in the operator's compartment to raise or lower a single axle unit, or varying load on an axle unit. Section 23 on RTAC vehicles prohibits the use of a lift axle where the tires of the lift axle are in contact with the ground. RTAC vehicles are operated on specially designated highways.		The Highway Traffic Act (C.C.S.M. c. H60) Vehicle Weights and Dimensions on Classes of Highways Regulation December 19, 1988 as amended. Regulation 575/88	http://web2.gov.mb.ca/laws/regs/current/_pdf-regs.php?reg=575/88 http://www.gov.mb.ca/mit/mcd/mce/pdf/mb_vehicle_weights_and_dimensions_guide.pdf	Manitoba and Saskatchewan MOU: Harmonization of Regulations and Cooperation on Transportation Issues, February 2011
Ontario	Liftable axles and controls 5. (1) A designated vehicle or designated vehicle combination may have axles in addition to those specified in the corresponding Schedule, but the additional axles must remain in the raised position. O. Reg. 457/10, s. 5 (2). (2) A designated truck or a tractor in a designated combination may not be equipped with or have controls, whether remote or manual, that would allow the driver from the cab of the truck or tractor to lift, deploy or alter the weight on a self-steering axle of the truck or of any drawn trailer unless, (a) the truck, truck-trailer combination or tractor-trailer combination is designed to carry raw forest products; or (b) the controls, (i) do not activate unless the emergency 4-way flashers are activated, (ii) contain		Highway Traffic Act R.S.O. 1990, C. H.8 Part VII Loads and Dimensions and Part VIII Weight The Official MTO Truck Handbook Regulations 2000, C.26, Sched. O, s.12 and O.Reg 413/05 Vehicle Weights and	https://www.ontario.ca/laws/statute/90h08 https://www.ontario.ca/laws/regulation/050413 http://www.mto.gov.on.ca/english/trucks/handbook/section1-3-7.shtml	

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
	a device that prevents lifting the axle or altering the axle weight when the truck or vehicle combination is travelling at a speed over 60 kilometres per hour, and (iii) in the case of a tractor-trailer combination, operate only on the most forward self-steering axle of the semi-trailer. O. Reg. 457/10, s. 5 (2). (3) The tractor in a designated tractor-trailer combination 12 may not be equipped with or have controls, whether remote or manual, that would allow the driver to lift, deploy or alter the weight on the tandem or tridem axles in the combination, unless the controls, (a) operate only on the forward axle of the lead trailer's tridem axle; (b) do not activate unless the emergency 4-way flashers are activated; and (c) contain a device that prevents lifting the axle or altering the axle weight when the combination is travelling at a speed over 60 kilometres per hour. O. Reg. 457/10, s. 5 (2). (3.1) A designated truck may be equipped with, (a) manual controls mounted outside the cab of the truck to lift or deploy its self-steering axle or forced-steer auxiliary pusher axle; (b) manual controls mounted outside the cab of the truck to alter the weight on its self-steering axle or forced-steer auxiliary pusher axle, but only for use outside of Ontario; (c) automatic controls that lift its self-steering axle when reversing and deploy it again when moving forward; and (d) automatic controls that lift or deploy its self-steering axle or forced-steer auxiliary pusher axle, depending on whether the truck is heavily or lightly loaded. O. Reg. 457/10, s. 5 (2). (3.2) A trailer in a designated combination may be equipped with, (a) manual controls to lift or deploy its self-steering axles; (b) manual controls to alter the weight on its self-steering axles, but only for use outside Ontario; (c) automatic controls that lift its self-steering axles when reversing and deploy them again when moving forward; and (d) automatic controls that lift or deploy its self-steering axles, depending on whether the trailer is heavily or lightly loaded. O. Reg. 457/10, s. 5 (2). (4) In subsection (3) and in Schedule 12, "tridem axle" means a triple axle as defined in section 114 of the Act that does not include a self-steering axle and that has the same number of tires at each wheel position, and includes an axle unit that is equipped with a device for altering the		Dimensions - for Safe Productive and Infrastructure Friendly Vehicles		

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
	weight transmitted to the highway surface. O. Reg. 413/05, s. 5 (4). Aggregate vehicles 25. (1) This section applies to aggregate vehicles, but does not apply to designated vehicles and combinations or to non-designated vehicles and combinations to which section 21 applies. O. Reg. 457/10, s. 22 (2). (2) Clauses 118 (1) (a) and (b) of the Act do not apply to aggregate vehicles. O. Reg. 457/10, s. 22 (2). (3) The maximum allowable GVW of an aggregate vehicle shall be determined by subtracting, in the case of a two-axle aggregate vehicle, 1,000 kilograms or, in the case of an aggregate vehicle of three or more axles, 1,500 kilograms from, (a) the maximum weight permitted on the front axle under section 116 of the Act plus the sum of the maximum allowable weights for all other axle units of the vehicle or vehicle combination as set out in section 116 of the Act; (b) the maximum weight permitted on the front axle under section 116 of the Act plus the sum of the maximum allowable weights for any two axle groups, three axle groups or four axle groups, or any combination of them, as set out in section 117 of the Act, plus the maximum allowable weight for any axle unit or units excluding any axle unit or units that are part of an axle group, as set out in section 116 of the Act; or (c) the maximum allowable GVW prescribed by clause 22 (1) (c) of this Regulation. O. Reg. 413/05, s. 25 (3); O. Reg. 457/10, s. 22 (3, 4). (4) Where the calculation of front axle weight for an aggregate vehicle powered by a tractor results in a weight over 6,500 kilograms, the front axle weight shall be deemed to be 6,500 kilograms. O. Reg. 413/05, s. 25 (4). (5) In this section and in Vehicle Weight Tables 1 to 29, "front axle weight," in respect of an aggregate vehicle, means, (a) for a single front axle, the maximum weight permitted under section 116 of the Act for a single axle, and (b) for a dual front axle, one-half the maximum weight permitted under section 116 of the Act for a dual axle. O. Reg. 413/05, s. 25 (5); O. Reg. 457/10, s. 22 (5). "				

Province	What the law says	Bridge formula (where found)	Source of Law	Website link	Multi-Province Partnerships
New Brunswick	Equipment 9(1) Subject to subsection (3) and sections 12.1 and 12.2, a person who operates or moves and an owner who causes or permits to be operated or moved on a highway a truck or truck tractor that is drawing a trailer or semi-trailer equipped with a lift axle shall ensure that the control that varies the mass carried by the axle is located outside of the cab of the truck or truck tractor in a position that is not accessible to the operator when the operator is in a normal operating position. 9(2) A control for a lift axle that puts the lift axle in the full up or full down position may be located inside the cab of a vehicle. 9(3) No person shall operate or move or cause or permit to be operated or moved on a highway an A train double, a B train double, a C train double, a truck with a tandem steering axle, a 16.2 metre semi-trailer or a pony trailer that is equipped with a lift axle, unless the lift axle is part of a tandem equivalent axle or a tridem equivalent axle. 2010-131		New Brunswick Motor Vehicle Act Motor Carrier Act R.S.N.B. 1973, C. M-16 New Brunswick Vehicle Dimension and Mass Regulation 2001-67, O.C. 2001-438	https://www.pxw1.snb.ca/snb7001/e/2000/2006e_4.asp http://laws.gnb.ca/en/showdoc/cr/2001-67	

2.6 Coordination with Trucking Industry Stakeholders

The research team held a workshop at CTR with trucking industry stakeholders on April 22, 2016, 9:00 a.m. to 12:00 p.m. During the workshop, the research team gave the background, stated purpose, and scope of the project; discussed plans on how to conduct the research; explained pavement consumption analysis and bridge consumption analysis; and introduced a survey that was designed to help gather key information regarding configuration and operational characteristics of SHVs. Appendix C provides the workshop agenda outline and presentation.

During the workshop, every attendee was given a chance to voice their opinions freely. A WebEx recording was made of the meeting and distributed to attendees with a website link and instructions how to download free software to view the recording. The WebEx recording includes both sound and the presentation slides for the entire workshop. The key discussions and findings from workshops are summarized below.

- The research team discussed House Bill (HB) 3061, which proposes to increase ready-mix truck GVW in increments associated with added axles up to a maximum of 80,000 lbs GVW for a seven-axle truck. It was noted that there does not appear to be a relationship between the increased load and added tare weight of additional axles, especially for four-axle or five-axle trucks. Six-axle ready-mix trucks have been observed in Texas.
- Martin Marietta Materials noted that they use five-axle ready-mix trucks so that they can legally run on the interstate, not to increase the total cargo weight the vehicle can carry. The Director of Policy from the Texas Trucking Association also expressed the same opinion. Many truck companies are using SHVs to distribute weight over multiple axles so that the weight over each axle is in line with the law; not necessarily to carry more cargo.
- The research team asked Martin Marietta Materials if there was interest in Texas in operating forward discharge ready-mix trucks. This design has different tire sizes and axle spacing that would require additional truck configurations to be evaluated. Martin Marietta Materials responded that forward discharge trucks have higher maintenance costs and though a few are currently operated, there were no immediate plans to implement forward discharge ready-mix trucks in Texas.
- The research team indicated that the DarWin ME program automatically distributes the total axle group load equally among the axles and does not provide a method for applying different axle weights within an axle group. Thus, the researchers will analyze SHV configurations using a linear elastic layered theory program to calculate stresses and strains at selected points within the pavement. Axle groups with equal axle loads will then be analyzed to identify a group/axle load configuration which has an equivalent strain level compared to the SHV lift axle configuration. The axle group with equal axle loads and equivalent strains will be used in the DarWin ME program to compute equivalent consumption factors (ECF).
- The research team asked Martin Marietta Materials how load is applied to the booster axle on a ready-mix truck, since there is no apparent (visible) piston or loading mechanism as is seen on a dump truck booster axle. During a field trip to the Martin

Marietta Materials ready-mix plant, the research team viewed the piston which is underneath the mixer truck and attached to a heavy cross beam. The piston is also attached to the booster axle and used to both deploy and load the axle which was demonstrated several times during this field visit. Axle weight data was collected for all axles in both unloaded and loaded conditions, with lift axle lifted/lowered and booster axle lifted and lowered to produce all variations of the potential load configurations.

- Les Findeisen pointed out that the tire size and footprint for liftable axles is often smaller than for fixed axles. The research team followed up with a discussion of the variety in tire sizes and lateral wheel path placement of liftable pusher, tag, and booster axles that has been observed during field data collection.
- The research team explained the difference between inventory rating and operating rating for bridges in the context of bridge load zone analysis. It was pointed out that short, heavy SHVs might require load posting of certain bridges, although the analysis of the Texas network will be time-consuming to conduct on a bridge-by-bridge basis. This cannot be accomplished within the scope of the 0-6897 project.
- An attendee noted that the bridges nationwide were designed for HS20 trucks (AASHTO established these as standard live-load models). He noted that HS20 trucks can produce a certain load in the bridge beams that the bridges were originally designed to accommodate, but SHV trucks can put a higher load on the bridges, as SHVs can be more compact, depending on their specific configuration.
- An attendee noted that majority of the interstate system was designed for loads even lower than those of HS20 trucks, so the requirement of load rating bridges becomes important, given the ever-increasing traffic loads. Another attendee noted that the trucking industry relies on the highway system (including bridges) to transport their goods, so a bridge breakdown has cost implications for the trucking industry.

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Chapter 3. SHV Field Data Collection and Analysis

3.1 Overview

As covered in Chapter 2, a thorough literature review and discussions with industries were conducted to identify publicly available SHV-related data sources at both national and state levels. The researchers reviewed the Texas VIUS, Texas WIM data, TxDPS weight enforcement data, TxDMV vehicle registration data, NCFRP Report 29, NCHRP Report 575, and other sources. The available data sources did not meet all data needs for this project, especially in terms of information trucks with liftable axles (i.e., number of liftable axles, loads on liftable axles, and spacing from a liftable axle to another axle/axle group). CTR conducted further data collection activities to obtain data and fill these gaps.

The researchers developed and implemented a data collection plan to characterize SHVs operating in Texas and prepared key inputs for the pavement, bridge, safety, and economic analysis. This chapter summarizes data collection efforts and analysis results regarding determining the types, configurations, and numbers of SHVs operating in Texas.

The researchers performed the following additional data collection activities:

- visited various project sites, including hot-mix plants, ready-mix plants, landfills, material supply yards, and quarries, to collect 2-hour truck traffic data counts;
- evaluated data from available agency databases and other sources, including 24-hour classification videos provided by TxDOT's Transportation Planning and Programming Division (TP&P);
- collected on-route truck description data both statewide and along a specified corridor;
- observed and measured SHV dimensions and weight at operation sites and companies;
- acquired DPS–CVE truck weight enforcement data obtained CVE's roadside stops;
- analyzed TxDOT manual visual counts (MVC) data;
- reviewed online Texas truck sales data;
- designed an online survey to communicate with industry and gather information.

The researchers developed a Truck Configuration Photographic Library (TCPL) as a comprehensive reference of the types of trucks operating on the Texas state network. The Library was used by the research team to help correctly identify trucks during route, corridor, and 24-hour video analysis. Identification photos of trucks were prepared for both daytime and nighttime conditions—nighttime conditions included identifying the types of reflectorized tape, lighting, and other markings required for different truck types. CTR researchers also took DPS–CVE training to better perform truck weighing using HAENNI WL 101 portable scales. Table 3.1 summarizes how each data collection effort contributed to determining the key inputs for analysis in later chapters. Moreover, a five-level evaluation system was used to evaluate the applicability of these sources.

- **A** – *Applicable*. The data can be used directly to determine a specific SHV operating characteristic. For example, when conducting 2-hour counts at a project site, CTR recorded the truck type for each count, and thus an 'A' is rated for the cell of *2-hr counts* and *Type*.

- **P** – *Partially applicable*. A data source provides related information, but can only be used to determine SHV operating characteristics after additional treatments of the data. For example, TxDPS weight enforcement data contains axle weight information. However, its sampling process is unknown, and may represent the higher end of axle weight distribution. Thus, the data cannot be used directly for the project.
- **G** – *General information*. A data source contains related information but cannot used to quantify an SHV operating characteristic. For example, company visits and discussions usually provide general view from industry on a topic, but do not help estimate the value of a specific SHV operating characteristic.
- **C** – *Applicable if combined with other data*. For example, on-route counts provide percentages of SU3, SU4, SU6, and SU7[1] configurations for dump trucks (these configurations are detailed in the next subsection). Combined with TxDMV data, which tells the total number of registered dump trucks in Texas, on-route count can be used to estimate how many SU3, SU4, SU6, and SU7 configurations of dump trucks operate in Texas.
- **N** – *Not applicable*. The data item does not provide related information.

Section 3.2 discusses each data collection activity in details.

[1] SU3 (three-axle SHV), SU4 (four-axle SHV), SU5 (five-axle SHV), SU6 (six-axle SHV), SU7 (seven-axle SHV).

Table 3.1: Summary of data collection activities and outputs

Data Source/ Collection Efforts		SHV operating characteristics											
		Type (i.e., dump, ready-mix, etc.)	Configuration					Count			Safety		
			Number of axles	Axle types (fixed or liftable)	Axle weight	Axle spacing	Tire designs used	Total number	Number by configura-tion and type	By region	Truck maintenance and design	Operation-al features	Crash history
Truck Configuration Photographic Library		A comprehensive reference of the types of trucks operating on the Texas state network											
DPS–CVE training		Enabled researchers to better perform truck weighing											
Agency databases	TxDPS	P	P	P	P	P	N	N	N	N	P	N	C
	TxDMV	A	P	N	N	N	N	C	C	C	N	N	N
	TxDOT truck classification	N	P	N	N	N	N	P	N	N	N	N	N
	TxDOT WIM data	N	P	N	P	P	N	P	N	N	N	N	N
Project site visits	2 hr. counts	A	A	A	N	N	N	C	C	C	N	N	N
	Field visits	A	A	A	A	A	A	N	N	N	G	G	C
Company sites visits		G	G	G	G	G	G	G	G	G	G	G	G
On-route data collection		A	A	A	N	N	N	C	C	C	P	N	N
TxDOT MVC data		A	A	A	N	N	N	C	C	C	P	N	N
Online truck sale data		P	P	P	N	N	N	P	P	N	N	N	N
Online survey		G	G	G	G	G	G	G	G	G	N	N	N

3.2 Data Collection Activities

3.2.1 Development of a Truck Configuration Photographic Library (TCPL)

Purpose of the Library

The TCPL was developed to provide the researchers with a comprehensive reference of the types of trucks operating on the Texas state network. The need for the tool was realized during truck data collection at fixed sites (landfills, quarries, ready-mix plants) due to the different truck operational and configuration types. The researchers saw, in some cases, trucks that were not readily identifiable according to operational type, which required further investigation to properly record in the data collection records. It was further noted that recording the operational types of trucks required the proper nomenclature for the truck type to properly classify it. We found that not all trucks operating at a landfill are waste management vehicles; many different types of SU, two-axle, SHV, tractor semi-trailer trucks operate at landfills—but these trucks could also perform other functions. Thus, identifying the operational type and potential for multiple uses helped in determining how the truck should be classified with regard to the TxDMV's VTR truck registration database. Based on discussions with TxDMV-VTR, trucks are registered according to operational type and weight classification. The number of axles and type of axle groups (single, tandem, tridem, fixed, liftable, etc.) are not recorded in the registration records since this information is not required by state law.

Further, the researchers obtained 24-hour traffic classification videos from the TxDOT TP&P Division's Traffic Analysis Section, which were used to supplement the truck configuration database described in this chapter. The TCPL provides users with a means for identifying the proper operational type of trucks seen on the videos both during daylight and nighttime operations, which will be discussed in a later section.

One of the project tasks was to determine the number of SHVs operating in Texas by operational type and configuration, both statewide and regionally. Since this estimate required sampling the trucks operating on the Texas network, several data types were used to provide the widest coverage possible and to provide a statistically valid sample. However, when a truck is registered, for example, as a dump truck, the truck configuration—tractor semi-trailer, SU three-axle, SU SHV, SU4, etc.—is not recorded. Thus, to estimate the number of SHV dump trucks operating in Texas, the research team collected data about dump trucks of all configurations based on sound statistical sampling procedures to determine the estimated number of registered trucks in each configuration category:

1) Five, six, or more axle tractor-semi trailer dump truck
2) Two-axle SU dump truck
3) Three-axle SU dump truck – no lift axles
4) Four-axle SU dump truck – no lift axles
5) SU3 – three-axle dump truck with one liftable axle
6) SU4 – four-axle dump with one liftable axle (different configurations)
7) SU5 – five-axle dump with two liftable axles (different configurations)

8) SU6 – six-axle dump with three liftable axles (different configurations)

9) SU7 – seven-axle dump with four liftable axles (different configurations)

This information helped answer additional questions such as these:

1) For a given operational type of truck, what percentage of registered trucks are SHVs?
2) For a given operational type of SHV, what are the percentages of different SHV configurations?
3) How are these SHVs distributed regionally and statewide?

Summary of Truck Types Included in the TCPL

The TCPL includes trucks of all operational types that have been observed on the Texas state-maintained highways. The TCPL currently contains nearly 800 photographs of trucks, including multiple photographs of the same truck operational type and configuration to assist in correctly identifying the truck from various angles of view (side, front [approaching the viewer], rear [departing from the viewer], among others). When possible, photos of Texas trucks have been used in the library, though in some cases a truck might be observed in Texas, but a photograph is not available. In addition, trucks of a particular operational type with different cargo loads are included in the TCPL to provide terminology regarding different types of modular cargo containers currently in use such as liquid totes and intermediate bulk containers.

Table 3.2 summarizes the general and more detailed truck operational types included in the library. It should be noted that certain Texas industries may attract large numbers of trucks, including SHVs that are not registered by the TxDMV-VTR. Some examples include:

1) **Agriculture – seasonal harvesting**: Custom harvesting companies from other states often begin the harvest in Texas and work to the Canadian border.
2) **Oil and gas production and transportation**: During the shale boom, many different oil companies from other states operated in Texas, serving a wide variety of needs directly involved in oil production or construction of oil production sites.
3) **Interstate or cross-border operations**: Cross-border movements of SHVs are likely limited to 50 miles or less because most SHVs are vocational-type trucks designed to serve a specific purpose or function.

Table 3.2: List of SHV truck operational types and configurations included in the TCPL

General Operational type (VTR-Registration)	Operational sub-types	SU-3 (3 axles 1 liftable)	SU-4 (4 axles 1 liftable)	SU-5 (5 axles 1 - 2 liftable)	SU-6 (6 axles 2- 3 liftable)	SU-7 (7 axles 3 - 4 liftable)
Box Van						
	Dry Box Van	X	X			
	Expedited Delivery	X	X			
Cranes (Lift Boom)						
	Truck mounted cranes		X	X	X	
Dump Truck		X	X	X	X	X
Flat Bed						
	Flat bed - no additional equipment		X	X		
	Flat bed - boom crane		X	X		
	Flat bed - knuckle boom		X			
Stake Bed		X	X			
Grain Truck			X			
	Silage, Corn, Wheat		X			
	Livestock Feed		X			
Tankers						
	Petroleum Tanker					
	Gasoline		X			
	Crude Oil		X			
	Corrosive Chemicals		X			
	Vacuum Tanker					
	Salt-Water		X			
	Sewer		X			
	Hydro-Excavation		X			
	Industrial		X			
	Environmental Haz Mat[1]		X			
	Food Grade Tanker		X			
	Compressed Gas Tanker		X			
Concrete (Ready Mix)						
	Drum Mixer		X	X	X	
	Volumetric Mixer		X	X		
	Concrete Pump Truck		X			
Garbage (Waste Management[1])						
	Garbage					
	Garbage Truck	X	X	X		
	Dumpster Service Truck		X	X		
	Roll-Off - Container		X			
	Roll-Off - Garbage Compactor		X			
	Grapple Truck		X			
Oil Field Equipment						
	Acid pumping and blending unit		X			
	Bulk Cement pumping and blending unit		X			
	Bulk Cement tankers		X			
	Frac pumping and blendng unit		X			
	Frac water heater		X			
	Hot Oiling Unit		X			
	Kill Truck		X			
	Nitrogen Pumping Unit		X			
	Oil Well Service Unit		X	X	X	
	Snubbing Unit		X			
	Tubing Workover Rig		X			
	Vacuum Trucks		X			
	Winch Tractor or Winch Truck		X			
	Workover truck		X			
Wrecker (Heavy Duty)			X			
Specialty Trucks						
	Quarry Explosives (HEET) truck		X			
	Railway Maintenance (road or railway ops)		X			

As mentioned previously, the TCPL includes photographs and guidelines for identifying truck configurations and types during both daylight and nighttime conditions. The guidelines for identifying trucks during nighttime conditions were necessary due to our use of 24-hour videos, which provided valuable truck operational and configuration information at locations distant from Austin. These videos span approximately 8 hours of nighttime conditions during which hundreds of trucks were observed. In worst cases where nighttime conditions make truck configuration and identification difficult, the TCPL's documentation of truck light and markings placement can help narrow down the possibilities to perhaps one or two truck types at most.

An example of information collected at a paving materials operation in San Marcos is used to demonstrate the applicability of the TCPL to identify truck types related to point count data. This operation includes a quarry, ready-mix plant, and hot-mix plant, so trucks of several operational types are entering and leaving the operation continuously. Though dump trucks and ready-mix trucks are usually easy to classify, other truck types such as dry pneumatic bulk tankers transporting cement and specialty trucks also operate at these locations. Figure 3.1 presents an example of one such specialty truck: an SHV SU4 quarry explosives truck operated by Austin Powder, which at first was not identified according to its functional type. The TCPL contains several photos of Austin Powder HEET trucks for future reference (HEET is the trade name of the explosive used to blast sections of a quarry to prepare for excavation, crushing, and aggregate grading operations). Figure 3.2 shows an alternate design also captured in the TCPL.

Figure 3.1: Austin Powder quarry explosives transport truck (SU4 with lifted tag axle)

Figure 3.2: Austin Powder quarry explosives transport truck (different design) (SU4 with lifted tag axle)

Summary

The TCPL has proved itself useful in correctly classifying truck operational and configuration types—whether SHVs, SU multi-axle trucks, tractor-semi-trailers, or other types such as cranes, concrete pump trucks, or oil field servicing rigs. Information contained in the library helps apply the correct nomenclature for the truck and its cargo using photos, YouTube videos, and text descriptions. The TCPL was used in the truck data collection and analysis procedures involving site visits, route truck data collection, point counts, and 24-hour video counts.

3.2.2 Agency Databases

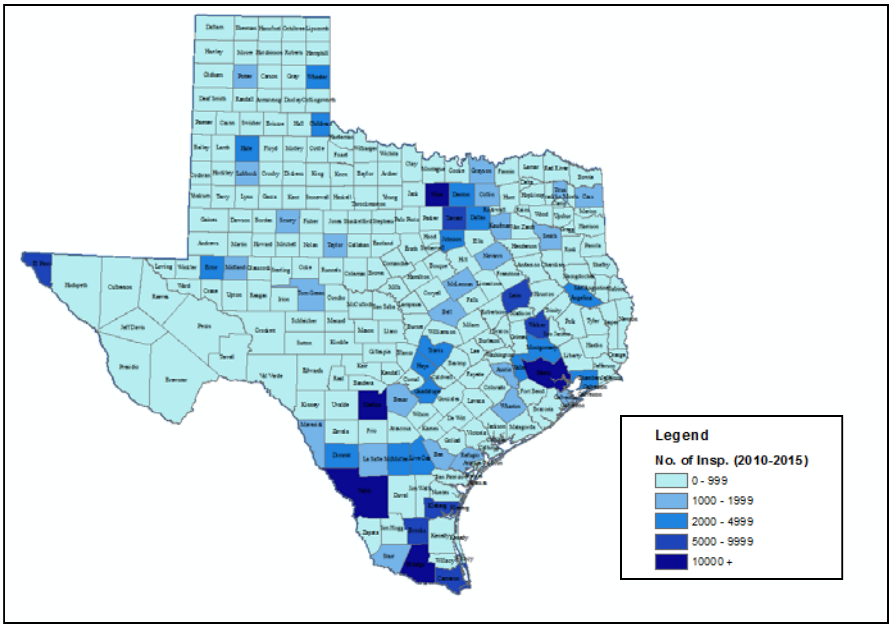
TxDPS Weight Enforcement Data

The DPS–CVE Service[2] is responsible for weighing and checking commercial vehicle traffic to make sure these vehicles are compliant with the laws regulating weight; motor carrier safety; registration; and transport of persons, hazardous material, and other property. They have a limited number of fixed weight stations located throughout the state. Additionally, TxDPS weight enforcement officers carry portable scales in their patrol vehicles and can pull over a suspicious vehicle for a weight check on the roadside. The enforcement officers observe the axle spacing of a truck. If they notice short axle spacing, they will measure the axle spacing of the truck and compare that with the FBF (Formula B) to judge if the truck is safe to cross an upcoming bridge.

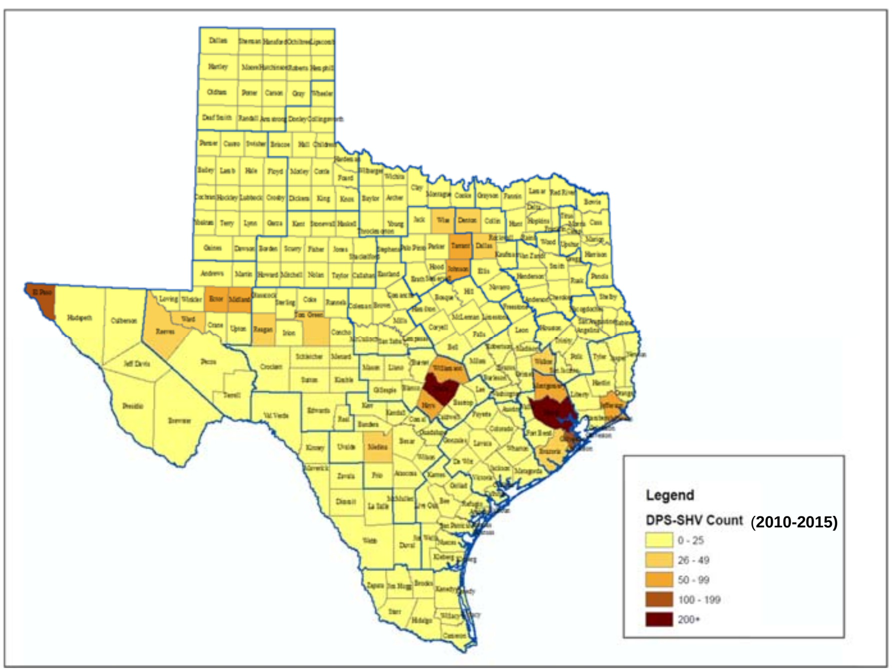
TxDOT received a sample of TxDPS weight enforcement data reported from 2010 to 2015. The data contains axle and weight information that proved to be a valuable resource for this project. Out of the total number of 292,000 records, around 3,000 SHVs were identified. Figure 3.3 shows the spatial distributions of the TxDPS inspections on all vehicles and identified SHVs in terms of

[2] TxDPS Commercial Vehicle Enforcement: https://www.txdps.state.tx.us/cve/index.htm

the number of inspections per county. While inspections in general appear to be more frequent in the counties within border and urban areas, SHV inspections are typically conducted more frequently in the counties around metropolitan areas (i.e., Travis County and Harris County) and El Paso.



(a) Inspections – all vehicles



(b) Inspections – SHVs

Figure 3.3: Spatial distributions of the TxDPS inspections

Among the identified SHVs, the percentages for SU4, SU5, SU6, and SU7 are 73, 21, 5, and 1%, respectively, while the proportions vary over years, as shown in Figure 3.4.

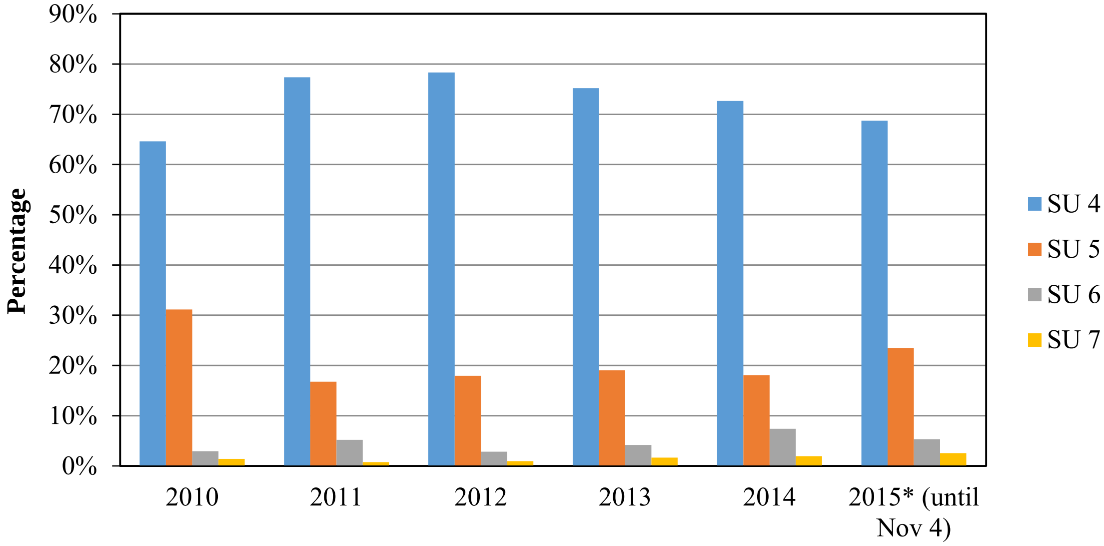


Figure 3.4: Percentage of SUs among inspected SHVs by TxDPS (2010–2015)

Figure 3.5 presents the percentages of SHVs by the load types they carry. Dump trucks represent about 64.1% of the SHVs from the TxDPS SHV sample, followed by SHVs carrying oil field equipment, ready-mix concrete, construction equipment, building materials, liquid, etc.

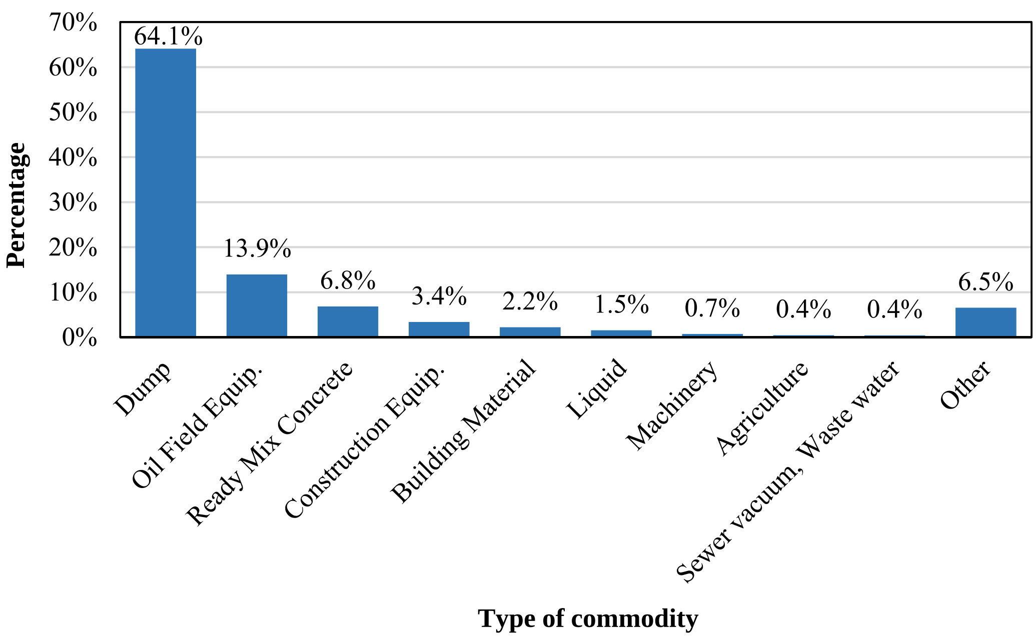


Figure 3.5: SHV classification by commodity type

Table 3.3 provides a summary on the axle weight distributions for each main truck configuration identified in the TxDPS sample data. The second column contains drawings for every SHV configuration. The single wheels are designated with an 'X', dual wheels with an 'O'. If an axle/axles are considered in a separate axle group, '--' will separate them from adjacent axles. The last column shows the violation rate for a truck configuration group. Violation of Bridge Formula B, maintenance, or other violations were considered. A more detailed analysis is presented in Section 3.3.1.

Table 3.3: Summary of weight and violations for the TxDPS sample data

Truck configuration		Total	Percentage/ SHV	Axle weight (lbs)						Violation
				Axle Group 1	Axle Group 2	Axle Group 3	Axle Group 4	Axle Group 5	GVW	
SU4	**X--XOO**	1319	60.30%	14,268	44,942				59,210	70.70%
	X----OO	427	19.50%	14,738	11,884	39,866			66,488	**77.50%**
	X--X--O--O	144	6.60%	19,394	19,503	25,476	25,275		89,648	71.50%
	X--OOX	75	3.40%	17,117	46,069				63,186	64.00%
	X--OO--X	216	9.90%	18,669	40,472	9,854			68,995	69.00%
	Others	6	0.30%	-	-	-	-	-	-	-
SU5	**X--XOOO**	9	1.40%	15,469	46,094				61,563	33.30%
	X--X--OOO	54	8.50%	18,979	20,106	71,719			110,804	**90.70%**
	X--X--O--O--O	257	**40.30%**	18,418	19,850	23,656	29,187	19,843	110,954	**91.10%**
	X--XOOX	25	3.90%	15,319	51,307				66,626	52.00%
	X--XOO--X	10	1.60%	18,957	44,129	11,386			74,472	60.00%
	X--X--OO--X	8	1.30%	18,470	9,740	35,120	9,540		72,870	50.00%
	X--XXOO	195	**30.60%**	16,133	51,278				67,411	72.80%
	X--XX--OO	11	1.70%	15,968	12,800	43,868			72,636	**90.90%**
	X--X--X--OO	44	6.90%	14,842	8,639	8,511	37,494		69,486	**79.50%**
	Others	24	3.80%	-	-	-	-	-	-	-
SU6	**X--X--OO--OO**	22	16.10%	14,341	10,697	21,035	21,482		67,555	72.70%
	X--XXOOO	11	8.00%	17,391	81,364				98,755	72.70%
	X--XXOOX	25	18.20%	17,846	58,232				76,078	44.00%
	X--XXXOO	40	29.20%	18,254	56,625				74,879	37.50%
	X--X--X--X--OO	14	10.20%	15,347	6,975	6,087	6,287	43,042	77,738	**92.90%**
	Others	25	18.20%	-	-	-	-	-	-	-
SU7	**X--XXXOOX**	28	62.20%	19,047	59,028				78,075	25.00%
	X--XXXX--OO	6	13.30%	19,080	58,350				77,430	50.00%
	Others	11	24.40%	-	-	-	-	-	-	-

While the TxDPS weight enforcement sample data provides information on truck types, configurations, and axle weight, use of the data for this research presents two major issues:

a. The sampling process is not random, which generates bias in the results. Many trucks are pulled over and weighed by the roadside because the enforcement officer observed a potential weight or other type of violation. Thus, the percentage of trucks violating the weight law among all the trucks weighed by the TxDPS is expected to be higher than the percentage of violators among all trucks. The observed axle weight and GVW can be greater than the average SHVs operating in Texas.

b. The database contains the number of axles, axle weight, and tire types (single/dual) of weighed trucks. However, there is no direct data field on the form indicating whether an axle is liftable. CTR combined information on the types of tires and axle configurations to make judgements regarding which vehicles are SHVs. Since TxDPS uses the indicator 'X' for an axle with single tires, and 'O' for an axle with dual tires, CTR was able to interpret various trucks based on knowledge of SHV and other types of configurations. For example, the research team judged that the configuration X-X-O-O represented a truck with a steering axle, a single tire lift axle, followed by a tandem axle with dual tires. However, certain truck configurations could be interpreted in different ways, which could lead to confusion and potential errors. For example, the configuration X-O-O-O could represent an SU truck with a steer axle and a tridem axle set with dual tires on each axle. Though not as common as liftable axles with single tires, liftable (non-steering) axles do exist. Thus, this same configuration could represent an SU4 with a dual tire, pusher, liftable axle followed by a tandem axle with dual tires. In cases that presented multiple interpretations or unclear conclusions, the vehicle was not used in the final set of data.

TxDMV Vehicle Registration Data

The researchers also requested and received motor vehicle registration data from the TxDMV-VTR in December 2015. The dataset includes data regarding how many vehicles of what type were registered in Texas through TxDMV as of December 2015, categorized by body style. A few examples of body styles included are dump, flatbed, and garbage. For the purposes of this project, there were a few challenges with the data received. Primarily, the dataset did not differentiate between trucks with and without liftable axles—only body type. TxDMV does not require a registrant to specify the number of liftable or boost axles that a vehicle has when registering a vehicle.

The researchers parsed the data set and identified a few body styles of trucks that are more prevalent in their implementation of liftable axles (SHVs). These include dump, garbage, concrete, etc. Next, the data was organized to prioritize those counties that had larger numbers of trucks with these particular body styles. This step was taken to help narrow down a geographic location where SHV usage is more likely to be observed. The results showed that the geographic locations more likely to contain SHV operations were metropolitan counties.

The TxDMV registration data also helped the researchers in determining the size of the truck population in Texas, as well as the population of certain types of truck operating in Texas. This analysis was done by considering the percentage of SHVs seen for a certain truck type from the on-route data collection, and then accounting for how many of those types of trucks are registered in Texas, to estimate how many SHVs of that type are operating in the state. Tables 3.4 and 3.5 show some summary statistics from the TxDMV registration data, collected from all 254 Texas counties.

Table 3.4: Total truck numbers (by body type) registered with the TxDMV as of December 2015

Truck Type	Number of Trucks	Percentage of Total (%)
Bobtail	4,197	0.58
Concrete	9,275	1.28
Container	2,582	0.36
Crane	8,907	1.23
Drilling	1,781	0.25
Dump	71,172	9.85
Flatbed	444,745	61.56
Garbage	9,155	1.27
Gondola	449	0.06
Grain	7,284	1.01
Lift Boom	7,970	1.10
Logging	4,667	0.65
Oil Field Equipment	39,354	5.45
Refrigerated Van	13,161	1.82
Stake Bed	5,462	0.76
Tanker	79,238	10.97
Well Drill	3,033	0.42
Wrecker	9,997	1.38
Total	722,429	100.00

Table 3.5: Total truck numbers (by county for a sample of 25 counties) registered with the TxDMV as of December 2015

County	Number of Trucks	Percentage of Total (%)
Harris	77,361	10.71
Dallas	31,192	4.32
Tarrant	32,149	4.45
Bexar	25,110	3.48
Travis	17,240	2.39
Collin	9,431	1.31
Hidalgo	12,157	1.68
Denton	9,343	1.29
McLennan	6,771	0.94
Williamson	7,191	1.00
Fort Bend	11,660	1.61
El Paso	6,311	0.87
Montgomery	12,952	1.79
Comal	4,849	0.67
Nueces	7,932	1.10
Ector	12,298	1.70
Lubbock	6,724	0.93
Potter	3,842	0.53
Brazoria	8,292	1.15
Midland	17,906	2.48
Johnson	7,761	1.07
Bell	7,041	97.00
Wise	7,925	1.10
Parker	7,894	1.09
Jefferson	5,133	0.71
Total	356,465	49.34

Truck Classification Data

TxDOT uses the FHWA-recommended 13-category scheme for its manual vehicle classification program. The scheme is divided into categories depending on whether the vehicle carries passengers or commodities. Non-passenger vehicles are further subdivided by the number of axles and number of units[3]. For SU commercial vehicles, there are three classes, as shown in Table 3.6.

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[3] Texas Department of Transportation. *Traffic Recorder Instruction Manual. Available at http://onlinemanuals.txdot.gov/txdotmanuals/tri/classifying_vehicles.htm*

Table 3.6: FHWA 13-Category Scheme—Classification Table (only for SU trucks)[3]

Category Number	Definition	Additional Identifiers	Sub-class
5	Single-unit trucks	2-axle, 6-tire, (dual rear tires), single-unit trucks.	Approx. 21' steering to rear axles; 8' bed dually with 4 full doors; dump or sewage truck (with or without 2-axle trailer); compact school bus or 4 full doors; extended limousines.
6	Single-unit trucks	3-axle, single-unit trucks.	Dump truck; single tractor with 3 axles and no trailer; oil field equipment.
7	Single-unit trucks	4 or more axle, single-unit trucks.	4 or more axle trucks on a single frame.

The TP&P Division collects vehicle classification counts at 650 to 750 Texas locations each year, employing three types of vehicle classification data collection methods and efforts[4]:

- automated vehicle classifier at approximately 250 sites with 48-hour data collection
- contract visual classification counts at approximately 400 sites with 24-hour data collection
- telemetry at 25 border sites with data collection 365 days a year

The truck classification data provide an overview of the SU truck population, but using it to quantify directly the SHV population and types is difficult, due to lack of information on liftable axles.

Weigh-in-motion Data

WIM devices can capture traffic volumes by vehicle classification and weight. The axle spacing and axle weight can also be collected at a certain accuracy level. Two types of WIM systems are used: bending plate systems and piezoelectric cable sensors. TP&P uses bending plate WIM equipment to collect data at up to 15 sites, where 48-hour data for each quarter of the year are surveyed. WIM data are also collected at the FHWA Long-Term Pavement Performance sites and at locations where site-specific WIM systems are justified for pavement design using piezoelectric systems.

NCHRP 12-63 used WIM data to study truck configurations for SHVs. The study used WIM data to extract information on axle configurations (number and spacing axles). It mentioned that margin of error on axle weights can commonly range from 10% to 15% in WIM data; that study did not use the WIM data for the load models. In addition to the accuracy concerns, WIM collection procedures fail in capturing if an axle is liftable axle or not. However, CTR developed a procedure to filter and extract potential SHVs as discussed in Section 3.3.2.

[4] Texas Department of Transportation. Traffic Data and Analysis Manual.

3.2.3 Project Site Visits

Site Visits for Configuration Investigation

To characterize the function, configuration, and proportion of SHVs operating within Texas, CTR visited various project sites, including quarries, ready-mix plants, hot-mix plants, and landfills, and spent two hours at each site to count the number of trucks going in or out.

To classify the data collected in terms of function, the trucks were categorized into quarry dump, hot-mix dump, ready-mix rear discharge, ready-mix forward discharge, garbage recycling, oil field winch, oil field vacuum, oil field other, sewer vacuum, agriculture/grain, agriculture/cotton, agriculture/other, heavy duty wrecker, fuel/lube, bottled gas, flat bed/concrete slabs, flat bed/other, roll-off truck, and other type. In terms of configuration, the trucks were categorized into two-axle truck, three-axle truck, three-axle truck, pup trailer truck, five-axle tractor trailer truck, six-axle tractor trailer truck, SHV, and SHV pup trailer. For SHVs, the trucks were further categorized into SU3, SU4, SU5, SU6, and SU7 configurations. The configurations were further explained using an axle identification system developed by CTR. The system designated a steer axle by the number 1, followed by the number of pusher lift axles (if any) such as 1L, 2L, 3L or 4L; the number of fixed drive axles (1, 2, or 3); the number of liftable tag axles (if any) again (1L, 2L); and finally a designation for a potential booster axle ("B"). The following examples show how the system was used in collecting data:

- 1-1L-2 SU4 with a steer axle, 1 liftable pusher axle, and 2 drive axles
- 1-1L-1 SU3 with a steer axle, 1 liftable pusher, and 1 drive axle
- 1-3L-2-B SU6 with a steer axle, 3 liftable pusher axles, 2 drive axles, and 1 booster axle
- 1-1L-2-1L SU5 with a steer axle, 1 liftable pusher, 2 drive axles, and 1 liftable tag axle

In addition, the notation Up, Down, and Mixed was used to characterize the status of the liftable axles. CTR collected a total of 3,266 trucks distributed among 58 site visits around Austin, Dallas, Houston, and San Antonio. The geographical distribution of these sites is illustrated in Figure 3.6.

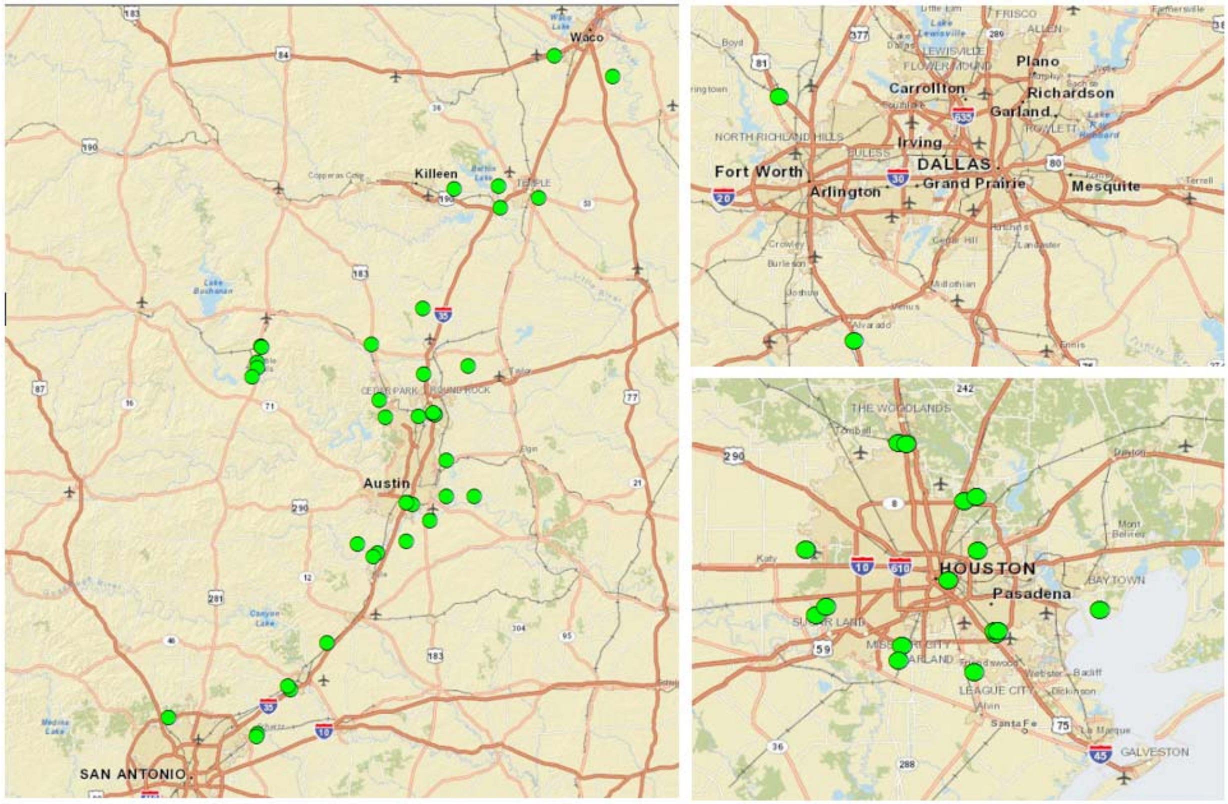


Figure 3.6: Geographic distribution of site visits for configuration investigation

As shown in Figure 3.6, most of the sites were located in areas between Austin and San Antonio. CTR developed a schedule based on SHV operations, which typically begin in the morning, peak at mid-day, and continue to decline until late afternoon, when most operations close for the day. In addition, it was observed that a facility might or might not be operational on any given day due to weather, reduced need for services/materials due to project closures, or trucking company routes/operations, among other reasons. In addition, the amount of truck traffic at a facility might vary substantially from one day to the next even during good weather conditions. Thus, there was a significant risk for TxDOT to travel long distances to collect data at fixed sites that might not be operational or, if operational, where few trucks would be observed. These factors affected CTR's decisions regarding the number and statewide distribution of fixed sites that were monitored. Also factored in was the travel distance (time) from CTR to the site. As CTR is based in Austin, most of the sites visited were located close to the Austin-San Antonio area as previously mentioned. However, CTR also conducted extensive data collection in Houston, and at least one site visit in Ft. Worth, Waco, and Wichita Falls; thus, Houston has the second highest number of sites visited.

The sites were categorized into different groups based on the location and number of trucks as illustrated in Figure 3.7. The greatest numbers of trucks were mostly concentrated in the urban areas such as Austin (500), New Braunfels (422), and Houston (417), with truck numbers decreasing when moving out from the urban areas.

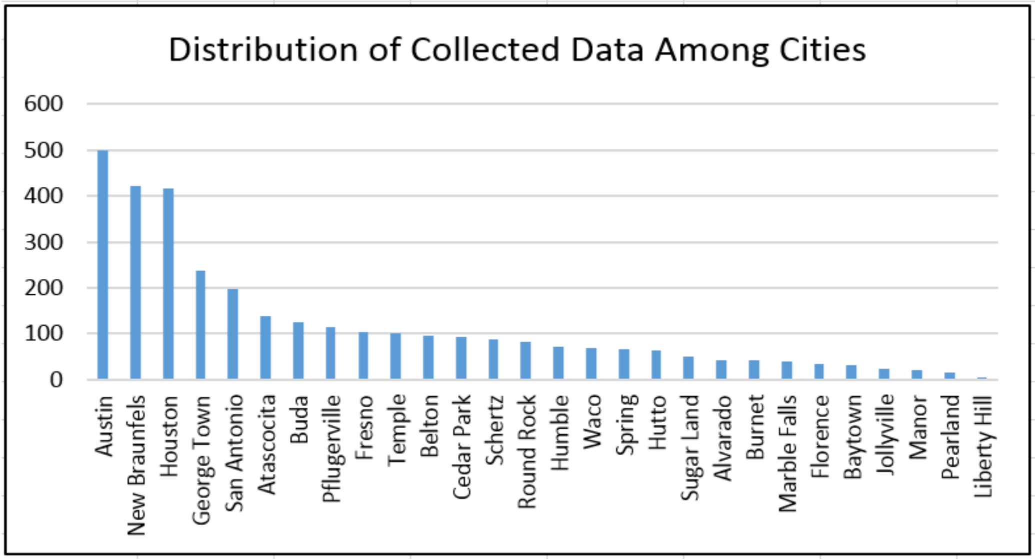


Figure 3.7: Number of vehicles by location

The number of trucks for different commodity types are shown in Figure 3.8. As illustrated, dump trucks represented the most prevalent type identified, followed by garbage/recycle trucks, and ready-mix trucks. Moreover, the SHV numbers follow the same trend as the total number of trucks; dump trucks represented the largest group, followed by garbage/recycle trucks, and ready-mix trucks. These results are consistent with the construction activities and number of residents in urban areas. In those areas, dump trucks and ready-mix trucks are needed to transport construction material. Furthermore, the total number of residents has a direct impact on the garbage trucks required to perform garbage collection activities.

It is worth noting that the SHV proportion of agriculture-related trucks is equal to zero, which suggests that the industry prefers other means of transport for this type of commodity. However, this result also indicates that more data collection is needed to better understand SHV operations in agricultural-related activities, if any. Note that the number of trucks specifically registered as for transporting grain comprised only 7,284 vehicles, although Texas crop harvesting certainly requires many more trucks than this. The literature review indicates that Texas crops are often harvested by custom harvesting crews from other states, such as Colorado, Montana, Iowa, and Missouri, to name a few. Custom harvesters travel in caravans that include transport trucks for combines and other agricultural equipment, SU and tractor-semi trailer grain haulers or dump trucks, and other types of SU and tractor-semi-trailer trucks. The SU and tractor-semi trailer trucks often travel alongside the combine in the field to receive the crop being harvested. These custom harvest crews often begin the harvest season in south Texas and work northward from Texas to the Canadian border. There are generally two harvest seasons per year during which custom harvest crews operate in Texas. According to discussions with TxDMV, no records are readily available to assist in determining the number of out-of-state registered agricultural trucks that operate in Texas during the harvest. CTR did request a database of temporary agricultural exemptions, which are issued much like a permit. However, this database, consisting of a mix of flat bed and dump trucks, comprised fewer than 1,000 vehicles. Thus, the numbers of agriculture trucks listed in Table 3.7 comprise only Texas-registered grain trucks.

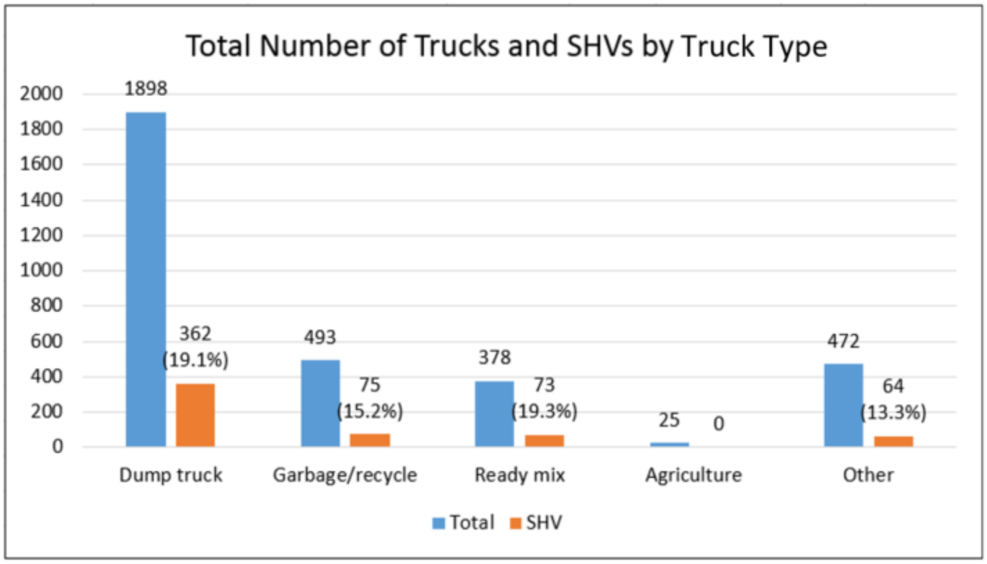


Figure 3.8: Total number of trucks and SHVs by truck type

Figure 3.9 illustrates the proportions of different types of SHVs. For these SHVs, 61% are SU4 (four-axle SHV), 16% are SU5 (five-axle SHV), 13% are SU6 (six-axle SHV), 8% are SU7 (seven-axle SHV), and only 2% are SU3 (three-axle SHV). The results suggest that the SU4 is the most popular type of SHV operating in Texas based on the project sites visited.

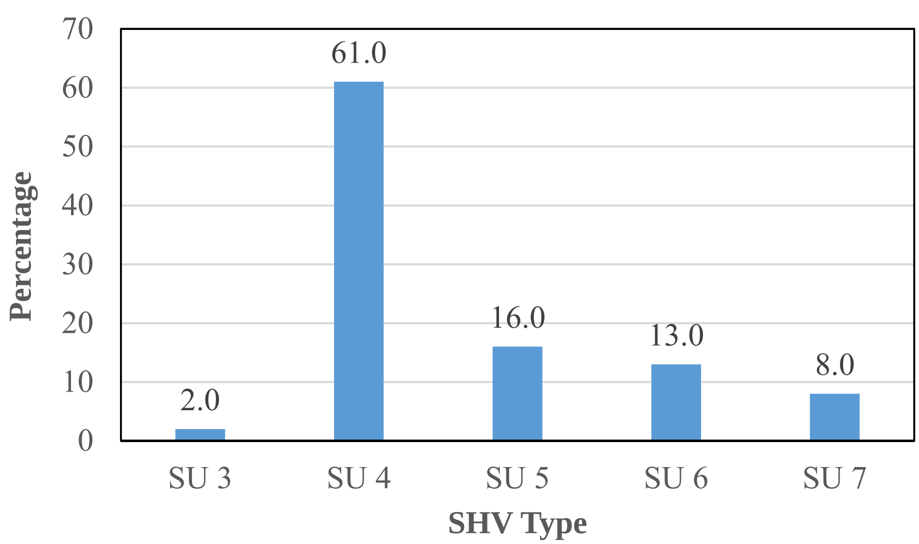


Figure 3.9: Distribution of SHVs by configuration

Estimate of SHVs Operating in Texas for Selected Truck Types

Table 3.7 provides our estimates of the total number of SHVs by type (SU3, SU4, SU5, SU6, and SU7) operating in Texas. The table includes the percentage observed for each truck type and commodity, and the estimated total number of trucks of each type and commodity. The estimated number of trucks was obtained by performing a simple statistical analysis based on the limited data set available, which was discussed in the previous section. It is worth noting that the available data was not enough to perform a more comprehensive analysis, and the estimated results shall be considered with caution. As shown in Table 3.7, the proportion of non-SHV trucks represents the largest percentage of all truck types, as expected. For the SHVs, the SU4 group represents the most prevalent type of SU. For this reason a much more comprehensive route- and corridor-level truck data collection process was undertaken, as discussed in a later section.

The fixed site visit information was used to estimate SHV numbers operating in Texas for selected truck types based on the following assumption: the statewide SHV distribution for each truck type is the same as was observed from the sample data. Taking dump trucks as an example, the proportions for SU3, SU4, SU5, SU6, SU7, and non-SHVs are 0.1, 10.4, 3.5, 2.6, 2.5, and 80.9%. Then, these proportions were transformed to represent the total number of trucks. For the dump trucks, a total of 37 SU3 were estimated, a total of 7425 of SU4, and so on. This analysis was performed for all commodities and SU types. The observed number of trucks is compared to the statewide truck estimate in Table 3.7.

Table 3.7: Number of different SHVs for different functions

Truck Type	Statewide Total Number	Percentage Observed						Statewide Number of Trucks—Estimated					
		SU3	SU4	SU5	SU6	SU7	Non-SHV	SU3	SU4	SU5	SU6	SU7	Non-SHV
Dump truck	71,172	0.1	10.4	3.5	2.6	2.5	80.9	37	7425	2475	1875	1800	57,560
Garbage/ recycle	9,275	1.6	12.2	1.4	-	-	84.8	151	1129	132	-	-	7,864
Ready-mix	9,155	-	7.7	5.0	6.6	-	80.7	-	702	460	605	-	7,387
Agriculture	7,284	-	-	-	-	-	100.0	-	-	-	-	-	7,284
Other	8,907	-	12.9	0.4	-	-	86.7	-	1151	38	-	-	7,718
Total	105,793	0.3	10.7	2.9	2.3	1.5	82.4	108	4193	1133	904	578	87,813

Note: The number of truck types and total number of trucks do not represent the entire number of registered trucks in Texas. This estimation is based only on truck types and numbers observed at fixed data collection sites.

Site Visits for Dimension Measurement

To obtain axle spacing and other dimensions of SHVs, the researchers visited one asphalt paving project located in Sunset Valley (in southwest Austin, between MoPac Expressway and Highway 290), shown in Figure 3.10. At this road resurfacing project, most of the trucks were SHV dump trucks delivering hot-mix asphalt (HMA) mixtures. These SHVs normally lift up their liftable axles before entering the sites to get better maneuverability.

Figure 3.10: Location of Sunset Valley paving project (from Google Map)

During the visit, CTR collected the following information for each truck (Figure 3.11 and Figure 3.12):

- Truck ID to differentiate the trucks;
- SHV types: SU4, SU5, SU6, or SU7;
- Front overhang: The distance between the first axle and the front bumper;
- Rear overhang: The distance between the rear axle and the rear of the truck;
- Width of the truck;
- Length of the truck (including the driving cab and dump bed);
- Length of dump bed;
- Axle spacing

Truck #	SHV_Type	FOH	Axle_Spacing_1	Axle_Spacing_2	Axle_Spacing_3	ROH	Width	Length	Dump Bed Length

FOH = front overhang (distance from the center of the steer axle to the front-most portion of the truck)
ROH = rear overhand (distance from the center of the last axle to the rear-most portion of the truck)

Figure 3.11: Dimension data collection inputs

Figure 3.12: Dimension measurement process

In addition, during the visit, CTR collected information about the tire dimensions and specifications, as well as the type of control system for the liftable axles, as shown in Figure 3.13

and Figure 3.14 respectively. The control system can be divided into two parts: the first part is the system that controls the pressure of the air bag suspension that is attached to the axle. The pressure/travel distance adjustment control is typically located outside of the cab and is calibrated by knowledgeable equipment shop personnel. This system is calibrated to result in a given amount of load in relation to the amount of pressure in the air bag, which is related to the amount of extension of the axle when deployed. The second system, located inside the cab, is operated by the driver and simply lowers or lifts the axle by deflating or pressurizing the air bag suspension. However, the driver cannot use the lift control to set the exact load of the liftable axle. The cab control panel can only be used to lower or lift the axle—thus, the amount of axle load can vary from truck load to truck load depending on how much material is placed in the cargo bed or drum. If similar amounts are placed each time (in terms of weight), the load on the axle will be similar from truck load to truck load since the amount of lift axle travel is already fixed.

Figure 3.13: Tire dimensions

Figure 3.14: Control system of the liftable axles

In total, during the Sunset Valley visit, CTR obtained the dimension data for 14 SHVs, including ten SU4 trucks, one SU5 truck, one SU6 truck, and two SU6 trucks. The detailed data is shown in Table 3.8.

Table 3.8: Basic information for the trucks investigated

Truck_ID	Date_Collected	City	SHV_Type	FOH	Axle_Spacing_1	Axle_Spacing_2	Axle_Spacing_3	Axle_Spacing_4	Axle_Spacing_5	Axle_Spacing_6	ROH	Width	Length	Dump Bed Length
				ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
1	10/19/2015	AUSTIN	4	2.3	15.0	4.7	4.3				2.5	7.6	28.8	17.1
2	10/19/2015	ROUND ROCK	4	2.4	12.0	4.6	4.5				3.9	7.9	27.4	16.8
3	10/19/2015	DALE	4	3.7	12.9	4.3	4.3				2.8	7.2	28.1	17.6
4	10/19/2015	DALE	4	2.4	13.1	4.3	4.4				3.8	7.8	28.1	17.2
5	10/19/2015	AUSTIN	4	2.1	15.0	4.8	4.4				NA	NA	NA	NA
6	10/19/2015	BUDA	4	4.0	13.8	4.8	4.3				3.5	7.8	30.4	18.6
7	10/19/2015	AUSTIN	4	4.0	10.9	4.9	4.3				3.4	7.8	27.6	14.9
9	10/19/2015	MANOR	4	2.3	14.5	4.2	4.4				4.1	8.1	29.4	16.9
12	10/20/2015	AUSTIN	4	3.7	10.0	5.7	4.3				3.8	7.4	27.4	17.8
14	10/20/2015	ROUND ROCK	4	2.0	13.2	4.6	4.3				3.8	7.8	27.9	18.8
8	10/19/2015	ROUND ROCK	5	3.0	11.0	3.9	4.3	4.6			3.8	7.8	30.6	19.0
10	10/19/2015	ROUND ROCK	6	3.9	15.0	3.6	3.3	3.5	4.8		3.7	8.5	34.7	20.3
13	10/20/2015	DEL VALLE	7	2.3	9.6	3.4	3.3	4.0	4.4	11.4	0.0	8.3	38.4	NA
11	10/20/2015	DEL VALLE	7	2.1	9.0	3.6	3.5	3.9	4.4	12.0	0.0	8.0	38.5	19.7

Sites Visits for Weight Measurement Training

The final type of site visit conducted involved weight measurement training for the CTR researchers. Six team members received this training at a TxDOT maintenance yard in the north Travis area. This training was complemented by the purchase of the same equipment TxDPS uses in their CVE activities. CTR purchased two HAENNI 101 scales (Figure 3.15) to measure trucks' axle weight. The HAENNI 101 scale has a range of 0–20,000 lb and it can work in an environment with temperatures ranging from 0 to 140 °F. When measuring weight no more than 2,500 lbs, it has an accuracy of ±100 lbs; when measuring weight 2500–10,000 lbs, it has an accuracy of ±200 lbs; when measuring weight 10,000–20,000 lbs, it has an accuracy of ±300 lbs.

Figure 3.15: HAENNI WL 101 scale

CTR also purchased several plywood sheets for use as blanks under wheel positions that were not being weighed to prevent mismeasurement between the axles due to variations in suspension compression. This is the same process used by DPS–CVE. The placement of the scales and wood sheets is shown in Figure 3.16, where the scales are placed under the tires of the axle to be measured, and the wood sheets are placed under the tires of other axles. Prior to the measuring process, the scales and wood sheets are placed just before the tires, and then one member guided the driver to drive the truck slowly onto the wood sheets and scales; after the truck stopped, the readings on the scale were recorded. See Figure 3.17.

Figure 3.16: Placement of scales and wood sheets during measurement

Figure 3.17: Weight measuring process

During the training, CTR researchers collected the weight data of one truck (unloaded three-axle dump truck provided by TxDOT) at 23 different positions in the maintenance yard, which were pre-marked before the measurement. In addition to considering the effects of environmental factors on the accuracy of weight measurement, CTR also took measurement of the pavement temperature, scale temperature, tire temperature, tire pressure, and the ground gradient at each position. Table 3.9 provides the detailed weight data at each position.

Table 3.9: Weight measurement at TxDOT north Travis area maintenance yard

Station	Axle 1 Weight			Axle 2 Weight			Axle 3 Weight			TARE WEIGHT	CARGO WEIGHT	TOTAL WEIGHT
	Left	Right	Total	Left	Right	Total	Left	Right	Total			
1-12	5250	4700	9950	3700	3300	7000	3600	3150	6750	23700	0	23700
1-21	5150	4800	9950	3600	3400	7000	3650	3150	6800	23750	0	23750
2-12	5200	4800	10000	3750	3300	7050	3700	3200	6900	23950	0	23950
2-21	5200	4800	10000	3700	3300	7000	3750	3200	6950	23950	0	23950
3-12	5150	4950	10100	3800	3350	7150	3600	3100	6700	23950	0	23950
3-21	5150	4900	10050	3800	3400	7200	3600	3100	6700	23950	0	23950
4-21	5200	4800	10000	3650	3350	7000	3600	3100	6700	23700	0	23700
5-21	5150	4900	10050	3800	3400	7200	3700	3050	6750	24000	0	24000
7-21	5150	4950	10100	3700	3250	6950	3750	3150	6900	23950	0	23950
8-21	5200	4850	10050	3850	3300	7150	3750	3150	6900	24100	0	24100
10-21	5200	4850	10050	3750	3350	7100	3650	3100	6750	23900	0	23900
12-21	5200	4850	10050	3700	3350	7050	3600	3150	6750	23850	0	23850
16-21	5000	5150	10150	3550	3550	7100	3450	3350	6800	24050	0	24050
18-21	4950	5150	10100	3550	3500	7050	3500	3300	6800	23950	0	23950
20-21	4950	5050	10000	3400	3500	6900	3400	3400	6800	23700	0	23700
22-21	4900	5100	10000	3450	3550	7000	3250	3350	6600	23600	0	23600
24-21	4850	5100	9950	3450	3550	7000	3300	3400	6700	23650	0	23650
26-21	4800	5250	10050	3650	3400	7050	3350	3450	6800	23900	0	23900
28-21	4750	5200	9950	3500	3500	7000	3350	3450	6800	23750	0	23750
57-12	4900	4900	9800	3600	3500	7100	3450	3300	6750	23650	0	23650
59-12	5050	4950	10000	3750	3400	7150	3550	3100	6650	23800	0	23800
60-12	5050	4900	9950	3850	3600	7450	3650	3150	6800	24200	0	24200
62-12	5000	4900	9900	3550	3500	7050	3500	3350	6850	23800	0	23800

3.2.4 Company Site Visits

CTR visited Martin Marietta Materials' plant site (Figure 3.18) and collected the following data for a SU5 ready-mix truck:

- First liftable axle: Pusher axle with single low profile tire, and
- Second liftable axle: Booster axle with single tire.

Figure 3.18: Martin Marietta Materials plant site visit

CTR measured the dimensions of the truck, and also collected axle weights, tire pressure, and temperature for different axle combinations of the liftable pusher axle and the booster axle. Table 3.10 describes the six designed axle combinations, depending on whether the liftable axles are up or down and whether the truck is loaded or not.

Table 3.10: Description of combinations

Combination number	Are liftable axles up/down?	Is booster axle up/down?	Unloaded or loaded material
1	Up	Up	Unloaded
2	Down	Up	Unloaded
3	Up	Up	Loaded
4	Down	Up	Loaded
5	Down	Down	Loaded
6	Up	Down	Loaded

Tables 3.11–3.15 describe the tire temperature, tire pressure, and axle weight data collected for the steer axle, liftable pusher axle, tandem axle, and booster axle of the SU5 ready-mix truck.

Table 3.11: Weight measures – steer axle for each of six measurement combinations

Combination number	Axle 1 (Steer axle)						
	Temperature		Pressure		Weight		
	Left	Right	Left	Right	Left	Right	Total
1	111	105	114	114	4,500	4,600	9,100
2	116	115	115	115	3,700	3,850	7,550
3	114	115	116	116	5,600	5,000	10,600
4	114	114	118	118	4,800	4,000	8,800
5	112	110	112	117	9,400	9,200	18,600
6	111	111	118	118	10,300	10,100	20,400

Table 3.12: Weight measures – liftable pusher for each of six measurement combinations

Combination number	Axle 2 (Liftable pusher axle)						
	Temperature		Pressure		Weight		
	Left	Right	Left	Right	Left	Right	Total
1	-	-	-	-	-	-	-
2	109	111	109	111	2,400	2,400	4,800
3	-	-	-	-	-	-	-
4	109	109	110	112	2,200	2,000	4,200
5	111	110	110	113	3,000	3,000	6,000
6	-	-	-	-	-	-	-

Note: blanks indicate that the pusher was lifted for the specified measurement combination

Table 3.13: Weight measures – first tandem axle for each of six measurement combinations

Combination number	Axle 3 (First Tandem Axle)						
	Temperature		Pressure		Weight		
	Left	Right	Left	Right	Left	Right	Total
1	106	103	112	112	5,700	5,600	11,300
2	114	106	112	140	4,900	5,000	9,900
3	116	117	116	116	14,000	12,000	26,000
4	107	109	116	116	14,000	11,400	25,400
5	111	110	115	116	6,600	6,150	12,750
6	110	110	114	116	8,200	8,100	16,300

Table 3.14: Weight measures – second tandem axle for each of six measurement combinations

Combination number	Axle 4 (Second Tandem Axle)						
	Temperature		Pressure		Weight		
	Left	Right	Left	Right	Left	Right	Total
1	109	112	114	114	6,050	5,100	11,150
2	110	103	112	110	5,500	4,500	10,000
3	112	110	116	114	15,000	10,700	25,700
4	112	110	116	114	14,300	10,100	24,400
5	109	108	115	114	4,900	6,000	10,900
6	110	108	116	114	5,500	6,600	12,100

Table 3.15: Weight measures – booster axle for each of six measurement combinations

Combination number	Axle 5 (Booster Axle)						
	Temperature		Pressure		Weight		
	Left	Right	Left	Right	Left	Right	Total
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	104	107	115	115	7,800	6,850	14,650
6	117	116	116	114	8,200	6,500	14,700

Note: blanks indicate that the booster was lifted for the specified measurement combination.

With the different combinations of axle configurations measured, as expected, lowering liftable axles reduced the load on other axles, especially adjacent axles. For example, comparing Combination 1 and Combination 2, we see that lowering the pusher axle reduced the weights of the steer and both tandems by approximately 1,500 lbs, 1,500 lbs, and 1,200 lbs respectively. A similar effect is noted when comparing Combination 3 and 4. A different result is observed when lowering the booster axle. Lowering and increasing weight on the booster axle increased the weight on axles at the front of the truck including the steer and pusher (if deployed). This effect is apparent when comparing Combinations 3, 4, 5, and 6. When the booster is lowered (Combinations 5 and 6), the steer axle weight increases significantly, while the weight on the tandem drive axles is reduced and apparently partially transferred on the booster axle.

In addition, a review of the tandem axle loads for the loaded condition showed that a variation of approximately 2,000 lbs from the left to right dual tire assembly was evident for Combinations 3 and 4. This was due to the position of the mixer drum, which was not rotating since the load consisted of aggregate, sand, and water, but no cement. This mixture is typically used to calibrate ready-mix trucks. Since the mixer drum was stationary, the position of the interior mixing fin or screw varies in width from the largest to the smallest cross section of the drum. The angular position of the drum and fins can shift the load from side to side within the drum, causing the load to oscillate from one side of the truck (dual tire set) to the other. When stationary, the position of the fins and load can place more load on one side of the truck than the other, as seen in these measurements.

The entire data collection process at the Martin Marietta site was performed over the course of one business day. In total, the measurement process of the six different axle configurations took around six hours. This data collection process was feasible during truck operations at the site only because CTR had permission to take as much time as needed, and the truck being measured was not in service at the time. However, for taking measurements during regular construction/mix operations, this timeframe would be infeasible. Therefore, the trip to Martin Marietta yielded the insight that current portable scale measurement practices were not fast enough to use for collecting axle weight data at a paving operation or other situations in which trucks were delivering loads and then leaving the site.

3.2.5 On-route Data Collection

Previous sections have described how CTR collected truck operational type and configuration data that was useful, but not of sufficient quantity to estimate the number and configuration of SHVs operating statewide and regionally. CTR needed a sufficient sample size of various truck types based on the number of registered trucks given in the TxDMV-VTR truck registration data. Statistical sampling was necessary since VTR truck registration data does not include information about the number of axles, axle group types, or if axles are fixed or liftable. Thus, a registered dump truck might be a five-axle tractor semi-trailer, a three-axle SU dump, or an SU4, SU5, SU6, or SU7 of unknown configuration.

To address this issue, CTR determined that it was necessary to collect a large sample of trucks operating within metropolitan, urban, and rural regions of the state in addition to the highway routes that connect these areas. Given a sufficiently large sample and the total number of registered trucks for a given operational type, statements can be made about the fleet composition whether SU or tractor semi-trailer and numbers and types of axles. As described in the following sections, the researchers collected data on 53,519 trucks during on-route data collection and 24-hour video counts. In addition, a corridor evaluation was performed during trips along RM 1431, IH 35, and FM 969, resulting in an additional 20,924 truck counts. Thus, 74,443 trucks were counted and described during the study, though the statistical analysis to determine numbers of SHVs was performed separately on each of these datasets as discussed later.

CTR collected on-route data to evaluate different SHV operational aspects as summarized below:

a. Collect a sufficient sample size based on statistical procedures to make statements about the numbers, operational types, and configurations of SHVs operating in Texas, both statewide and regionally. Use TxDMV-VTR truck registration data as a general guide for sampling areas.

b. Collect truck data within major metropolitan (>200,000 population), intermediate (199,000–50,000 population), and small urban areas (49,999–5,000 population), as well as rural areas (< 5,000 population).

c. Collect truck data along route links outside the boundaries of metropolitan and urban areas on route links.

d. Evaluate the variation in SHV operational types, numbers, and configurations along a given route under different conditions. For this purpose, truck traffic data was collected on multiple days along RM 1431 EB/WB, IH 35 NB/SB, and FM 969 EB/WB during different hours of the day, in both day and nighttime conditions, on different days of the week, during different months, and in different weather conditions.

   Truck data was aggregated by time of day and part of the day (day-parting) using the five-part definition developed by Nielson Audio and provided in Table 3.16 (this guideline is used to relate urban traffic volumes to radio programming):

Table 3.16: Nielson Audio day parts

Morning drive time	6 AM to 10 AM
Midday drive time	10 AM to 3 PM
Afternoon drive time	3 PM to 7 PM
Evening drive time	7 PM to midnight (12:00 AM)
Overnight drive time	Midnight to 6 AM

e. Evaluate how SHV operations might vary between urban and rural areas along route links. This information can help determine the radius of operation for SHVs and SU trucks (how far they travel outside a populated area) compared to tractor-trailer, regional, and long-haul operations.

On-route Truck Data Collection Procedure

A SONY PX333 audio recorder was used to collect truck data while driving along highway corridors. The PX333 can store up to 44 hours of recordings and allows the user to download files to a computer for processing and analysis. During data collection, a driver would travel along a route and describe the trucks that were passing by in the opposite direction or in a lane in the same direction. On-route data collection included the same information collected during on-site visits at ready-mix plants, landfills, and other fixed-site locations at which SHVs were thought to operate. However, during the on-route data collection there was no prior knowledge about potential SHV operations, the truck types, and configurations. During data collection the following information was verbally recorded as a minimum. It is worth noting that collecting and describing passing trucks was a challenge due to the high truck volumes along major freight corridors such as IH 35.

1. Route designation of the truck being observed: IH 35, US 287, SH 146, etc.
2. Direction in which the truck was traveling based on road signage; IH 35 NB, IH 10 EB, etc.
3. Periodic notation of the time
4. Periodic notation of Texas reference markers (a TxDOT system documenting the state-maintained highway network of on-system roadways) or mile markers
5. Weather conditions (sunny, raining, overcast, etc.)
6. Periodic notation of crossing roadways, overpasses, interchanges, or other physical references
7. Periodic notation of ramp numbers and destinations town or cities; for example, Exit 250, SH 45 Toll, Loop 1 Toll
8. Truck configuration: SU and number of axles, SHV type, tractor-semi trailer, and number of axles and axle group types
9. If an SHV, whether the axles were up, down, or mixed, and which axles were up/down
10. Truck operational type: box van, dump, ready-mix truck, ocean container, roll-off truck, etc. Note all truck types were collected, not just those known to operate as SHVs. Thus,

information was collected about gooseneck or step-deck five-axle tractor trailers, tractors towing twin trailers, and many other configurations not related to SHVs. This was done to obtain a sample that could be used to make statements about the percentage and numbers of SHVs in operation as a percentage of all trucks, trucks of the same registration type, and numbers of SHVs with different axle configurations.

11. When visible, a description of the load being carried or whether the truck was empty
12. When visible, the trucking company name. This information was collected for use in conjunction with the Federal Motor Carrier Safety Administration SaferSys database and the TxDMV Truck Stop database to determine if a truck was an owner/operator unit or part of a small, intermediate, or large fleet. Though this information was not examined further in this project, future studies of SHV operations can make use of this information.
13. Additional comments as appropriate to help current and future data collection efforts, such as locations of heavy truck generators, major industries, or materials plants

The data was transcribed from the audio recording to an Excel spreadsheet of the same format as data collection for an on-site visit. Transcription time typically exceeded the travel time or duration of the recording. It was found that pausing the audio until a truck was approaching reduced the length of the recording, though pausing and restarting the audio could have resulted in lost information or fewer reference statements about time, location, and local landmarks.

Figure 3.19 shows an excerpt from a transcribed Excel file containing on-route data collected on IH 10 in Houston.

	E	F	G	H	I	J	K	L	M
1	Timestamp (Press CTRL, SHIFT, +, : all at once)	Highway Route & direction in which trucks were travelling	Company	Truck Configuration	Function	SHV Type	Are Liftable Axles Up/Down?	Is Booster Axle Up/Down?	Position of axle (config code)
2	8:06 AM								
3		IH 10 W FR	unknown	SHV	Volumetric Mixer	SU4	Down		1L-2
4		IH 10 W FR	unknown	SHV	Volumetric Mixer	SU4	Down		1L-2
5		IH 610 N	unknown	5-axle Tractor Trailer	Compressed Gas				
6		IH 610 N	unknown	5-axle Tractor Trailer	Compressed Gas				
7		IH 610 N FR	unknown	3-axle straight truck	Roll Off				
8		IH 610 N FR	Woody Bogler	5-axle Tractor Trailer	Box Van				
9		IH 610 N FR	Cheb	4-axle Tractor Trailer	Box Van				
10		IH 610 N FR	Energy Alloys	5-axle Tractor Trailer	Flat Bed empty				
11		IH 610 S	Centex	SHV	Ready Mix	SU4		up	2-1B
12		IH 610 S	unknown	SHV	Dump	SU5			2L-2
13		IH 610 S	unknown	5-axle Tractor Trailer	Bulk Tanker				
14		IH 610 S	unknown	5-axle Tractor Trailer	Flat Bed empty				
15		IH 610 S	unknown	5-axle Tractor Trailer	Dump				
16		IH 610 S	unknown	5-axle Tractor Trailer	Flat Bed empty				
17		IH 610 S	unknown	5-axle Tractor Trailer	Dump				
18		IH 610 S	unknown	5-axle Tractor Trailer	Flat Bed empty				
19		IH 610 S	Dupré	5-axle Tractor Trailer	Fuel tanker				

... Houston 1-28-16 Thursday | Houston 1-27-16 Wednesday | Austin to Houston 1-26-16 | Backgroun ...

Figure 3.19: A small sample of truck data collected in Houston on 1-27-2016 transcribed from audio to Excel

Analysis of On-Route Data to Determine Distribution of Registered Trucks

As an audio recording from an on-route trip was completed, the data was transcribed to an Excel file, then summarized before adding the data to a comprehensive database spreadsheet. The Excel database contains numbers of trucks observed by operational type and configuration, which is aggregated to provide a total sample summary for all trucks recorded.

Table 3.17 lists the summary data for 32,088 trucks that were collected during on-route data collection supplemented by additional data from 24-hour videos recorded at TP&P truck classification sites, which increased the sample to 53,519 trucks. Table 3.18 provides the summary for trucks observed in urbanized areas and along routes linking urbanized areas.

Table 3.17: Summary of on-route truck data

Truck Operational Type	Total Vehicles	Percent of Grand Total All Vehicles
Car Transporter	472	0.8819%
Car Transporter empty	108	0.2018%
Saddle Mount Unit	50	0.0934%
Boat Transporter	3	0.0056%
Box Van - SU 2- or more axles	938	1.7526%
Box Van SU 3	5	0.0093%
Box Van SU 4	6	0.0112%
Box Van SU 5	0	0.0000%
Box Van 3-axle tractor trailer (28-1/2')	286	0.5344%
Box Van 5-axle tractor Trailer	24,839	46.4116%
Box van - Refrigerated 5-axle tractor trailer	1,268	2.3693%
Box Van 4-axle tractor Trailer	842	1.5733%
Box Van - Refrigerated 4-axle tractor trailer	4	0.0075%
Box Van Cloth Side	192	0.3588%
Box Van Double Trailer Unit	1,136	2.1226%
Dump single unit - 2- or more axles	1,294	2.4178%
Dump single unit SU 3	0	0.0000%
Dump single unit SU 4	280	0.5232%
Dump single unit SU 5	127	0.2373%
Dump single unit SU 6	57	0.1065%
Dump single unit SU 7	108	0.2018%
Dump Tractor Trailer	4,327	8.0850%
Bulk Tanker 5-axle tractor trailer	1,025	1.9152%
Bulk Tanker 6-axle tractor trailer	1	0.0019%
Bulk Tanker - Double 28-1/2' Trailers	1	0.0019%
Milk tanker	55	0.1028%
Asphalt Tanker	64	0.1196%
Asphalt Tanker SU 2- or more axles	24	0.0448%
Crude Oil Tanker SU 2 or more axles	32	0.0598%
Crude Oil Tanker SU 4	3	0.0056%
Crude Oil Tanker	781	1.4593%
Chemical Tanker	444	0.8296%
Compressed Gas Tanker	162	0.3027%
Food Grade Tanker	88	0.1644%
Fuel Tanker - SU 2- or more axles	155	0.2896%
Fuel Tanker SU 4	22	0.0411%
Fuel Tanker SU 5	0	0.0000%
Fuel Tanker - tractor trailer	789	1.4742%
Acid Tanker	13	0.0243%
Salt Water Vacuum Truck	145	0.2709%
Industrial Vacuum Truck (SU) 2 or more -axles	64	0.1196%
Industrial Vacuum Truck SU 4	17	0.0318%
Industrial Vacuum Truck SU 5	0	0.0000%
Sewer Vacuum Truck (SU) 2- or more axles	28	0.0523%
Sewer Vacuum Truck SU 4	1	0.0019%
20' Ocean Container 20' chassis Box	456	0.8520%
20' Ocean Container 40' chassis Box	80	0.1495%
20' Ocean Container Chassis empty	16	0.0299%
20' Ocean Container ISO Tank in Frame	82	0.1532%
40' Ocean Container Box	1,083	2.0236%
45' Ocean Container Box	4	0.0075%
40' Ocean Container Chassis empty	110	0.2055%
40' ISO Tank Frame	6	0.0112%
Intermodal 53' Container	432	0.8072%
Garbage or Roll Off Unit - SU 2 or more fixed axles	945	1.7657%
Garbage or Roll Off Unit - SU 3	4	0.0075%
Garbage or Roll Off Unit - SU 4	82	0.1532%
Garbage or Roll Off Unit - SU 5	1	0.0019%
Heavy Duty Roll Off - Tractor Trailer	102	0.1906%
Garbage Transfer	91	0.1700%
Scrap Dump	148	0.2765%
Beverage Transporter	31	0.0579%
Grain Hauler 5-axle	202	0.3774%
Grain Hauler 6-axle	8	0.0149%

Truck Operational Type	Total Vehicles	Percent of Grand Total All Vehicles
Flat bed loaded	3,396	6.3454%
Flat bed empty	1,837	3.4324%
Flat bed loaded (SU) 2- or more fixed axles	272	0.5082%
Flat bed loaded SU 4	29	0.0542%
Flat bed loaded SU 5	3	0.0056%
Flat bed empty (SU) 2- or more fixed axles	211	0.3943%
Flat bed empty SU 4	22	0.0411%
Flat bed empty SU 5	3	0.0056%
Step Deck loaded	742	1.3864%
Step Deck empty	320	0.5979%
Low Boy loaded	240	0.4484%
Low Boy empty	189	0.3531%
Double Drop Deck Tractor-trailer 5 or more axles Loaded	15	0.0280%
Double Drop Deck Tractor-trailer 5 or more axles Empty	21	0.0392%
Livestock Trailer	81	0.1513%
Liquid Livestock Feed Tanker 5-axle	9	0.0168%
Logging Truck 5-axle	0	0.0000%
Mulch or Woodchip Hopper Truck 5-axle	15	0.0280%
Moving Van	109	0.2037%
Ready Mix Truck (SU) 2-axle	3	0.0056%
Ready Mix Truck (SU) 3-axle	628	1.1734%
Ready Mix Truck SU 4	95	0.1775%
Ready Mix Truck SU 5	50	0.0934%
Ready Mix Truck SU 6	1	0.0019%
Ready Mix Truck SU 7	0	0.0000%
Volumetric Ready Mix Truck (SU) 3-axle	27	0.0504%
Volumetric Ready Mix Truck SU 4	9	0.0168%
Volumetric Ready Mix Truck SU 5	1	0.0019%
Mobile Crane (SU) 3- or more axles	39	0.0729%
Mobile Crane SU 4	2	0.0037%
Mobile Crane SU 5	0	0.0000%
Crane Truck 2 or 3 fixed axles	42	0.0785%
Crane Truck 4 or more fixed axles	5	0.0093%
Crane Truck SU4	6	0.0112%
Crane Truck SU5	0	0.0000%
Mobile Home or Portable Building transporter	56	0.1046%
Stake Bed 2- or more axle SU	76	0.1420%
Stake Bed SHV SU4	1	0.0019%
Heavy Wrecker (SU) 2- or more axles	74	0.1383%
Heavy Wrecker SU 4	19	0.0355%
Concrete Beam Hauler multiple axles	57	0.1065%
Concrete Beam Hauler 5- or more axles empty	15	0.0280%
Pole Trailer - various loads (pipe, telephone poles etc.)	3	0.0056%
Water Tank Truck 2- or more axles	38	0.0710%
5-axle Tractor Trailer Water Tank Truck	3	0.0056%
Concrete Pump Truck (SU) 3- or more axles	36	0.0673%
Concrete Pump Truck SU4	1	0.0019%
Oil Field Winch Truck 2- or more fixed axles	12	0.0224%
Oil Field Winch Truck SU 4	3	0.0056%
5-axle Tractor Trailer - oil field frack pump	12	0.0224%
5-Axle Tractor Trailer - Frac Water Heater	3	0.0056%
5-Axle Tractor Trailer - Frac Blending Unit	9	0.0168%
5-axle Tractor Trailer - oil field Pumping Unit	5	0.0093%
5-axle Tractor Trailer - oil field equipment (unknown purpose)	18	0.0336%
Nitrogen pump Truck - 2 or more axles	6	0.0112%
Wireline Truck - 2 or more axles	53	0.0990%
Slickline Truck 2- or more axles	10	0.0187%
Dual Cement Pot 5-axle tractor trailer	17	0.0318%
Cement Blending Unit 5- or more Tractor Trailer	2	0.0037%
Hot Oiling Unit 2- or more axles	2	0.0037%
Oil Well Servicing unit 3 - 5 axles	2	0.0037%
Oil Well Servicing unit 6 or more axles	0	0.0000%
4- or More Axle Tractor - Trailer Mud Tank truck	6	0.0112%
SU 2- or more fixed axles Pressure Pump Truck	52	0.0972%
Pressure Pump Truck SU 4	7	0.0131%
Pressure Pump Truck SU 5	0	0.0000%
Other Types	357	0.6671%
Other Types - SHV SU4	3	0.0056%
Total Single Unit Trucks - 3- or more fixed axles	4,735	
Total SHVs	967	
Total all Single Unit Trucks	5,693	
Total Vehicles Counted	53,519	100.0000%

Table 3.18: Total trucks, SUs, and SHVs observed in urbanized areas and along routes linking urbanized areas

On-Route and 24-Hour Video Truck Data Collection Numbers and Percentages within Urbanized Areas or on Routes Linking Urbanized Areas													
Truck Type and Data Collection Condition	Houston[1]	Austin - San Antonio	Wichita Falls	Austin - Waco	Marble Falls	Austin	Dallas	El Paso	Midland	Pharr	Laredo	Lubbock	Totals
Total Trucks observed in an Urbanized Area	4,316		923		142	6,375	2,944	9,836	1,060	1,942	1,823	2,280	31,641
Total Trucks observed on routes linking Urbanized Areas	7,770	4,498	8,465	871	274								21,878
												Total Trucks Observed	53,519
Single Unit Trucks Observed in an Urbanized Area (% Total Trucks UA)	**334** (7.7%)		**46** (5%)	**66** (7.6%)	**50** (35%)	**1,141** (17.9%)	**349** (11.9%)	**885** (9.0%)	**161** (15.2)	**210** (10.8%)	**505** (27.75)	**220** (9.6%)	**3,632** (11.5%)
Single Unit Trucks Observed on Routes Linking Urbanized Areas (% Total Trucks on links	**700** (9.0%)	**489** (10.9%)	**455** (5.4%)		**82** (30%)								**1,026** (4.5%)
SHVs Observed in an Urbanized Area (% SU Trucks)	**72** (21.6%)		**3** (6.5%)		**17** (34%)	**323** (28.3%)	**59** (16.9%)	**120** (13.6%)	**31** (19.25%)	**16** (7.6%)	**8** (1.6%)	**4** (1.8%)	**577** (15.8%)
SHVs Observed on Routes Linking Urbanized Areas (% SU Trucks)	**137** (19.6%)	**85** (17.4%)	**45** (9.9%)	**16** (24.2%)	**22** (26.8%)								**168** (16.3%)

[1] Two week-long data collection trips were made to Houston. During the second trip, heavy rains occurred during the last three days, which likely affected the operation of SU trucks and SHVs that support construction and other outdoor activities.

Based on the route data, a statistical analysis was performed to determine the estimated numbers of SHVs of each configuration for dump trucks, ready-mix trucks, and waste management vehicles as discussed in the following section. Route counts helped ensure that the same trucks were not counted twice (for repeat trips along the same route, the researchers could not ensure that the same truck was counted more than one time). The route video counts and repeat route (corridor) counts were analyzed separately.

Dump Trucks

- Total number of registered dump trucks in Texas, per TxDMV registration data = 71,172
- 6,193 dump trucks were counted during route and video data collection, representing approximately 12.2% of all trucks observed. This sample included 4,327 tractor-semi trailer dumps and 1,866 SU dumps (including SHVs). Based on this sample, the researchers estimate that the 71,172 dump trucks in Texas, of all configurations, are distributed as shown in Table 3.19 (95% confidence with 2% error):

Table 3.19: Estimated number of dump trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Five-axle tractor trailer dumps	49,727	69.8%
Three-axle SU dumps	14,871	20.9%
SU4	3,218	4.5%
SU5	1,460	2.1%
SU6	655	0.9%
SU7	1,241	1.7%
Total	71,172	100%

Ready-mix Trucks

- Total number of registered ready-mix trucks in Texas, per TxDMV registration data = 9,275
- 848 ready-mix trucks were counted, representing approximately 1.6% of all trucks observed. Based on this sample, the researchers estimate that the 9,275 ready-mix trucks in Texas are distributed as shown in Table 3.20 (95% confidence with 4% error):

Table 3.20: Estimated number of ready-mix trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Three-axle SU trucks	8,236	88.8%
SU4	459	4.9%
SU5	558	6.0%
SU6	22	0.02%
SU7	0	0.00%
Total	9,275	100.0%

Waste Management Trucks

- Total number of registered waste management trucks in Texas, per TxDMV registration data = 9,155
- 1,032 waste management trucks were counted, representing approximately 1.9% of all trucks observed. Based on this sample, the researchers estimate that the 9,155 waste management trucks in Texas are distributed as shown in Table 3.21 (95% confidence with 3% error):

Table 3.21: Estimated number of waste management trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Three-axle SU trucks	6,301	68.8%
SU3	27	0.03%
SU4	547	5.9%
SU5	7	0.07%
SU6	0	0.0%
SU7	0	0.0%
Five-axle tractor trailer	2,274	24.8%
	9,155	100.0%

* Includes five-axle garbage transfer tractor-trailers, scrap dumps, and heavy roll-off units

Analysis of Corridor Data in Austin to Determine Distribution of Registered Trucks

In the previous section, information about route count (network-statewide) truck data for all registered truck operational types was presented to determine the estimated configuration distribution of specific truck types known to operate as SHVs, including dump, ready-mix, and garbage trucks. In this section, information will be discussed regarding the second analysis using truck data collected during repeat trips on a specified corridor in the Austin District. The goal of this analysis was to determine if the percentages of truck configurations changes depending on whether a network (statewide) or local corridor analysis is conducted.

CTR obtained truck data during 87 one-way trips along an approximately 30-mile long corridor in the Austin District. Figure 3.20 shows the route travelled for the repeat trips. The trips were made along a 10-mile section of RM 1431 from Cedar Park to its junction with IH 35 southbound, 20.3 miles along IH 35 southbound to IH 35 junction with FM 969, then 0.75 miles west on FM 969 for a total one-way trip length of 31.05 miles. The return trip was along the same route in reverse order. Several facilities along this route either operate or serve vocational trucks (both non-SHVs and various configurations of SHVs) and tractor semi-trailers. Truck operational types include dumps, ready-mix, flat beds, tanker trucks, and waste management trucks, among others.

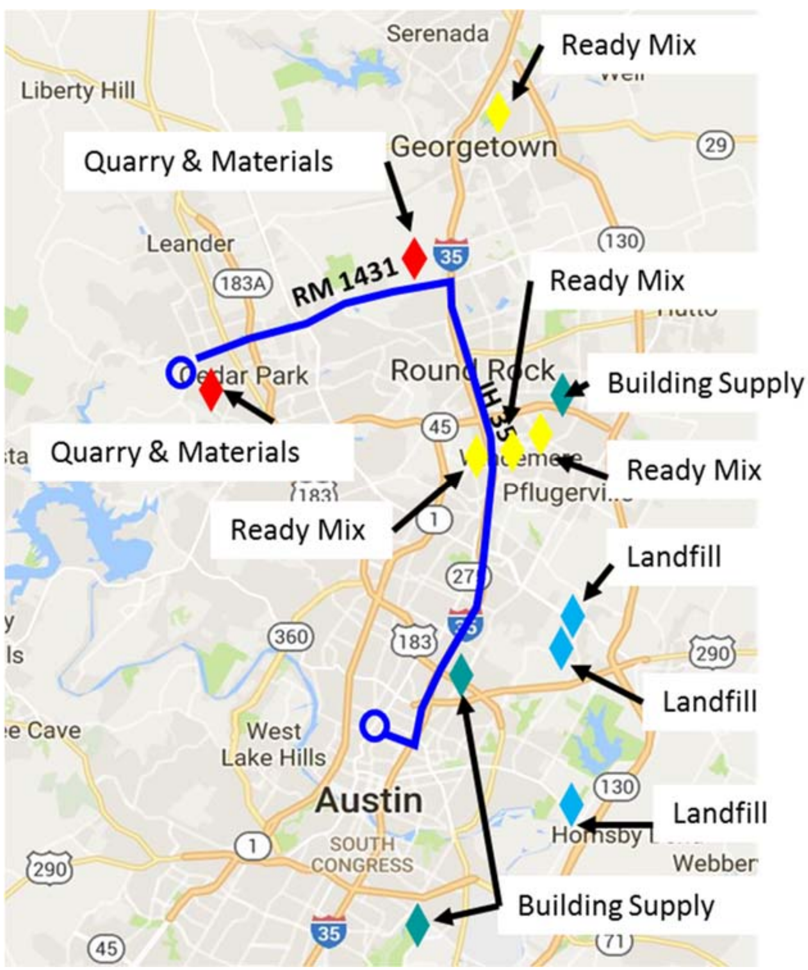


Figure 3.20: Map showing the route taken in both directions to collect repeated samples of truck data

Table 3.22 shows the truck data that was collected during 87 repeat trips along the corridor organized using the same categories used for the network route (statewide) truck data. The trips were made at different times of the day and days of the week over a period of months. The distributions of all trucks, SU trucks, and SHVs by drive times and days of the week are shown in Figures 3.21–3.30.

Table 3.22: Trucks counted during repeat trips on RM 1431, IH 35, and FM 969

Truck Operational Type	Total Vehicle Counts	Percent - Grand Total
Car Transporter	166	0.79%
Car Transporter empty	31	0.15%
Saddle Back Unit	25	0.12%
Boat Transporter	1	0.00%
Box Van - SU 2- or more axles	83	0.40%
Box Van SU 3	0	0.00%
Box Van SU 4	2	0.01%
Box Van SU 5	1	0.00%
Box Van 3-axle tractor trailer (28-1/2')	228	1.09%
Box Van 5-axle tractor Trailer	9486	45.34%
Box Van 5-axle tractor Trailer Refrigerated	381	1.82%
Box Van 4-axle tractor Trailer	389	1.86%
Box Van 4-axle tractor Trailer Refrigerated	23	0.11%
Box Van Cloth Side	92	0.44%
Box Van Double Trailer Unit	338	1.62%
Dump single unit - 2- or more axles	737	3.52%
Dump single unit SU 3	19	0.09%
Dump single unit SU 4	570	2.72%
Dump single unit SU 5	385	1.84%
Dump single unit SU 6	192	0.92%
Dump single unit SU 7	144	0.69%
Dump Tractor Trailer	2776	13.27%
Bulk Tanker 5-axle tractor trailer	261	1.25%
Bulk Tanker 6-axle tractor trailer	0	0.00%
Bulk Tanker - Double 28-1/2' Trailers	1	0.00%
Milk tanker	3	0.01%
Asphalt Tanker	31	0.15%
Asphalt Tanker SU 2- or more axles	4	0.02%
Crude Oil Tanker SU 2 or more axles		0.00%
Crude Oil Tanker SU 4		0.00%
Crude Oil Tanker	25	0.12%
Chemical Tanker	44	0.21%
Compressed Gas Tanker	23	0.11%
Food Grade Tanker	25	0.12%
Fuel Tanker - SU 2- or more axles	59	0.28%
Fuel Tanker SU 4	13	0.06%
Fuel Tanker SU 5	0	0.00%
Fuel Tanker - tractor trailer	157	0.75%
Acid Tanker	4	0.02%
Salt Water Vacuum Truck	13	0.06%
Industrial Vacuum Truck (SU) 2 or more -axles	16	0.08%
Industrial Vacuum Truck SU 4	6	0.03%
Industrial Vacuum Truck SU 5	1	0.00%
Sewer Vacuum Truck (SU) 2- or more axles	8	0.04%
Sewer Vacuum Truck SU 4	0	0.00%
20' Ocean Container 20' chassis Box	21	0.10%
20' Ocean Container 40' chassis Box	0	0.00%
20' Ocean Container Chassis empty	0	0.00%
20' Ocean Container ISO Tank in Frame	9	0.04%
40' Ocean Container Box	17	0.08%
45' Ocean Container Box	0	0.00%
40' Ocean Container Chassis empty	1	0.00%
40' ISO Tank Frame	0	0.00%
Intermodal 53' Container	94	0.45%
Garbage or Roll Off Unit - SU 2 or more fixed axles	269	1.29%
Garbage or Roll Off Unit - SU 3	0	0.00%
Garbage or Roll Off Unit - SU 4	24	0.11%
Garbage or Roll Off Unit - SU 5	1	0.00%
Heavy Duty Roll Off - Tractor Trailer	4	0.02%
Garbage Transfer	18	0.09%
Scrap Dump	46	0.22%
Beverage Transporter	52	0.25%
Grain Hauler 5-axle	43	0.21%
Grain Hauler 6-axle	0	0.00%
Flat bed loaded	1343	6.42%
Flat bed empty	602	2.88%
Flat bed loaded (SU) 2- or more fixed axles	125	0.60%
Flat bed loaded SU 4	25	0.12%
Flat bed loaded SU 5	1	0.00%
Flat bed empty (SU) 2- or more fixed axles	66	0.32%
Flat bed empty SU 4	27	0.13%
Flat bed empty SU 5	8	0.04%
Step Deck loaded	235	1.12%
Step Deck empty	89	0.43%
Low Boy loaded	80	0.38%
Low Boy empty	94	0.45%
Double Drop Deck Tractor-trailer 5 or more axles Loaded		0.00%
Double Drop Deck Tractor-trailer 5 or more axles Empty		0.00%
Livestock Trailer	12	0.06%
Liquid Livestock Feed Tanker 5-axle	0	0.00%
Logging Truck 5-axle	1	0.00%
Mulch or Woodchip Hopper Truck 5-axle	26	0.12%
Moving Van	94	0.45%
Ready Mix Truck (SU) 2-axle	0	0.00%
Ready Mix Truck (SU) 3-axle	316	1.51%
Ready Mix Truck SU 4	4	0.02%
Ready Mix Truck SU 5	13	0.06%
Ready Mix Truck SU 6	0	0.00%
Ready Mix Truck SU 7	0	0.00%
Volumetric Ready Mix Truck (SU) 3-axle	20	0.10%
Volumetric Ready Mix Truck SU 4	12	0.06%
Volumetric Ready Mix Truck SU 5	3	0.01%
Mobile Crane (SU) 3- or more axles	15	0.07%
Mobile Crane SU 4	0	0.00%
Mobile Crane SU 5	0	0.00%
Crane Truck 2 or 3 fixed axles	0	0.00%
Crane Truck 4 or more fixed axles	0	0.00%
Crane Truck SU4	0	0.00%
Crane Truck SU5	0	0.00%
Mobile Home or Portable Building transporter	40	0.19%
Stake Bed 2- or more axle SU	29	0.14%
Stake Bed SHV SU4	0	0.00%
Heavy Wrecker (SU) 2- or more axles	30	0.14%
Heavy Wrecker SU 4	13	0.06%
Concrete Beam Hauler multiple axles	39	0.19%
Concrete Beam Hauler 5- or more axles empty	27	0.13%
Pole Trailer - various loads (pipe, telephone poles etc.)	5	0.02%
Water Tank Truck 2- or more axles	28	0.13%
5-axle Tractor Trailer Water Tank Truck	0	0.00%
Concrete Pump Truck (SU) 3- or more axles	38	0.18%
Concrete Pump Truck SU4	1	0.00%
Oil Field Winch Truck 2- or more fixed axles	0	0.00%
Oil Field Winch Truck SU 4	0	0.00%
5-axle Tractor Trailer - oil field frack pump	0	0.00%
5-Axle Tractor Trailer - Frac Water Heater	0	0.00%
5-Axle Tractor Trailer - Frac Blending Unit	0	0.00%
5-axle Tractor Trailer - oil field Pumping Unit	0	0.00%
xle Tractor Trailer - oil field equipment (unknown purpo	16	0.08%
Nitrogen pump Truck - 2 or more axles	0	0.00%
Wireline Truck - 2 or more axles	0	0.00%
Slickline Truck 2- or more axles	0	0.00%
Dual Cement Pot 5-axle tractor trailer	0	0.00%
Cement Blending Unit 5- or more Tractor Trailer	0	0.00%
Hot Oiling Unit 2- or more axles	0	0.00%
Oil Well Servicing unit 3 - 5 axles	0	0.00%
Oil Well Servicing unit 6 or more axles	0	0.00%
4- or More Axle Tractor - Trailer Mud Tank truck	0	0.00%
SU 2- or more fixed axles Pressure Pump Truck	0	0.00%
Pressure Pump Truck SU 4	0	0.00%
Pressure Pump Truck SU 5	0	0.00%
Other Types	82	0.39%
Other Types - SHV SU4	3	0.01%
Total Single Unit Trucks - 2- or more fixed axles	1,789	8.55%
Total SHVs	1,449	6.93%
Total all Single Unit Trucks	3,238	15.48%
Total Vehicles Counted	20,924	100.00%

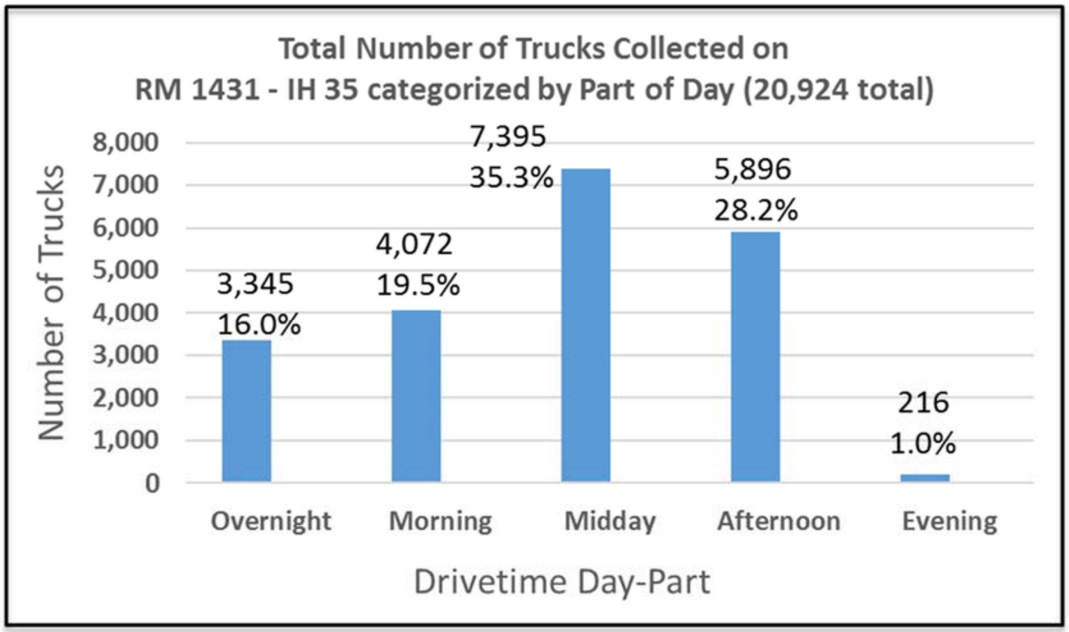


Figure 3.21: Distribution of all trucks observed along RM 1431 – IH 35 by drive-time segment

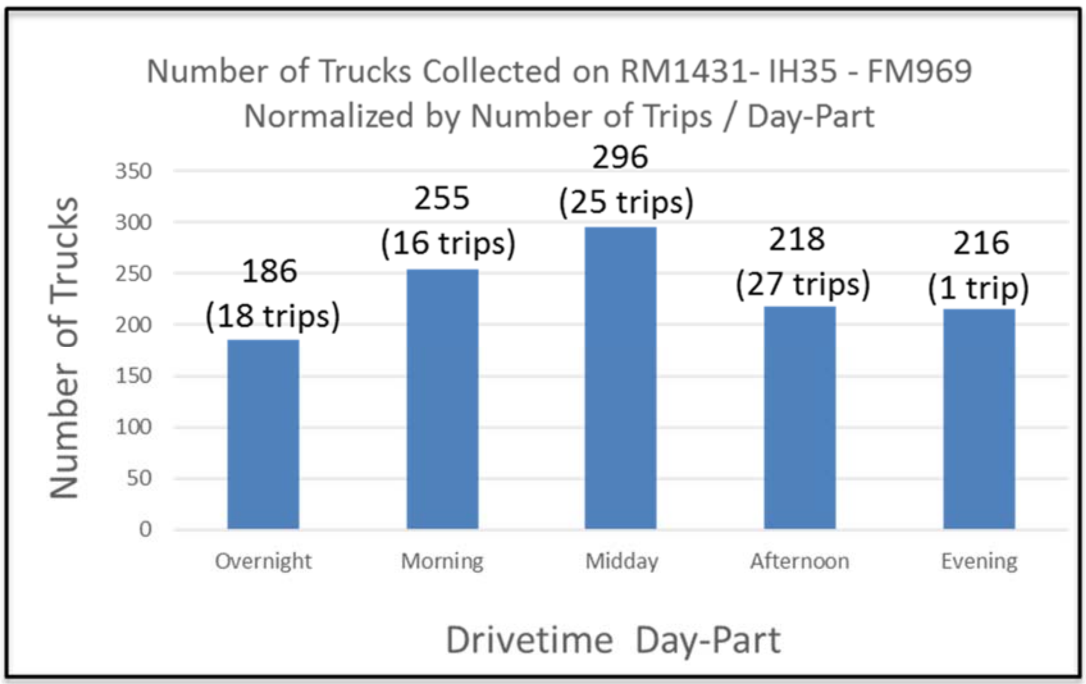


Figure 3.22: Distribution of total trucks normalized by number of trips made during each drive-time segment

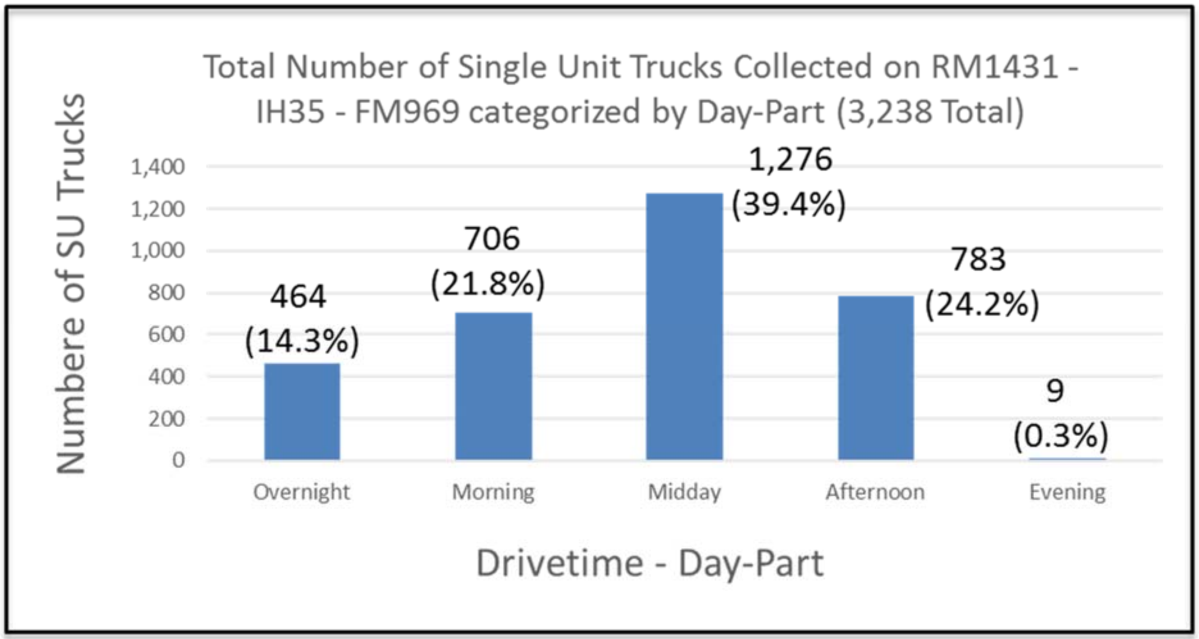


Figure 3.23: Distribution of SU trucks observed during a 1-hour period aggregated for each drive-time segment

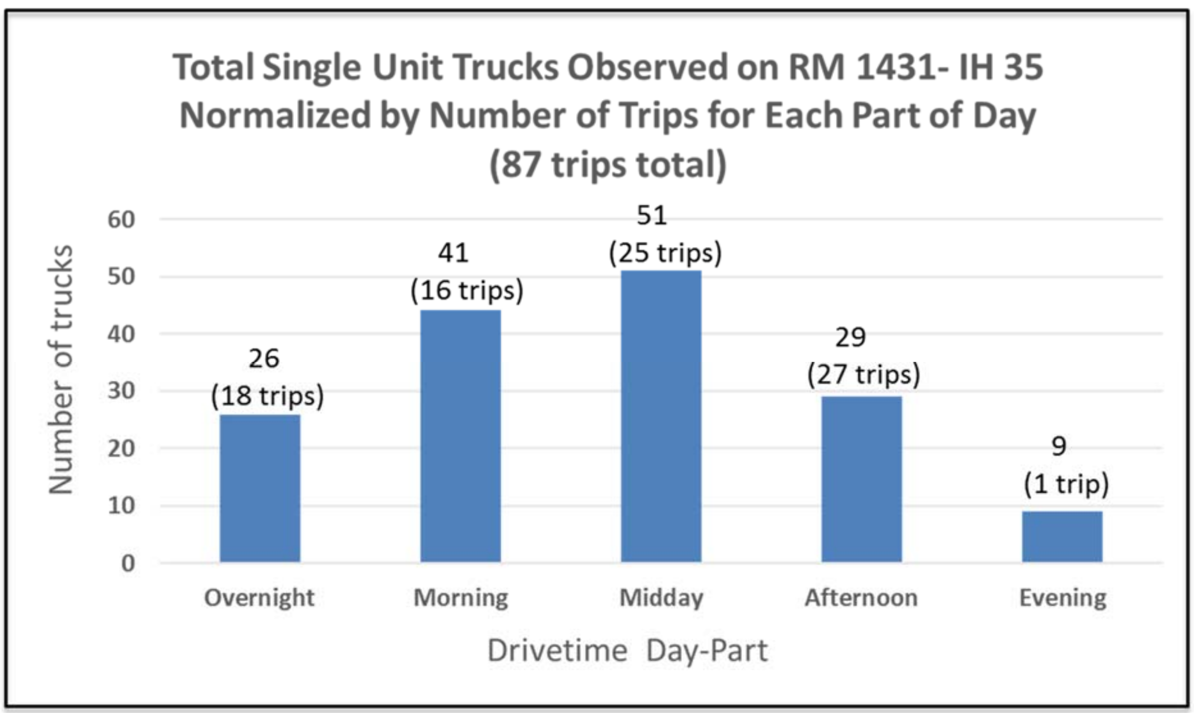


Figure 3.24: Distribution of SU trucks normalized by number of trips made during each drive-time segment

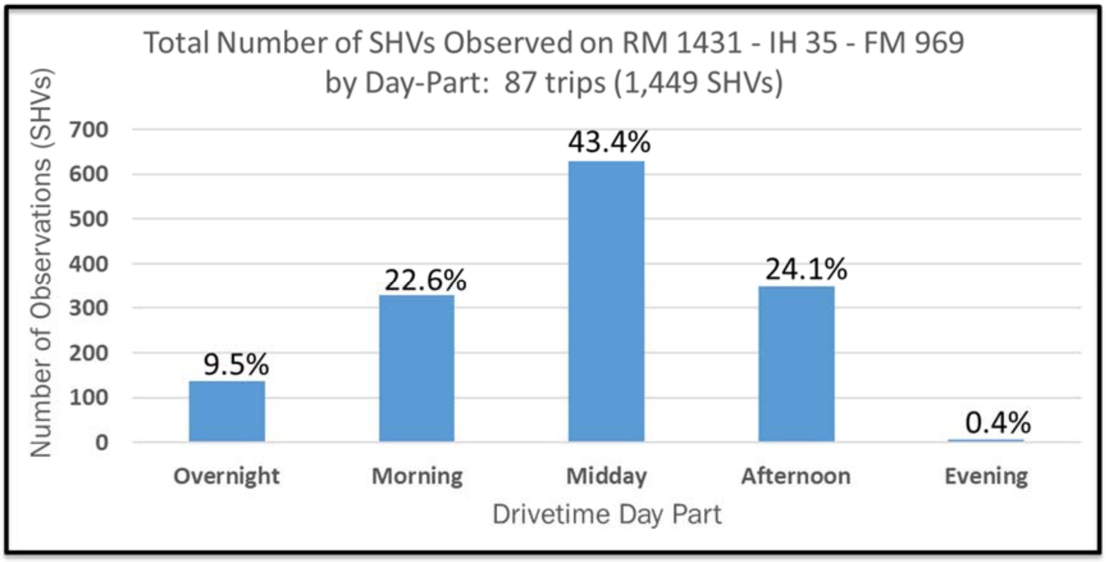


Figure 3.25: Distribution of SHVs observed during a 1-hour period aggregated by drive-time segment

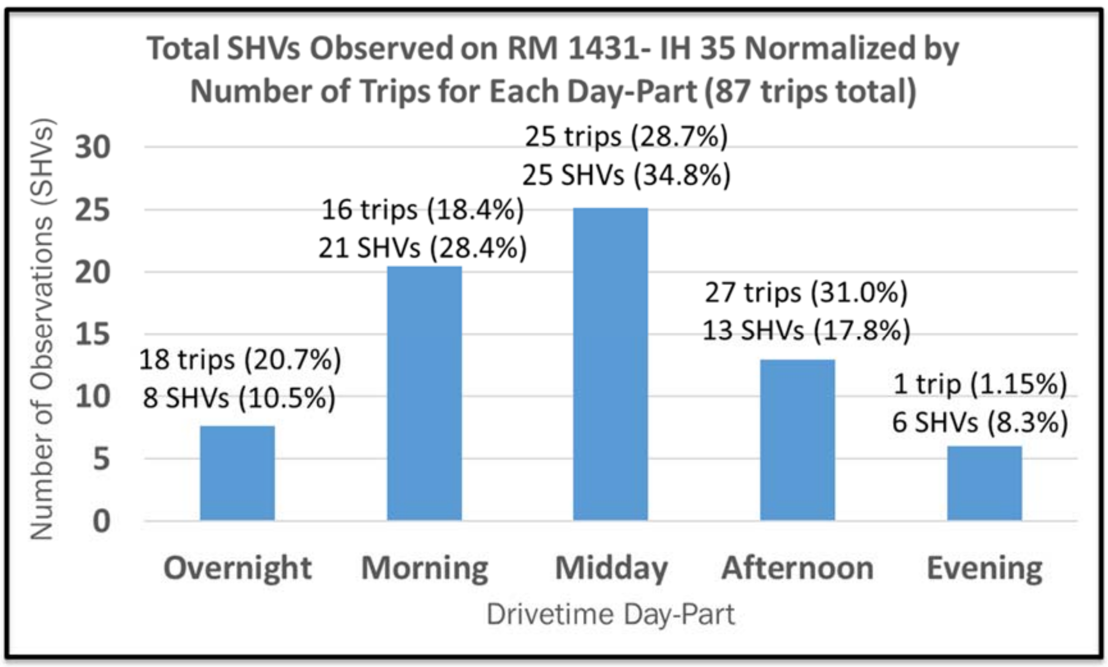


Figure 3.26: Distribution of SHVs normalized by number of trips made during each drive-time segment

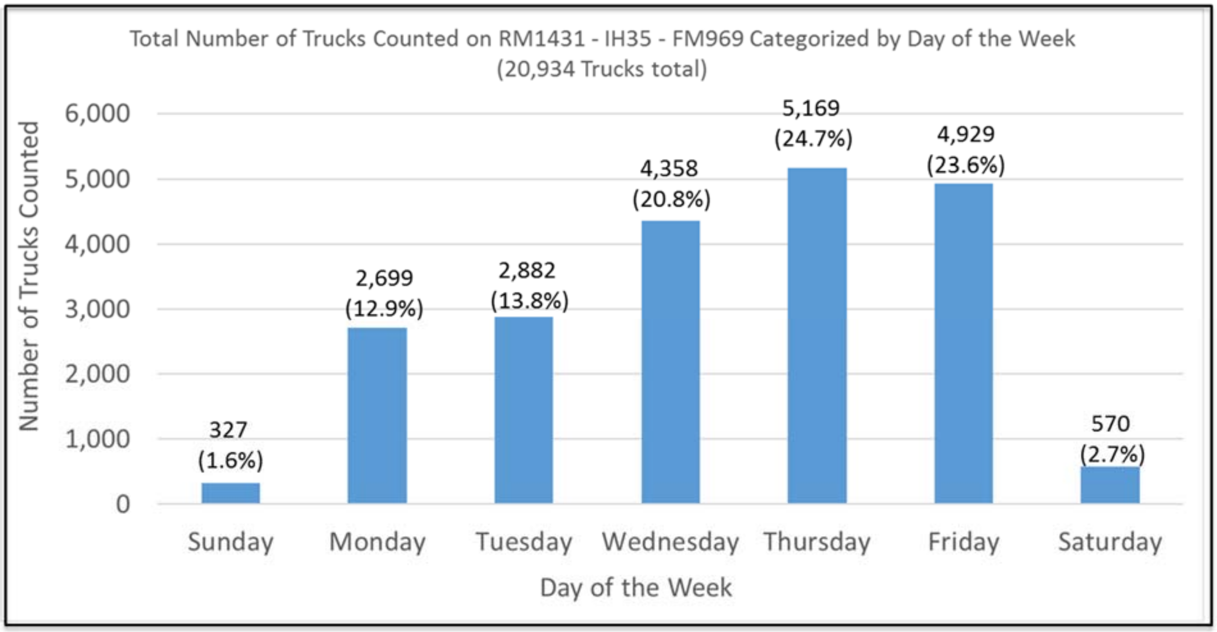


Figure 3.27: Total number of trucks observed on different days of the week

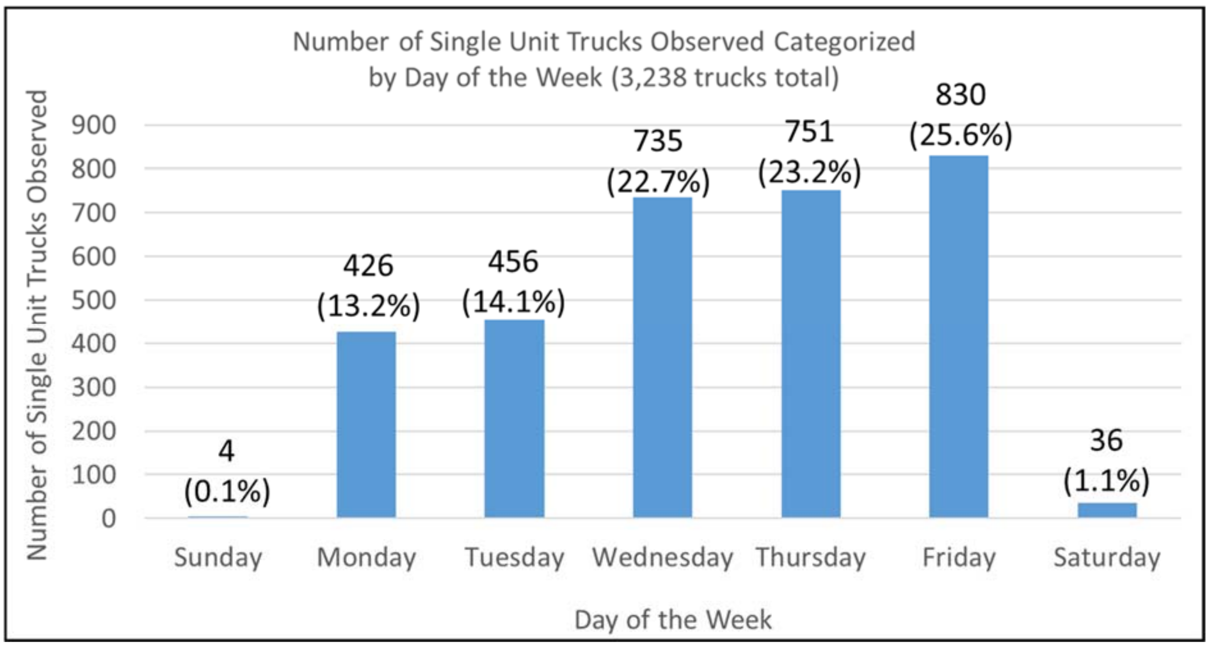


Figure 3.28: Total number of trucks observed on different days of the week

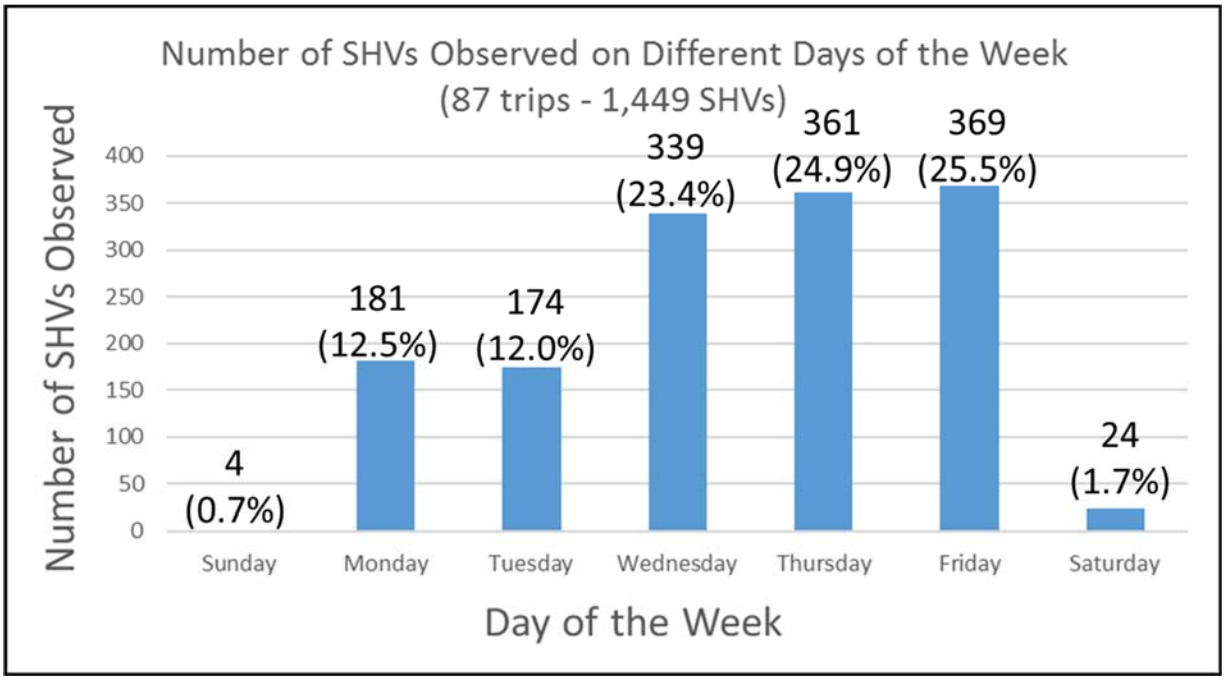


Figure 3.29: Distribution of SHVs observed on different days of the week

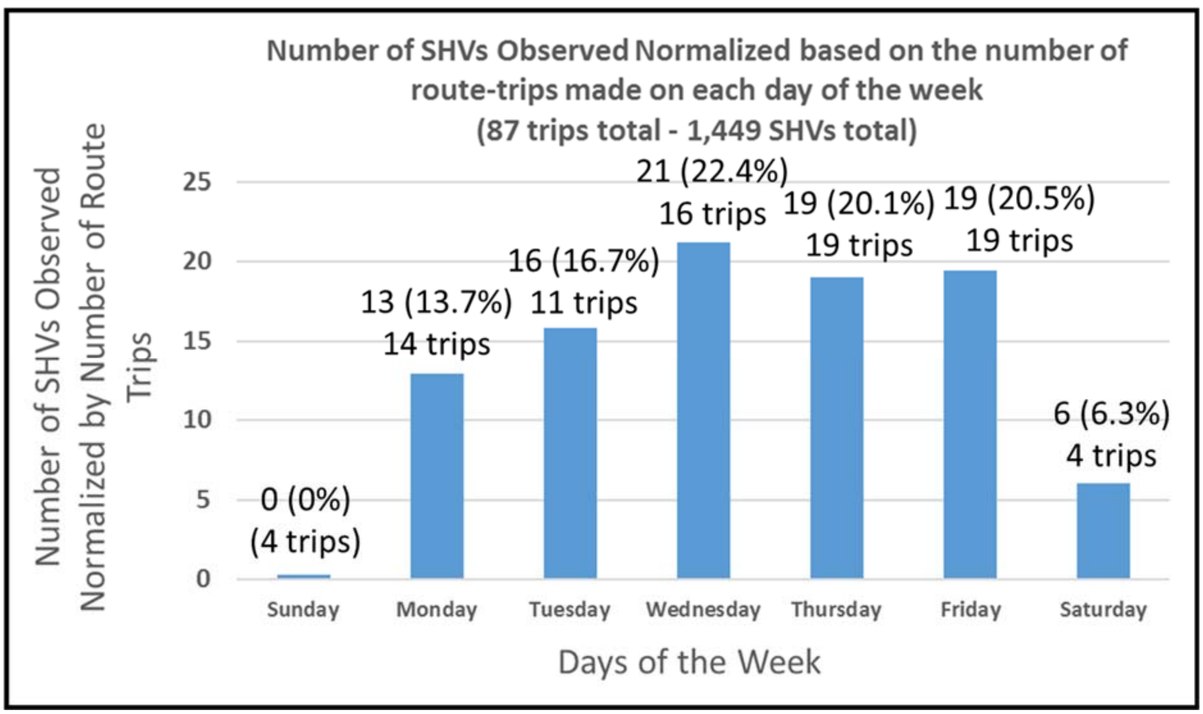


Figure 3.30: Distribution of SHVs normalized by number of route trips for different days of the week

It is important to note that these figures represent the number of SHVs observed during 87 sampling intervals of approximately one hour and therefore do not represent the total number of SHVs that operate along the route corridor during any given 24-hour period. This sampling methodology was studied further on other route types as a means for estimating the total number of SHVs operating per day, per week, and potentially longer periods of time. Based on experience gained during the fixed site and network-level (statewide) data collection efforts, CTR recognizes the seasonal nature and day-to-day climatic impacts that can affect truck operations and facility operations that are served by SHVs.

Based on the repeat trip data, a statistical analysis was performed to determine the estimated numbers of SHVs of each configuration for dump trucks, ready-mix trucks, and waste management vehicles as discussed in the following section. The population of registered trucks for the repeat trip data was not based on the total number of registered trucks for the state, but rather was based on registered trucks for counties within a 50-mile radius of the center point of the repeat trip corridor. Truck operators in general prefer a one-hour or approximately 50-mile one-way trip as the maximum travel distance to be profitable; ready-mix truck operators in particular prefer a 25-mile maximum round trip. This distance is based on time per delivery and fuel consumption, both of which affect profitability. The National Ready Mixed Concrete Association (NRMCA) has conducted annual surveys of ready-mix truck fleet operations. These surveys, taken over a period of years, show that the average loaded ready-mix fuel consumption is about 3.3 mpg. A loaded 18-wheeler dump can be expected to get about 5 mpg; thus, longer round trips affect profitability in terms of time and fuel consumption. A 50-mile radius encompasses the following counties shown in Table 3.23 with the numbers of registered dump, ready-mix, and waste management vehicles.

Table 3.23: Registered dump, ready-mix, and waste management vehicles in counties within a 50-mile radius of the repeat trip corridor

County	Dump	Ready Mix	Waste Management
Travis	3,411	302	626
Williamson	1,205	149	51
Bell	3,527	32	120
Bastrop	317	1	17
Burnet	380	11	1
Lee	135	2	0
Caldwell	155	4	2
Blanco	149	1	8
Hays	476	83	7
Milam	150	0	0
Llano	138	6	1
Fayette	203	3	10
Gillespie	337	1	4
Totals	**10,246**	**594**	**843**

Dump Trucks

- Total number of registered dump trucks in region, per TxDMV registration data = 10,246
- 4,823 dump trucks were counted, representing approximately 47.1% of all trucks observed. This sample included 2,776 tractor-semi trailer dumps and 2,047 SU dumps (including SHVs). Based on this sample, the researchers estimate that the 10,246 registered dump trucks in the repeat trip corridor region are distributed as shown in Table 3.24:

Table 3.24: Estimated number of dump trucks of each configuration
(Repeat counts corridor-level)

Truck Configuration	Estimated Number of trucks (Repeat trips)	%/Repeat	Estimated Number of trucks (Network)	%/Network
Five-axle tractor trailer dumps	5,897	57.6%	49,727	69.8%
Three-axle SU dumps	1,566	15.3%	14,871	20.9%
SU3	40	0.04%	0	0.0%
SU4	1,211	11.8%	3,218	4.5%
SU5	818	7.98%	1,460	2.1%
SU6	408	3.98%	655	0.9%
SU7	306	2.98%	1,241	1.7%
Total	10,246	100.0%	71,172	100%

Again, the repeat corridor data collection likely included duplicate counts of each truck type from the day-to-day, week-to-week and month-to-month periods. Thus, these numbers cannot be used to estimate the actual number of trucks for each configuration for statewide applications based on sound statistical principles, although the analysis does provide information about truck configurations operating along this specific corridor. The number and distribution of truck configurations do vary by day of the week and hour of the day as shown in Figures 3.25 through 3.30.

Ready-mix Trucks

- Total number of registered ready-mix trucks in counties within the 50-mile radius, per TxDMV registration data = 598. In all, 368 ready-mix trucks were observed, representing approximately 3.9% of all trucks observed. Based on this sample, the researchers estimate that the 598 ready-mix trucks in the region are distributed as shown in Table 3.25:

Table 3.25: Estimated number of ready-mix trucks of each configuration

(Repeat counts corridor-level)

Truck Configuration	Estimated Number of trucks (Repeat trips)	%/Repeat	Estimated Number of trucks (Network)	%/Network
Three-axle SU trucks	546	91.3%	8,236	88.8%
SU4	26	4.4%	459	4.9%
SU5	26	4.4%	558	6.0%
SU6	0	0.0%	22	0.02%
SU7	0	0.0%	0	0.00%
Total	598	100.0%	9,275	100.0%

Waste Management Trucks

- Total number of registered waste management trucks in counties within the 50-mile radius, per TxDMV registration data = 843
- 362 waste management trucks were observed, representing approximately 3.5% of all trucks observed. Based on this sample, the researchers estimate that the 843 waste management trucks in counties within the 50-mile radius are distributed as shown in Table 3.26 (95% confidence with 4% error):

Table 3.26: Estimated number of waste management trucks of each configuration

(Repeat counts corridor-level)

Truck Configuration	Estimated Number of trucks (Repeat trip)	%/Repeat	Estimated Number of trucks (Network)	%/Network
Three-axle SU trucks	626	74.3%	6,301	68.8%
SU3	0	0.0%	27	0.03%
SU4	56	6.6%	547	5.9%
SU5	2	0.02%	7	0.07%
SU6	0	0.0%	0	0.0%
SU7	0	0.0%	0	0.0%
Five-axle tractor trailer*	157	18.8%	2,274	24.8%
Totals	843	100.0%	9,155	100.0%

* Includes five-axle garbage transfer tractor-trailers, scrap dumps, and heavy roll-off units

Table 3.27: SHV operational types observed along route RM 1431 – IH 35 – FM 969 over 87 days of data collection

Day-Part	SHV Operational Types Observed During Different Days of the Week - 87 one-way trips										
	Dump	Ready Mix	Waste Management	Flat bed Loaded	Flat bed Empty	Vacuum Trucks	Fuel Tankers	Box Vans	Crane Trucks	Wreckers	Stake Beds
Sunday	0	0	0	0	0	0	1	0	0	0	0
Monday	196	5	5	4	5	0	1	53	0	3	0
Tuesday	154	4	2	6	4	1	1	1	0	1	0
Wednesday	319	8	3	4	14	2	2	1	0	3	0
Thursday	324	8	2	7	7	4	4	0	0	5	0
Friday	332	6	11	5	7	0	3	1	0	1	0
Totals	1325	31	23	26	37	7	12	56	0	13	0

Based on Figures 3.20–3.30, and Tables 3.16–3.26, we drew the following observations about facilities associated with SHVs.

a. **Quarries:** quarries might or might not operate their own fleet of trucks, but rather serve a wide range of trucking companies or construction businesses that operate tractor semi-trailers of different designs, SU two- or three-fixed axle trucks, and SHVs. Thus, trucks arrive at the quarry, pick up materials, and travel divergent paths to the project locations within the metro area or at rural locations.

   The radius of operation from a quarry to a project is an economic factor considered by the trucking company or construction firm, though the quarry might be the only materials source within reasonable travel distance. Quarries might be located in a rural area or have been overtaken by urban sprawl such that trucks operating from the quarry are mixed with local traffic and other types of heavy truck operations.

   Quarries are most often associated with dump trucks, though certain quarries may also incorporate other types of activities, such as a ready-mix plant, concrete casting/pre-stressing yard, or hot-mix plant. Thus, other truck types were observed, such as ready-mix trucks, volumetric ready-mix trucks, bulk tankers carrying cement, flat beds, drop decks, or double drop decks loaded with cast concrete components, and heavy haul OS/OW tractor/gooseneck trailers carrying heavy equipment. In addition, task-specific SHVs such as quarry explosives trucks or vacuum tank trucks that can transport environmental liquid waste were occasionally seen.

b. **Ready-mix Plants:** Ready-mix plants that have been observed might operate their own fleet of trucks composed of three-axle SU trucks and SHVs. Moreover, dump trucks and bulk tankers deliver materials such as aggregates, sand, and cement. Certain ready-mix truck companies in Texas currently only operate three-axle ready-mix trucks while other companies operate a mixed fleet of three-axle, SU4s, SU5s, and SU6s. Certain ready-mix plants might provide mix to several different ready-mix companies while others only service their own trucks and operations. In Houston the former operation type was most frequently observed, while in Austin, San Antonio, and Waco, the latter was more common.

   Though volumetric mixers are not distinguished from drum-type mixers in registration records, volumetric ready-mix plants tend to operate their own, small fleet of trucks and are much less commonly seen than drum-type mixers. This difference may in part be due to the fact that concrete mix produced from a volumetric mixer might not be accepted for structural concrete applications, based on agency specifications. Thus, ready-mix from volumetric mixers is more commonly used for sidewalks, driveways, rip rap, ditch liners, and other non-structural applications.

c. **Materials Yards:** For purposes of this study, a materials yard is an operation that incorporates two or more of the following functions: ready-mix plant; hot-mix plant; concrete casting yard; quarry (including excavation of aggregates, sand, soil, cement materials, dimensional stone, concrete structural members, and other materials or components used to construct public, commercial, or residential infrastructure). These operations quite often service a wide range of different companies, public agencies, and truck types. Trucks types may include tractor semi-trailer dumps with five or more axles and bulk tankers, SU dumps, ready-mix and volumetric ready-mix trucks, and SHVs, including dumps and ready-mix trucks.

CTR recognizes that highway, building, and other infrastructure project sites offer opportunities to observe material transport truck operations and types. As discussed in previous sections, project site visits have been made to collect detailed data about specific trucks. However, data collection within a construction project site presents certain safety risks that must be considered due to the movement of construction trucks arriving, waiting to deliver, delivering materials, and leaving the site. Data collection of truck type and configuration are relatively straightforward and safe, though collecting truck and tire dimensions may be more challenging—though doable. Based on experience collecting portable scale axle weights at two sites, it was determined that collecting truck axle weights using HAENNI portable scales at an operating construction site would be too dangerous for CTR personnel and disruptive to construction operations.

d. **Building Materials Suppliers:** Commercial, residential, and public sector construction is serviced by a wide range of operations that manufacture bricks, concrete blocks, pre-fabricated concrete components, lumber, plywood, drywall, shingles, concrete pipe and reinforced concrete box sections, insulation, and other materials. Building materials suppliers might operate their own fleet of trucks or service construction companies and trucking companies involved in commercial, residential, or public construction projects. Tractor-semi trailers (either flat beds or step-decks) often transport housing lumber or large quantities of drywall, although SU trucks and SHVs also transport most of the materials listed above. SU trucks (including SHVs) might also tow a pup trailer to increase the amount of materials being hauled. These trucks often incorporate a boom lift, knuckle-boom, or pallet fork lift to deliver the materials at ground level or to lift them to upper floors of a building.

e. **Landfills:** As with quarries, landfills are often located in rural areas, though landfills can be overtaken by urban sprawl. Landfills may be a) public facilities that serve public and private companies of all types or, b) facilities owned by a particular waste management company, and therefore, primarily served by their trucks. Landfills are served by trucks of many different types and configurations, including tractor semi-trailer dumps, environmental liquid waste vacuum tank trucks, and hazardous materials trucks from industrial operations, such as vacuum box roll-off containers. In addition, SU and SHV garbage trucks, dumpster service trucks, roll-offs, garbage compacter roll-offs, vacuum tank trucks, brush dumps, and grapple-trucks may operate from landfills. Again, based on their locations, landfill truck traffic might be intermixed with local traffic including light vehicles and heavy trucks.

f. **Petro-chemical and Oil Industry Operations:** Petro-chemical operations are centered in Houston and other Texas cities; however, oil and gas exploration is regional and primarily associated with the Permian Basin (west Texas), the Barnett Shale (north-central Texas), Granite Wash Formation (north-west Texas), the Eagleford Shale (south Texas), and the Haynesville/Bossier Shale (northeast Texas). Obtaining truck data, including SU trucks and SHV operations, in urbanized areas associated with the petro-chemical and oil refinery operations is easier than obtaining truck operations data at oil and gas exploration sites in the shale plays. Typically, oil and gas exploration is primarily rural and spread out in nature, though during the shale boom certain corridors or highway routes did carry extremely large volumes of trucks. Now that the shale-fracturing (fracking) boom has slowed significantly, it is more challenging to obtain truck data, including SHV operations associated with oil and gas exploration. However, based on various sources, including truck sales and company web sites describing their services, it is evident that the oil industry uses a variety of truck types that are SHVs. Refer to the TCPL for examples of oil industry SHVs.

g. **Agriculture and Livestock Production:** Agricultural activities are more challenging to observe in relation to truck operations and types of trucks used. Agricultural-related trucks include the transport of harvested crops and produce, livestock feed (both solid and liquid), transportation of livestock and poultry during the various stages of production, and supporting activities to maintain the facilities associated with agricultural production. Agricultural activities are often seasonal and custom harvesting in Texas is supported by a wide variety of out-of-state operations that begin the harvest in Texas and then move northward through Oklahoma, Kansas, Iowa, and finally Canada to harvest wheat, corn, sorghum, and other grains or cereals. In addition, some custom harvesting operations produce silage (crops harvested to feed livestock). In Texas large silage pits have been constructed in Gainesville, Aquilla, and San Angelo, among other locations. The Aquilla silage pit alone consists of 150,000 tons of silage that is transported from the field to the silage pit by tractor-semi trailer grain, dump trucks, SU fixed-axle trucks, and SHVs. In addition, field operations of the harvesting equipment are supported by SU fixed and SHV fuel lube and mechanics trucks. Obtaining public records about these trucks is challenging since many of these trucks are registered out of state.

h. **Logging and Biomass:** The Texas logging industry is primarily located in northeast Texas and is serviced by tractor-semi trailers that transport cut logs to saw mills. However, harvesting of forestry and agricultural biomass to produce wood chips for mulch, wood biomass electric power plants, and production of ethanol are also to be considered. The research team made a field visit to a biomass facility in Austin and obtained literature on this subject. Findings suggest this industry employs tractor semi-trailer trucks to transport logs and biomass in Texas. However, in other states SU trucks (including SHVs) are also used to transport logs and biomass.

Observations on RM 1431/IH 35 On-Route Data – Repeated Trips on the Same Corridor

- A higher percentage of all trucks (63%), SU trucks (63%), and SHVs (67%) travel the RM 1431/IH 35 route during the combined midday and afternoon times of day.
- Daily temperatures would be expected to be highest during the same times of day that truck activity is the highest. Thus, routes that are surfaced with HMA pavement could be expected to experience higher rutting rates compared to those routes that carry greater percentages of trucks during the evening, overnight, and morning segments.

- Conversely, routes built with continuously reinforced concrete pavement or jointed concrete pavements would expand with increasing temperatures, resulting in tighter cracks and joints that tend to increase load transfer.
- Approximately 50.4% of SHVs were observed on Thursday and Friday while 23.4% were observed on Wednesday and 24.2% were observed (equally distributed) on Monday and Tuesday. The remaining fractions were observed on Saturday and Sunday.
- Quarries, ready-mix plants, and similar construction material sources, served by dump and ready-mix trucks, have fixed hours of operation between approximately 6:00 AM and 5:00 PM. However, overnight construction operations may involve hot-mix paving or ready-mix pours from mobile, on-site batch plants. For this reason, SU vocational trucks, including SHVs may operate 24 hours a day.
- On interstate routes, three-axle ready-mix trucks primarily travel on the frontage roads, although operation of three-axle ready-mix trucks on IH mainlanes has been observed during overnight hours. In Austin, ready-mix trucks operating on the IH mainlanes tend to be SU4 or SU5 configurations; SU6 ready-mix trucks have been observed in the Houston area.
- Dump trucks, waste management trucks, construction materials trucks (primarily flat beds), and fuel tankers of all configurations travel along both the IH mainlanes and frontage roads. It is important to notice that the numbers of SU7 ready-mix trucks appear to be increasing as companies that previously operated only tractor-semi trailer dumps are now investing in SU7, dumps including insulated dumps for transporting HMA.
- Based on observations and discussions with SHV operators, there is a practical radius of operation from the material source origin (whether quarry, ready-mix plant, or hot-mix plant) that is typically measured in one-way or round-trip travel time in minutes rather than mileage. Travel time in minutes would be most important for trucks transporting ready-mix concrete or HMA since the materials being hauled might be rejected at the project site (due to high temperatures or loss of ready-mix workability, or loss of temperature in the case of HMA). For quarried materials, the delivery time and the distance would likely be more an economic consideration due to construction progress or delays.
- Waste management trucks have been observed operating both during clear and rainy weather conditions. However, in Houston, after several days of rain, a landfill might close operations or trucks might choose not to operate due to the difficulty of traveling the unpaved landfill road to a location at the top of the embankment where the load is dumped. Residential and commercial garbage, dumpster service, and roll-off trucks continue to operate in all but the worst weather conditions.
- The number of SHV load repetitions that a pavement or bridge experiences depends on:
    i. The type of operation(s) that exist along a given route segment.
    ii. The layout of the highway routes and bridge locations within the immediate vicinity of these operation(s).

iii. The time or distance radius around each operation representing the maximum travel distance that construction or trucking companies think is economically viable from that location.

iv. The overlap(s) of circles based on the operational radii for each facility. Locations where circles overlap represent regions that higher numbers of trucks (including SHVs) could be expected to occur. As distances from the source point of operation increase, trucks routes would likely diverge in relation to the locations of construction projects; set routes of operation (in the case of waste management vehicles); contractual agreements known only to the truck operator; and other factors. Other factors could include crashes, flooding, or traffic congestion that results in decisions to take alternate routes to reduce delivery time.

v. At points where several operational circles overlap the highway, pavements and bridges could be expected to receive the most daily load repetitions from trucks of all types operating from these plants (including SHVs), as seen in Figure 3.31. A factor not yet accounted for in this method is the intensity of truck activity originating or arriving at each facility location.

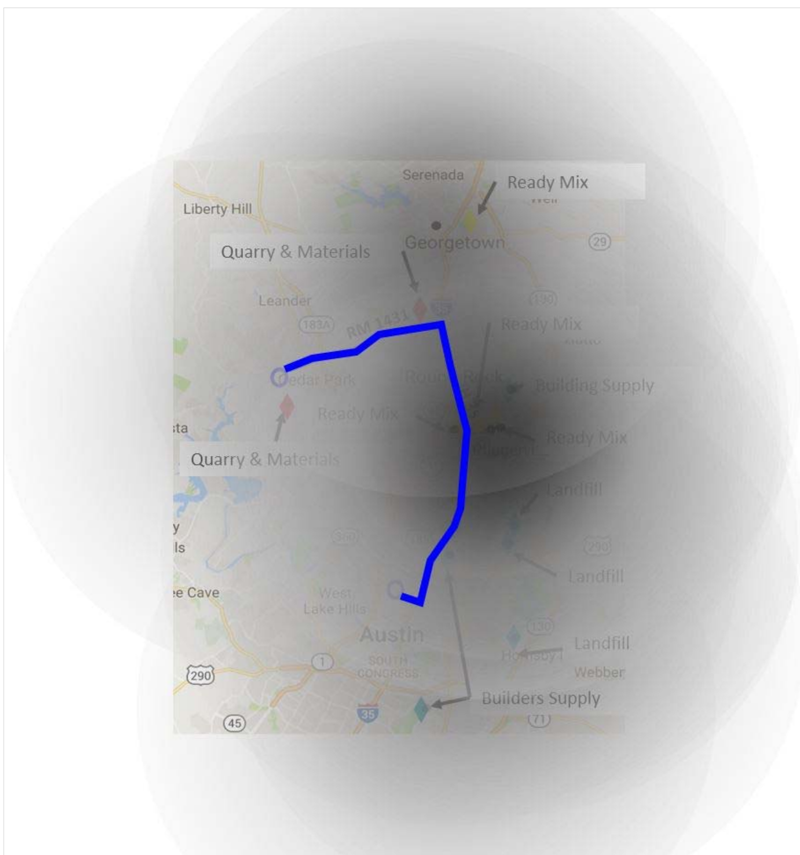


Figure 3.31: RM 1431/IH 35 route with overlapping facility operational radii—darker locations denote higher overlapping activities.

vi. It is apparent that bridges along IH 35 and crossing IH 35 within the darkest shades of the overlapping circles could be expected to carry larger numbers of trucks of all types, including SHVs. Highway pavements and bridges immediately adjacent to the entrance/exit locations would experience more load repetitions subject to whether the roadway/bridge was uni-directional only (such as an IH frontage road) or two-way (as is the case with RM 1431). In this instance, pavements and bridges on one-way routes approaching the facility could be expected to carry unloaded trucks, whereas those departing the facility will experience primarily loaded trucks.

Thus, the RM 1431 bridge across IH 35 has been observed to carry large numbers of trucks of all types, including large numbers of SHVs. This is also true for bridges north and south of the dark overlapping region in Figure 3.31. As distance/time from these locations increases, the number of truck routes increases and diverges, reducing the number of SHVs travelling any given route. It is noted that the RM 1431 bridge across IH 35 was converted to a diverging diamond configuration, which essentially changes the lanes on which predominately loaded/unloaded trucks travel over the bridge. It may be interesting to investigate whether this traffic operations strategy can also yield benefits in terms of increased bridge life.

3.2.6 Online Truck Sale Data

CTR looked into various online truck sale websites to determine both the number of SU trucks and SHVs for sale in Texas, the operational type, and the composition of their configurations. Of 1,540 online truck ads observed, we identified 347 SHVs, accounting for approximately 22.5% of the data. Three-axle trucks comprised the largest share of truck for sale, with 990 entries (approximately 64%).

SHV Configuration and Operational Type Distributions

Within the category of SHVs for sale in Texas, the vast majority were SU4s (278 trucks for sale, approximately 80%). The second-most popular configuration for the SHVs was SU5 (at approximately 12%), and the remainder was made up of SU3s, SU6s, and SU7s.

By function, most of the trucks for sale, both SHVs and non-SHVs, were dump trucks or ready-mix trucks. For non-SHVs, other popular functions observed were bucket/boom truck, crane truck, tank truck, vacuum truck, and roll-off truck. However, the three main types of trucks found in the SHV category were dump truck, mixer trucks, and oil field winch trucks.

Truck Age

In terms of truck age data, the research team observed that approximately 78% of all observed trucks for sale were model year 2000 or newer. This approximate percentage held steady not just in general for all trucks, but even within individual truck configurations. For each type of SHV—i.e., SU3s, SU4s, SU5s, etc.—the percentages of trucks for sale that were model year 2000 or newer were 80% (SU3), 74% (SU4), 75% (SU5), 90% (SU6), and 100% (SU7). For three-axle trucks, this percentage was 78%. Similarly, when looking at trucks within this most recent decade

(2010–2016), all of the percentages were around the 30% mark, for all configurations. Figure 3.32 shows the distribution of trucks for sale by age.

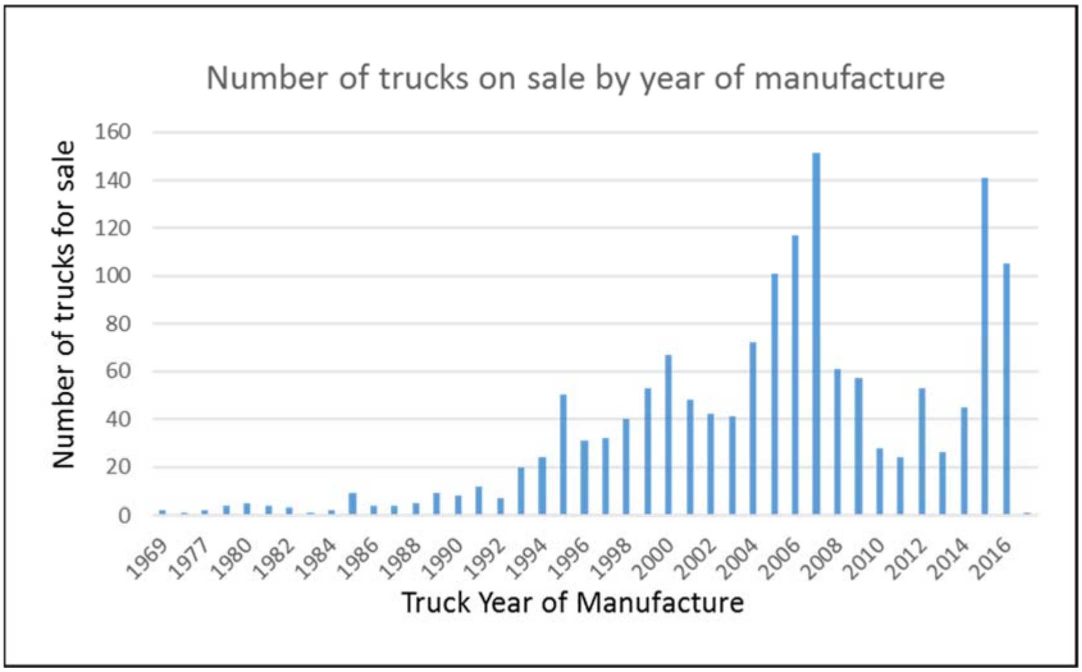


Figure 3.32: Vocational trucks for sale by age in Texas based on internet sales sources

The age of trucks for sale is important in that truck engine efficiency—in terms of fuel economy, implementation of new environmental equipment, and changes in truck transmission types—is evolving at an ever-faster rate. Thus newer ready-mix and waste disposal trucks will most likely have automatic transmissions, and engines that are more fuel efficient and produce less pollutants. Newer dump trucks still tend to have standard transmissions, though the engines are more fuel efficient and produce less pollutants. Fuel economy for vocational trucks still tends to lag behind that of tractor semi-trailer trucks. Based on information from the NRMCA, the average fuel consumption for a ready-mix truck is 3.3 mpg; whereas newer five-axle tractor trailers can achieve 6 mpg or higher with plans to achieve 10 or more mpg within five years. The fuel efficiency of a tractor trailer is of course dependent on whether a five-axle tractor trailer is operating as the tractor only, tractor + empty semi-trailer, tractor + partially loaded semi-trailer, or tractor + fully-loaded semi-trailer.

Though fuel efficiency does not affect pavement or bridge consumption rates, it will affect the amount of fuel tax revenue a particular type or class of truck might generate. The amount of gas tax revenue would also be directly affected by the total number of miles (VMT) traveled and the percentage of loaded and unloaded VMT. This information is important to consider when determining the relationships between the base case truck and trucks of heavier weight or different configurations.

Truck Design Features

In considering the trucks for sale in Texas and five-axle tractor trailers, we see some differences between these two vehicle types that affect fuel efficiency:

a. Lack of aerodynamic features on vocational trucks that can increase fuel consumption when operating above 50 mph.

b. Vocational trucks, such as dumps, ready-mix trucks, oil field equipment, and agricultural trucks, tend to operate both on- and off-road. Thus suspension, tire, and axle designs differ from those found on over-the-road trucks, which can result in rougher rides and potentially lower fuel economy compared to trucks that operate strictly on-road. Rougher rides can translate into greater load impacts to pavements and bridges, especially for stiff walking-beam type suspensions.

c. Vocational trucks tend to have larger engines (larger displacement or more horse power) per 1,000 lbs GVWR due to the challenges of off-road operations that might require climbing steeper grades on unpaved construction or landfill sites. Large engines provide power for both the truck and its equipment, such as the mixer drum, hydraulics, and other truck-mounted equipment. The literature indicates that dump truck operators have been advised to choose engines in the 400 to 450 HP range, though larger engines are sometimes selected.

d. Vocational trucks often operate in urbanized areas with more stop-and-go traffic due to traffic signals, signage, and traffic congestion. The five-axle tractor trailer trucks often seen operating on regional or long-haul operations can have greater fuel economy due to constant speed controls, close attention to tire designs and tire pressures, and better all-round maintenance that some vocational trucks.

Truck Odometer Mileage

Regarding mileage of the trucks for sale, the trends were also similar amongst all trucks regardless of SHV or non-SHV. In general, approximately 87% of trucks had below 500,000 miles on the odometer, and this number was 85% and 84.9% when looking at SHVs and three-axle straight trucks respectively. However, there was a significant difference when looking at the number of trucks that had 100,000 miles or fewer on the odometer.

The values for the percentage of all trucks with 100,000 miles or lower on the odometer and the percentage of three-axle trucks with this mileage were similar, at 38% and 29.5% respectively, but the corresponding percentage for SHVs was 24%. This means that, comparatively, a smaller proportion of SHVs is relatively new (defined as 100,000 miles or fewer). Figure 3.33 shows the distribution of truck odometer mileage by mileage classifications.

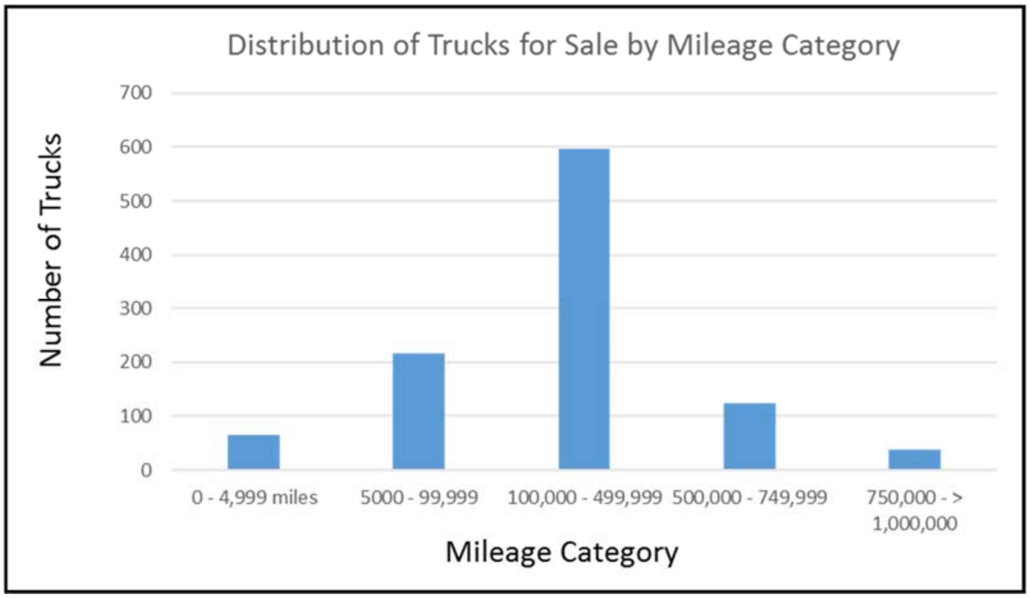


Figure 3.33: Distribution of trucks for sale by odometer mileage

It is expected that as truck mileage increases, maintenance issues affecting fuel efficiency will also increase. Thus, a new engine could be expected to have better fuel economy than the same engine after 500,000 miles or more due to worn internal engine parts, maintenance issues, and other factors. At present truck mileage is not documented in registration records. While it is documented during vehicle inspections, this information is not available to researchers for evaluation.

An additional factor to consider is that though truck diesel engines are designed to routinely operate 1,000,000 miles or more, certain trucks that are for sale are advertised as having rebuilt or replacement engines. Thus, the truck odometer might only report mileage up to 999,999 miles and then return to 0 miles. Truck hours of operation can also be used to estimate truck engine age, since maintenance is performed according to hours of operation rather than engine miles. However, few trucks for sale report hours of engine operation.

3.3 Characterizing Axle Weight and Axle Spacing using TxDPS and WIM Data

In this section, the TxDPS weight enforcement data and the WIM data sets were used to estimate axle weight and axle spacing for typical SHVs operating in Texas. The data collection activities previously described provide a detailed description of SHVs operating in Texas, typical configurations, regions of operations, and commodities employing these types of SU trucks. However, this data fails to characterize SHV axle weights and axle spacing, which are necessary inputs for the pavement and bridge consumption analysis. For this reason, CTR further analyzed the TxDPS and WIM data to obtain typical SHV configurations, GVWs, axle weights, and axle spacing.

3.3.1 TxDPS Weight Enforcement Data Processing and Analysis

As described in Section 3.2.2, CTR received a sample of TxDPS weigh enforcement data reported from 2010 to 2015. The data contains truck configurations in terms of axles and their corresponding axle weights. This sample represented the only source with available information to characterize SHVs for the pavement and bridge consumption analysis. This dataset contains information such as the report number, year, time start, county, roadway, unit type, commodity, scale type, axle diagram, and axle weights. The analysis presented is based on the axle diagrams and axle weights. As discussed in Section 3.2.2, around 3,000 SHVs were identified out of the total number of 292,000 records. To analyze the dataset, a systematic procedure was developed (shown in Figure 3.34).

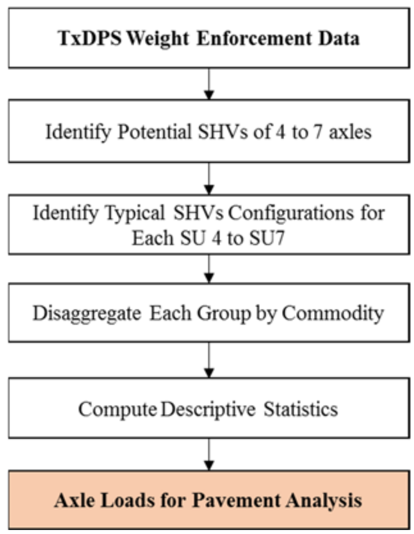


Figure 3.34: TxDPS weight enforcement data processing and analysis procedure

The first step was to identify potential SHVs from the dataset. For this purpose, a procedure was developed to extract the axle diagram along with its corresponding axle weight as illustrated in Figure 3.35. This procedure was performed for configurations ranging from four to seven axles. Also, three-axle vehicles were extracted to serve as base case for comparison purposes. After potential SHVs were identified, a filtering protocol was applied to eliminate records that did not represent typical SHV configurations and axle weights according to national studies and findings from the data collection activities previously described. This procedure yielded around 3,000 SHVs.

The next step was to identify the most common SHV configurations for each of the different groups identified in the previous step (i.e., SU4, SU5, SU6, and SU7). The final selection of truck configuration was performed based on the amount of data points and findings from the previous section. This final selection is discussed in the next section. While analyzing the various configurations, it was noticed that GVWs presented a large variation. For this reason, each truck configuration was disaggregated into three commodities: dump trucks, ready-mix trucks, and garbage trucks. These commodities were selected based on the amount of data points identified in the TxDPS database.

Year	Road Way	Mile Post	Commodity	Scale Type	Axle_Diagram
2013	FM0800	550	OIL FILTERS	RoadSide	X(8500)--X(18700)--OO(37500)
2013	NULL	0	ASPHALT	RoadSide	[20]--X(15600)--[8]--X(3800)--OO(36000)
2013	SH0174	296	HOT MIX	RoadSide	X(13200)--X(5600)--OO(34,000)
2013	IH0035	62	DIRT	RoadSide	X(7100)--X(11100)--OO(27400)

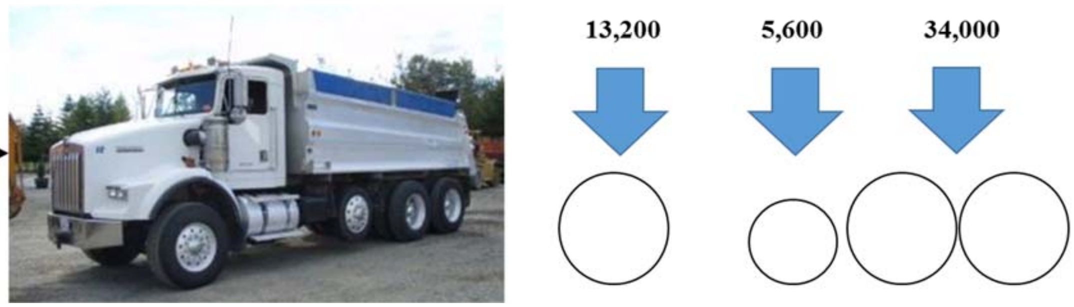


Figure 3.35: Identifying SHVs from the TxDPS weight enforcement data

Finally, sample descriptive statistics were computed to characterize each configuration for each SU group being considered. The variations and uncertainties of the axle weights were considered when analyzing the data; therefore, not only the sample mean was estimated, but also five different percentiles (i.e., 5, 25, 50, 75, and 95). Furthermore, this last step was performed to overcome the bias limitation of the dataset. As discussed in the previous section, the TxDPS database tends to be biased towards loaded trucks, including loaded trucks that are suspected to be overloaded, whereas WIM data contains both loaded and unloaded trucks irrespective of legal loading. However, as discussed in the next section, WIM data does not include information about the truck operational type (dump, ready-mix, flat bed, waste management vehicle, etc.)

3.3.2 WIM Data Processing and Analysis

The TxDPS weight enforcement sample contains information about truck configurations and their corresponding axle weights. However, this data set does not contain information about axle spacing, which is a key input parameter for the bridge consumption analysis. CTR received a sample of WIM data reported from 2010 to 2015 comprised of approximately two million records. The advantage of the WIM data is that it contains vehicle classification, axle spacing, and axle weights. However, identifying SHVs is challenging since trucks, including SHVs, are not classified into a specific vehicle operational type or commodity category. Moreover, this data fails to capture whether an axle is a liftable or a booster axle. Based on the advantages and limitations previously stated, CTR developed a procedure to extract SHV records. The overall procedure is illustrated in Figure 3.36.

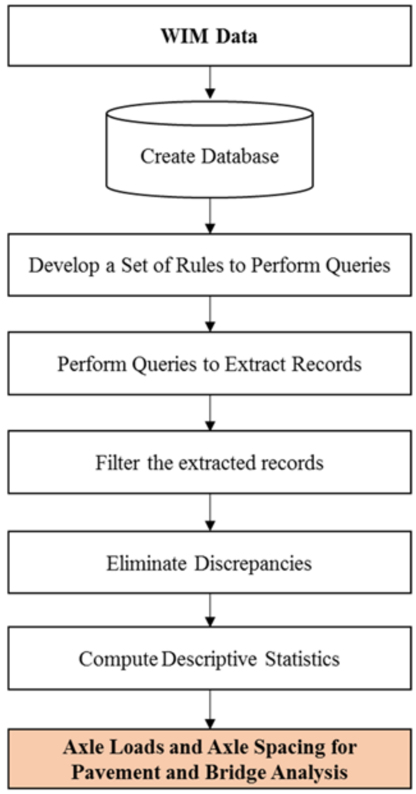


Figure 3.36: WIM data processing and analysis procedure

The first step was to create a database to efficiently analyze approximately two million records. The database was created using MySQL and was accessed through a Hypertext Preprocessor (PHP) application. PHP is a popular general-purpose scripting language used to create dynamic web pages and access MySQL. In the second step, CTR developed a set of rules to narrow down potential SHVs. These rules were defined based on the findings from the previous data collection efforts and recommendations provided by the NCHRP Report 575. These rules included parameters such as axle spacing, axle weights, vehicle classification, and truck configurations. Then, CTR performed the queries to extract records, filter the extracted records, and eliminate discrepancies. Finally, sample descriptive statistics were computed to characterize each configuration for each SU group being considered. The variations and uncertainties of the axle weights were considered when analyzing the data; therefore, not only the sample mean was estimated, but also five different percentiles (i.e., 5, 25, 50, 75, and 95). CTR recommends treating the axle weight and axle spacing from WIM data carefully; it is a challenge to identify SHVs from this data set.

3.3.3 Results

Table 3.28 through Table 3.32 provide a summary of the axle weight results for each configuration and commodity identified in the TxDPS sample data and WIM data. Because the WIM data does not specify commodities, no specific commodities are listed in the following tables. The truck configurations are identified at the top of each table. It is worth noting that that "X" refers to single wheel axle, and "O" refers to dual tire axle. The numbers located at the top of the GVW columns indicate the number of data points for each of the various configurations. Also, please note that blank spaces were used for configurations where data points were not found in both data sources.

Table 3.28: Three-axle truck axle weights

Conf.	X-OO				
Dump Truck	PCTL	Axle			19692
		1	2	3	GVW
	5	11,026	14,915	14,915	40,857
	25	12,468	16,866	16,866	46,200
	50	13,755	18,607	18,607	50,968
	Mean	13,332	18,034	18,034	49,400
	75	14,600	19,750	19,750	54,100
	95	18,405	24,897	24,897	68,200
Ready-Mix Truck	PCTL	Axle			3975
		1	2	3	GVW
	5	12,660	16,095	16,095	44,850
	25	17,162	21,819	21,819	60,800
	50	18,842	23,954	23,954	66,750
	Mean	18,000	22,884	22,884	63,768
	75	19,533	24,833	24,833	69,200
	95	20,652	26,256	26,256	73,164
Garbage Trucks	PCTL	Axle			3559
		1	2	3	GVW
	5	10,729	12,985	12,985	36,700
	25	13,477	16,311	16,311	46,100
	50	15,611	18,894	18,894	53,400
	Mean	15,427	18,671	18,671	52,770
	75	17,424	21,088	21,088	59,600
	95	19,821	23,989	23,989	67,800
WIM	PCTL	Axle			800000
		1	2	3	GVW
	5	6,955	5,495	5,151	17,600
	25	8,693	6,868	6,438	22,000
	50	11,578	9,147	8,575	29,300
	Mean	12,668	10,009	9,382	32,059
	75	16,161	12,769	11,970	40,900
	95	20,864	16,484	15,452	52,800

* Number located at the upper right corner of each group refers to the total number of SHV records found in the DPS or WIM data sets

Table 3.29: SU4 truck axle weights

Conf.		X-X-OO					X-OO-X				
Dump Truck	PCTL	Axle				1472	Axle				
		1	2	3	4	GVW	1	2	3	4	GVW
	5	11,931	7,245	16,620	16,704	52,500					
	25	12,647	7,680	17,617	17,707	55,650					
	50	13,249	8,045	18,456	18,550	58,300					
	Mean	13,408	8,142	18,678	18,773	59,002					
	75	13,988	8,494	19,485	19,584	61,550					
	95	15,701	9,534	21,872	21,983	69,090					
Ready-Mix Truck	PCTL	Axle					Axle				158
		1	2	3	4	GVW	1	2	3	4	GVW
	5						15,565	17,234	17,234	8,548	58,580
	25						17,908	19,828	19,828	9,835	67,400
	50						18,559	20,549	20,549	10,193	69,850
	Mean						18,528	20,515	20,515	10,176	69,733
	75						19,223	21,285	21,285	10,557	72,350
	95						20,740	22,964	22,964	11,390	78,058
Garbage Trucks	PCTL	Axle				13	Axle				21
		1	2	3	4	GVW	1	2	3	4	GVW
	5	8,443	4,138	15,260	15,260	43,100	16,202	15,029	15,029	4,090	50,350
	25	11,421	5,598	20,643	20,643	58,305	17,202	15,956	15,956	4,342	53,455
	50	13,245	6,492	23,939	23,939	67,615	19,430	18,022	18,022	4,904	60,379
	Mean	12,508	6,131	22,608	22,608	63,855	19,799	18,365	18,365	4,997	61,525
	75	13,368	6,553	24,163	24,163	68,246	22,816	21,164	21,164	5,759	70,904
	95	13,947	6,836	25,208	25,208	71,200	24,022	22,282	22,282	6,063	74,650
WIM	PCTL	Axle				12426	Axle				284
		1	2	3	4	GVW	1	2	3	4	GVW
	5	8,288	4,720	10,254	10,138	33,400	9,577	10,140	10,044	5,339	35,100
	25	10,968	6,247	13,569	13,416	44,200	9,822	10,400	10,301	5,476	36,000
	50	12,730	7,250	15,749	15,571	51,300	11,180	11,837	11,725	6,233	40,975
	Mean	13,996	7,971	17,315	17,119	56,400	13,533	14,329	14,193	7,545	49,600
	75	13,823	7,872	17,101	16,907	55,703	13,382	14,169	14,035	7,461	49,048
	95	14,840	8,451	18,359	18,150	59,800	15,559	16,474	16,318	8,675	57,025

* Number located at the upper right corner of each group refers to the total number of SHV records found in the DPS or WIM data sets

Table 3.30: SU5 truck axle weights

Conf.		X-XX-OO						X-X-OO-X					
Dump Truck	PCTL	Axle					245	Axle					
		1	2	3	4	5	GVW	1	2	3	4	5	GVW
	5	14,715	6,919	6,828	15,994	15,994	60,350						
	25	15,544	7,309	7,213	16,895	16,895	63,750						
	50	16,214	7,624	7,524	17,624	17,624	66,500						
	Mean	16,456	7,738	7,636	17,887	17,887	67,492						
	75	17,455	8,207	8,100	18,972	18,972	71,588						
	95	19,157	9,008	8,890	20,823	20,823	78,570						
Ready-Mix Truck	PCTL	Axle						Axle					8
		1	2	3	4	5	GVW	1	2	3	4	5	GVW
	5							16,418	5,762	18,773	18,773	7,774	67,500
	25							17,102	6,002	19,555	19,555	8,098	70,313
	50							17,914	6,287	20,483	20,483	8,483	73,650
	Mean							17,990	6,314	20,570	20,570	8,519	73,963
	75							18,655	6,548	21,332	21,332	8,834	76,700
	95							19,738	6,927	22,569	22,569	9,347	81,150
Garbage Trucks	PCTL	Axle						Axle					14
		1	2	3	4	5	GVW	1	2	3	4	5	GVW
	5							16,497	7,807	14,870	14,870	7,156	61,200
	25							16,920	8,007	15,252	15,252	7,340	62,770
	50							17,730	8,390	15,982	15,982	7,691	65,775
	Mean							17,682	8,368	15,939	15,939	7,671	65,599
	75							18,215	8,620	16,419	16,419	7,902	67,575
	95							19,165	9,070	17,276	17,276	8,314	71,100
WIM	PCTL	Axle					3,134	Axle					207
		1	2	3	4	5	GVW	1	2	3	4	5	GVW
	5	4,313	2,166	2,205	5,041	5,075	18,800	5,909	2,984	5,825	5,695	3,187	23,600
	25	10,484	5,264	5,361	12,253	12,338	45,700	8,457	4,271	8,338	8,151	4,562	33,780
	50	13,352	6,704	6,827	15,605	15,712	58,200	13,808	6,973	13,613	13,308	7,448	55,150
	Mean	14,522	7,291	7,426	16,972	17,089	63,300	16,006	8,084	15,780	15,427	8,634	63,930
	75	14,241	7,150	7,282	16,644	16,758	62,074	15,073	7,612	14,860	14,527	8,130	60,202
	95	15,302	7,683	7,824	17,884	18,007	66,700	17,501	8,839	17,254	16,867	9,440	69,900

* Number located at the upper right corner of each group refers to the total number of SHV records found in the DPS or WIM data sets

Table 3.31: SU6 truck axle weights

Conf.		X-XXX-OO							X-XX-OO-X							
Dump Truck	PCTL	Axle						52	Axle						19
		1	2	3	4	5	6	GVW	1	2	3	4	5	6	GVW
	5	12,831	5,931	5,361	5,456	18,061	18,061	65,700	15,563	6,361	6,308	15,253	15,253	8,711	67,450
	25	13,837	6,395	5,781	5,883	19,477	19,477	70,850	17,199	7,030	6,971	16,857	16,857	9,627	74,540
	50	14,452	6,680	6,038	6,145	20,343	20,343	74,000	17,790	7,271	7,210	17,435	17,435	9,958	77,100
	Mean	14,565	6,732	6,085	6,193	20,503	20,503	74,581	17,889	7,312	7,251	17,533	17,533	10,014	77,532
	75	15,204	7,027	6,352	6,464	21,401	21,401	77,850	18,528	7,573	7,510	18,159	18,159	10,371	80,300
	95	17,147	7,925	7,164	7,291	24,137	24,137	87,800	19,716	8,059	7,991	19,324	19,324	11,036	85,450
Ready-Mix Truck	PCTL	Axle							Axle							
		1	2	3	4	5	6	GVW	1	2	3	4	5	6	GVW
	5														
	25														
	50														
	Mean														
	75														
	95														
Garbage Trucks	PCTL	Axle							Axle							
		1	2	3	4	5	6	GVW	1	2	3	4	5	6	GVW
	5														
	25														
	50														
	Mean														
	75														
	95														
WIM	PCTL	Axle						4,781	Axle						145
		1	2	3	4	5	6	GVW	1	2	3	4	5	6	GVW
	5	6,594	3,378	3,363	3,180	7,460	7,825	31,800	7,750	3,088	3,527	8,540	8,526	3,470	34,900
	25	13,396	6,862	6,831	6,461	15,155	15,895	64,600	11,791	4,699	5,366	12,993	12,972	5,279	53,100
	50	15,179	7,776	7,741	7,321	17,172	18,011	73,200	16,055	6,398	7,307	17,691	17,662	7,188	72,300
	Mean	15,780	8,084	8,047	7,611	17,853	18,725	76,100	16,943	6,752	7,711	18,670	18,639	7,586	76,300
	75	15,481	7,930	7,895	7,467	17,514	18,370	74,657	16,420	6,543	7,473	18,093	18,064	7,352	73,945
	95	16,112	8,254	8,217	7,771	18,228	19,119	77,700	17,476	6,964	7,954	19,257	19,225	7,825	78,700

* Number located at the upper right corner of each group refers to the total number of SHV records found in the DPS or WIM data sets

Table 3.32: SU7 truck axle weights

Conf.	PCTL	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW
X-XXX-OO-X									
Dump Truck									25
	5	16,598	6,162	4,411	5,480	13,370	13,340	10,823	70,213
	25	17,924	6,654	4,763	5,917	14,437	14,406	11,687	75,820
	50	18,602	6,906	4,944	6,141	14,984	14,951	12,130	78,690
	Mean	18,429	6,841	4,897	6,084	14,844	14,812	12,016	77,956
	75	19,172	7,117	5,095	6,329	15,443	15,409	12,501	81,100
	95	19,644	7,292	5,220	6,485	15,822	15,788	12,809	83,095
Ready-Mix Truck									
	5								
	25								
	50								
	Mean								
	75								
	95								
Garbage Trucks									
	5								
	25								
	50								
	Mean								
	75								
	95								
WIM									482
	5	11,329	4,020	3,980	3,951	9,682	9,731	6,207	48,900
	25	15,247	5,410	5,356	5,317	13,031	13,096	8,354	65,810
	50	17,422	6,182	6,120	6,076	14,890	14,964	9,546	75,200
	Mean	18,395	6,527	6,462	6,416	15,721	15,800	10,079	79,400
	75	18,021	6,394	6,330	6,285	15,402	15,479	9,874	77,784
	95	18,905	6,708	6,641	6,593	16,157	16,238	10,358	81,600

* Number located at the upper right corner of each group refers to the total number of SHV records found in the DPS or WIM data sets

By examining the results, the following important observations can be obtained from the TxDPS weight enforcement data:

- The values presented in Tables 3.27 through 3.31 provide an initial characterization of the typical SHV configurations, axle weights, and GVWs traveling through the state. It is worth noting that based on DPS data the least and greatest difference between the 5th percentile and 95th percentile GVW for all three-axle truck types ranges from 27,343 lbs to 35,200 lbs. The least and greatest difference between the 5th and 95th percentile GVW for all SHV types ranges from 9,900 lbs to 28,100 lbs.
- The maximum GVW at the 95th percentile for three-axle trucks is 73,164 lbs and for SHVs it is 87,800 lbs, though surprisingly this is for an SU6, not an SU7. The highest 95th percentile GVW for an SU7 is 83,095 lbs. The variations found in this analysis are expected, and CTR suggests utilizing the developed distributions instead of deterministic values for further analyses.

- The average GVWs for all three commodities and their respective typical configurations tend to be slightly greater than the Texas weight limits discussed in Chapter 1. However, as mentioned in previous sections, the TxDPS data is biased toward overloaded trucks. CTR suggests the mean GVW and axle weights of SHVs traveling in Texas.
- By observing the number of data points in each table, the most common SHV configurations were identified. From the total data set extracted and analyzed, 73% were identified as dump trucks, 14% as ready-mix trucks, and the remaining 12% as garbage trucks. Furthermore, 93% of the records corresponded to SU4.
- SU4 and SU5 ready-mix trucks showed higher GVWs when compared to dump and garbage trucks; though SU6 ready-mix trucks were observed in Houston, no axle or GVW weight data was obtained specifically for SU6 ready-mix trucks.
- The GVWs of SU4 and SU5 dump trucks and garbage trucks showed similar values as the weight percentile increased. However, an SU5 dump truck commonly comprises two pusher axles, whereas an SU5 garbage truck comprises one pusher and one tag axle. The garbage truck pusher axle exceeds the weight of either of the dump truck's two pusher axles by approximately 1,000 lbs at the 5th percentile but decreases with increasing percentile weights until they are nearly equal at the 95th percentile. The garbage truck pusher axle is consistently about 650 lbs to 700 lbs heavier than the garbage truck tag axle on an SU5 for all percentiles.
- It was observed that as additional lift axles were added, there was an incremental increase of about 6,000 to 8,000 lbs in the GVW for dump trucks and ready-mix trucks. Liftable axles tend to carry less weight than booster axles. These results are consistent with data collection activities reported in the previous sections.
- It is interesting to notice that the configurations with booster axles tend to exhibit higher steering axle weights compared to those configurations without booster axles. These results illustrate how a booster axle enables operators to increase the steering axle weight without exceeding the Texas weight limits. The results suggest that these configurations are more common on ready-mix trucks, less common on dump trucks, and not yet implemented on garbage trucks. Though certain TxDPS configurations are shown as X-00-X, the last X is not a booster axle, but rather a tag axle.

Similarly, the following important observations can be obtained from the WIM data analysis:

- It is important to note that CTR was unable to extract the type of commodity being transported by each truck since this information is not contained in WIM data. Thus, the records were not disaggregated as for the analysis performed using the TxDPS data set.
- As expected, the WIM results show lower GVW values for all configurations since the data set includes both loaded and unloaded trucks. For this reason, the GVWs and the axle weights show higher variations than those obtained from the TxDPS data set.
- Of the total number of records (~2,000,000), only 1% was identified as an SHV. Of the SHVs, approximately 60, 16, 23, and 1% were identified as SU4, SU5, SU6, and SU7,

respectively. Interestingly, this distribution follows the same pattern as the one obtained from the TxDPS data analysis.

- As expected, an increase in the total number of axles resulted in an increase of about 5,000 to 10,000 lbs. in the GVW.

Figures 3.37 through 3.43 show box plots comparing the TxDPS and the WIM data analysis results for each of the seven configurations analyzed. Furthermore, these figures also include a characterization of the axle spacing of each configuration.

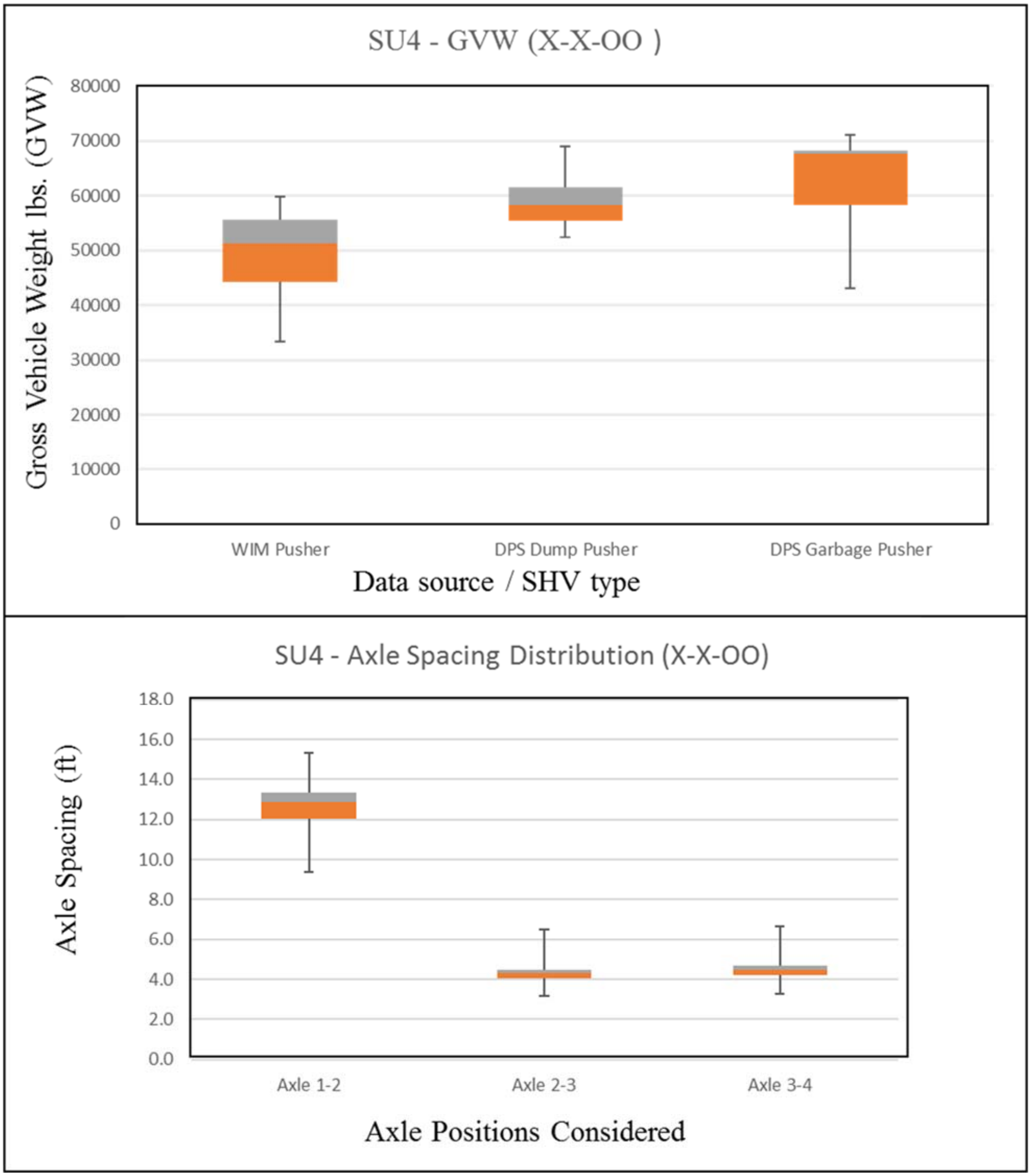


Figure 3.37: SU4 – Configuration X-X-OO – Summary

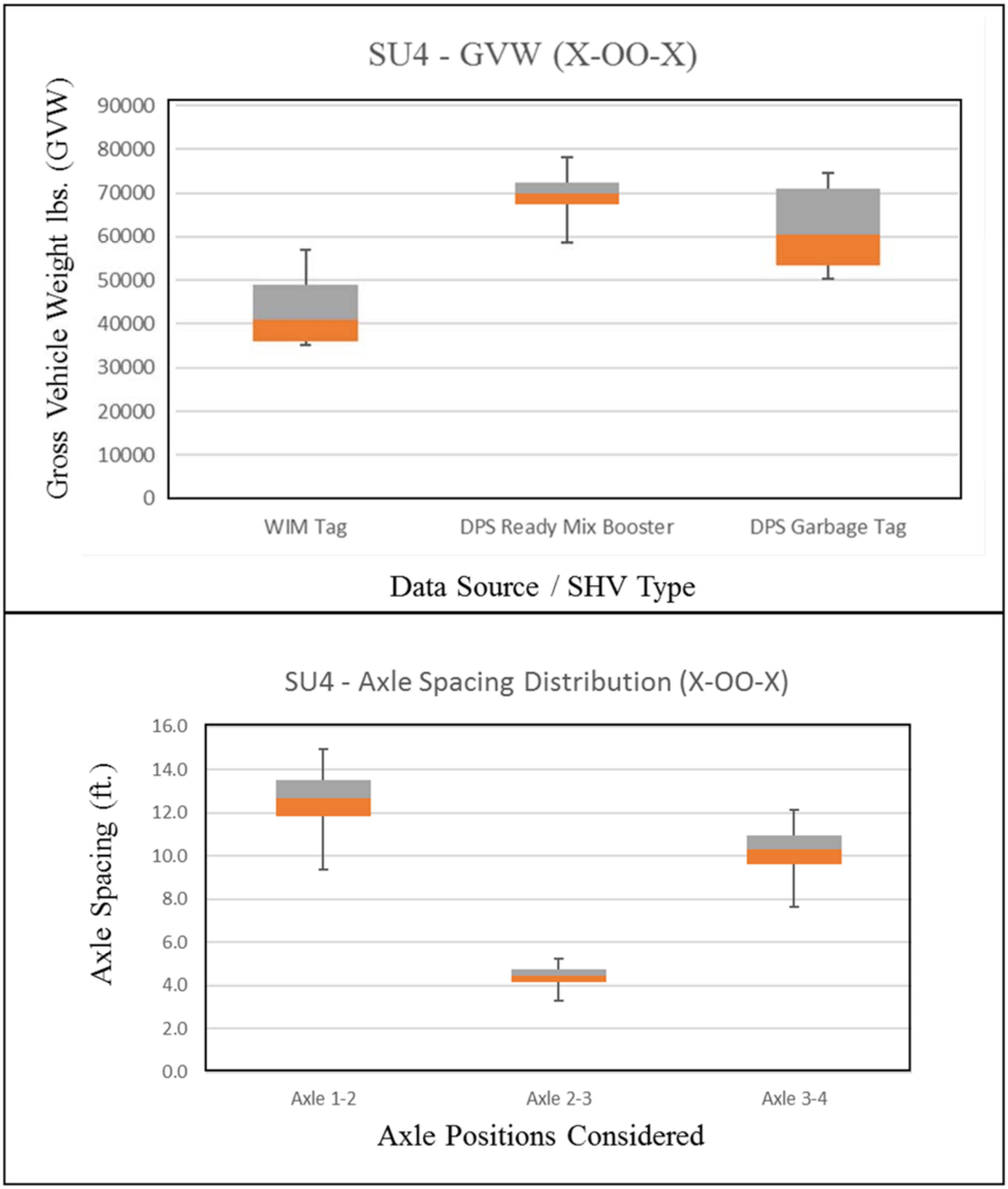


Figure 3.38: SU4 – Configuration X-OO-X – Summary

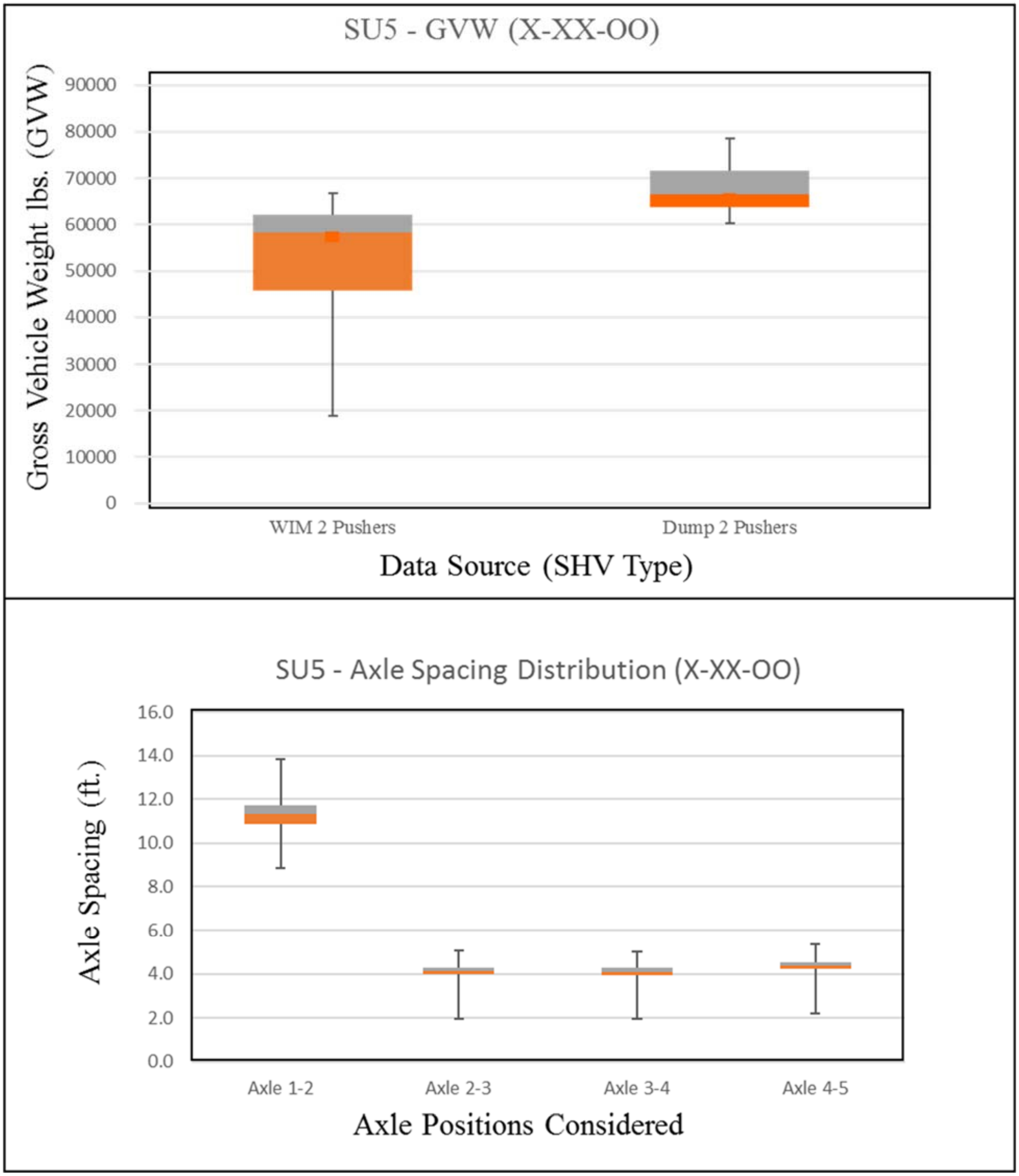


Figure 3.39: SU5 – Configuration X-XXOO - Summary

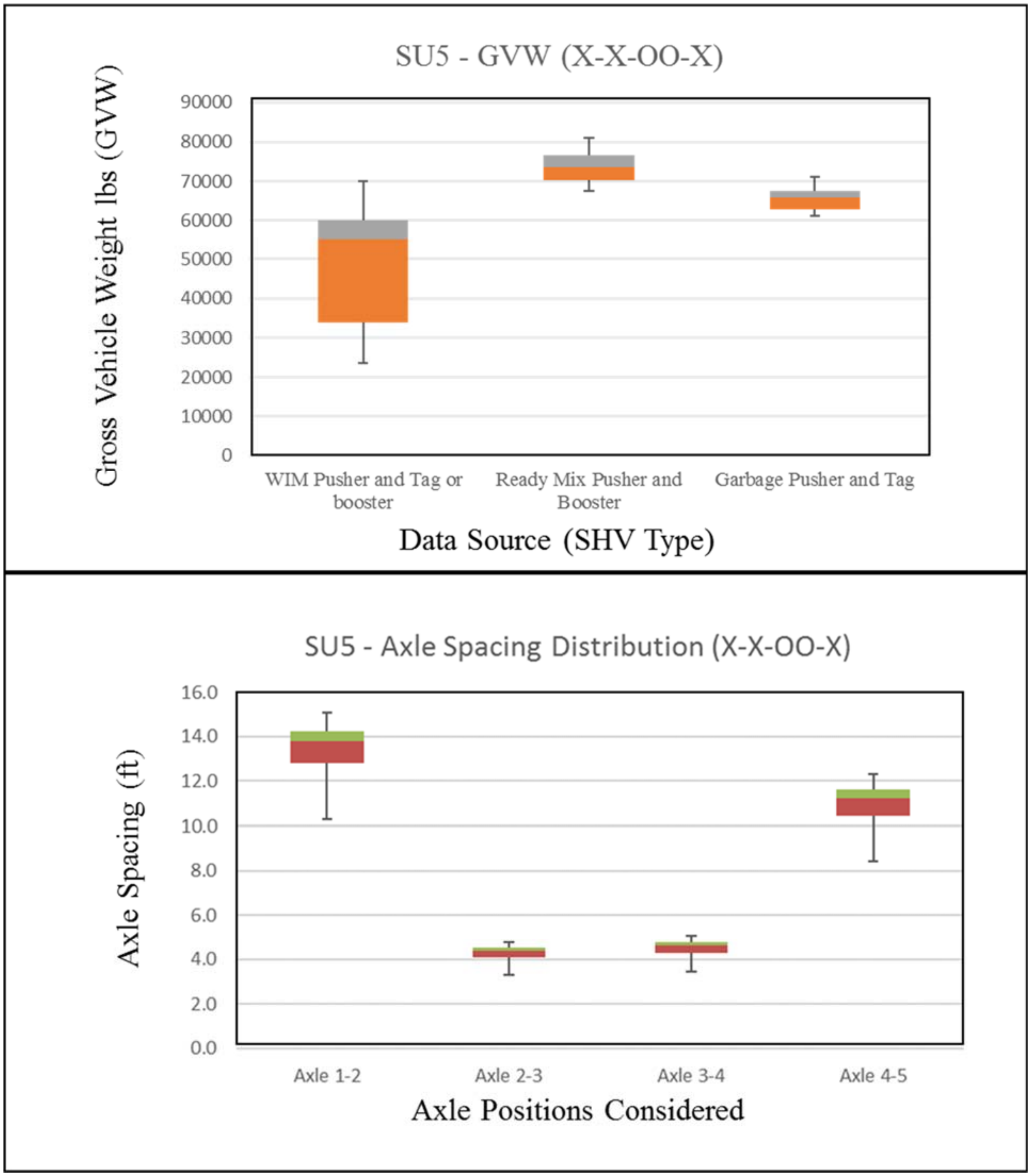


Figure 3.40: SU5 – Configuration X-XOO-X - Summary

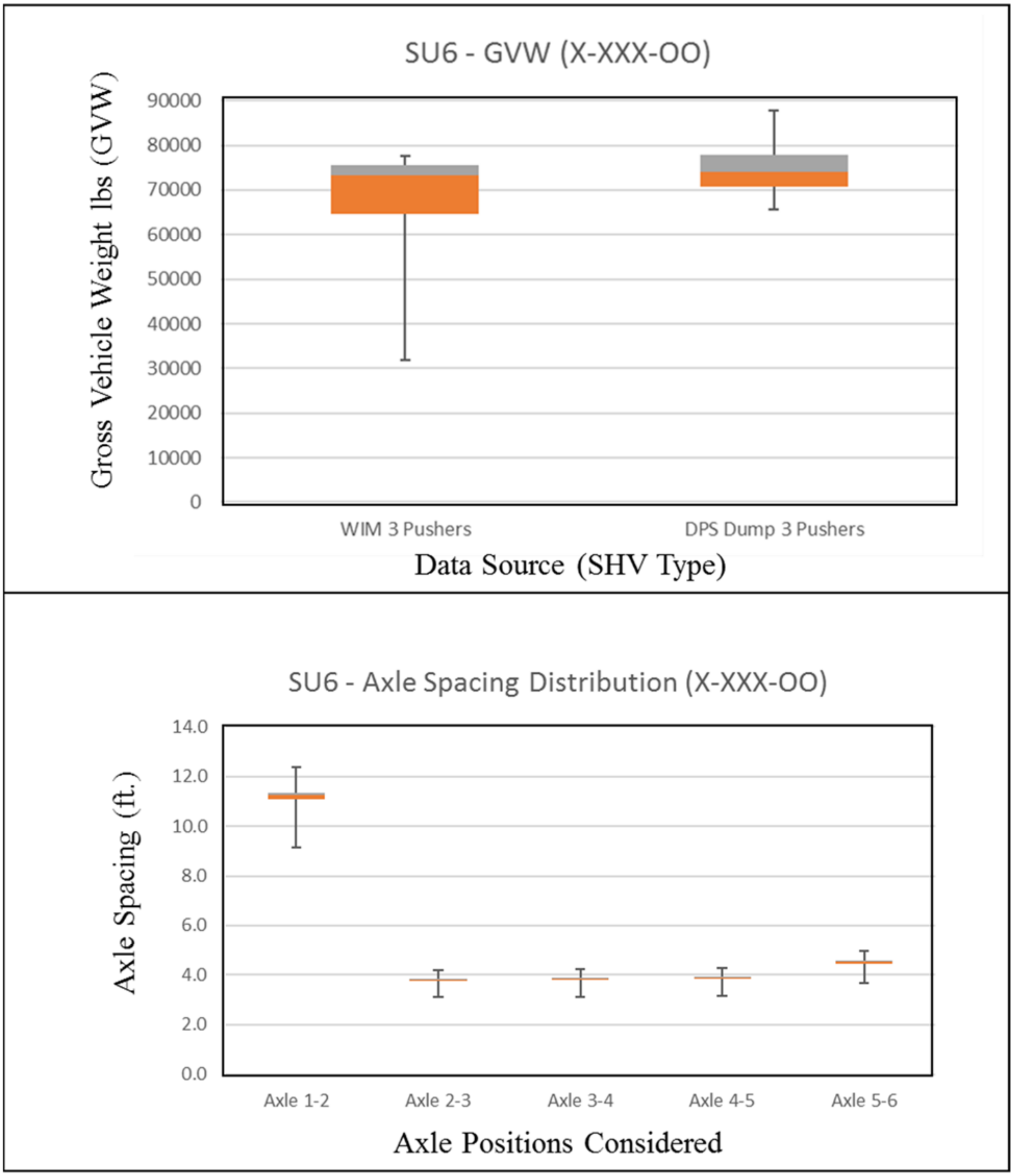


Figure 3.41: SU6 – Configuration X-XXXOO - Summary

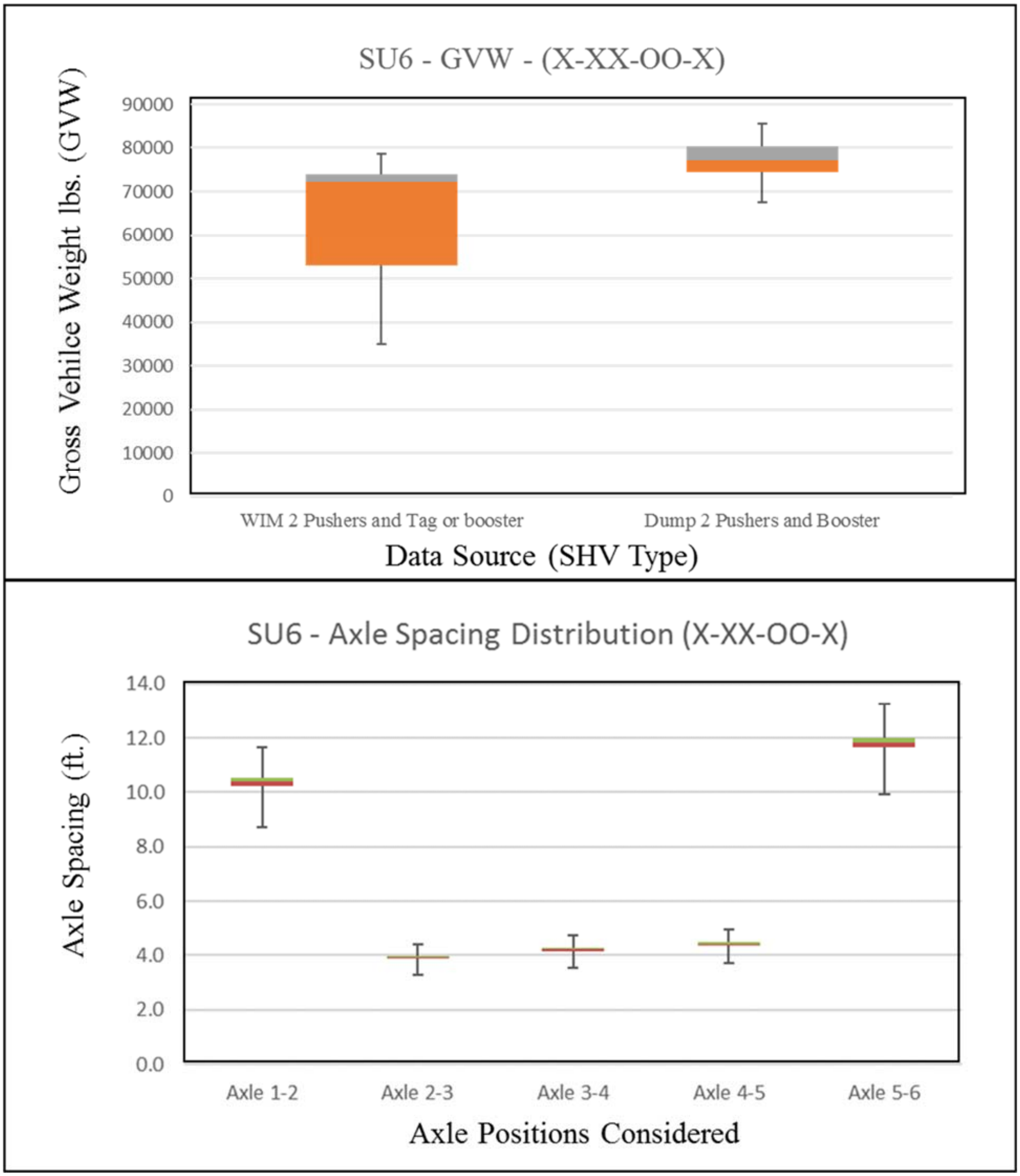


Figure 3.42: SU6 – Configuration X-XXOO-X - Summary

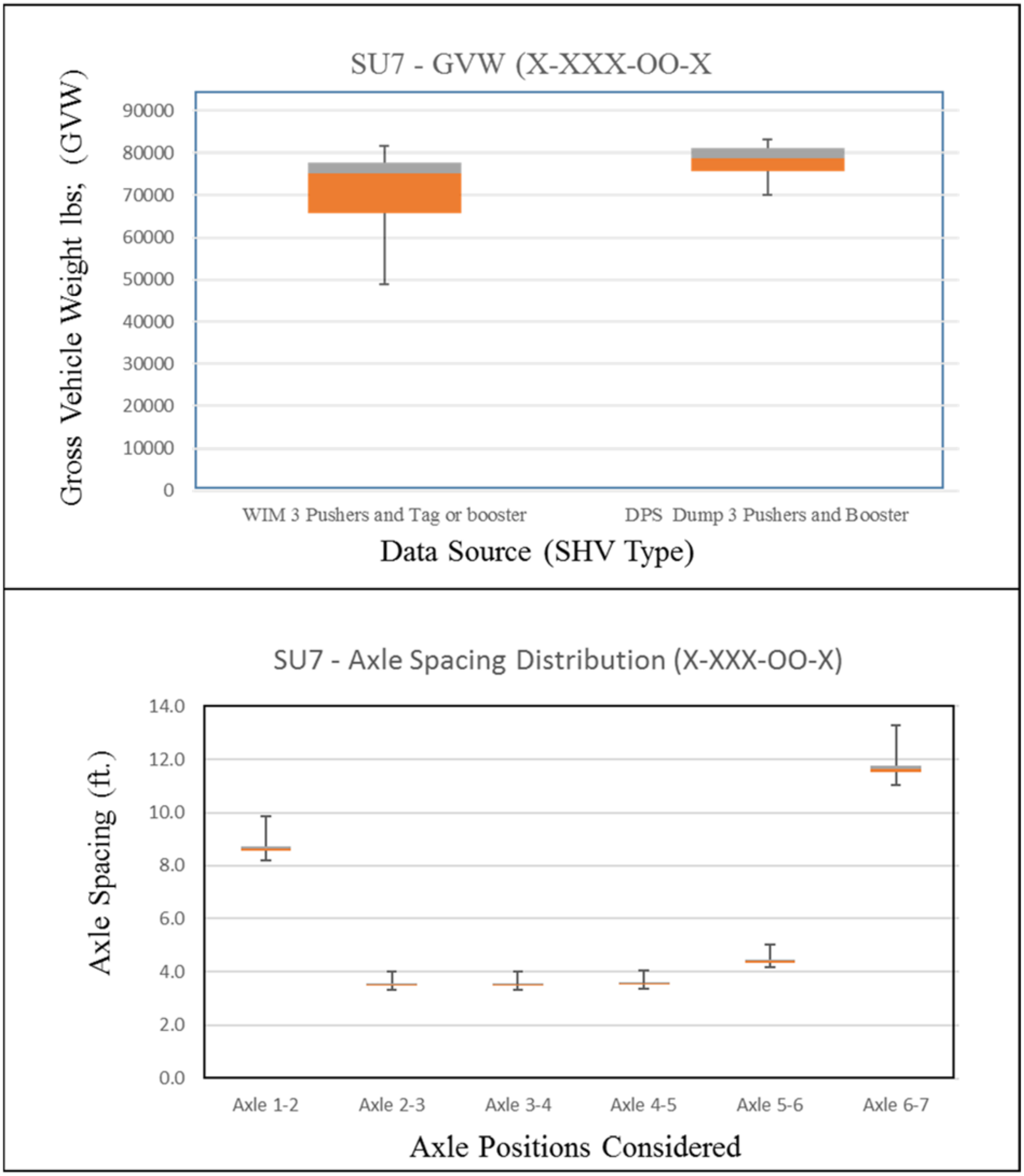


Figure 3.43: SU7 – Configuration X-XXXOO-X - Summary

Table 3.33 presents the average values of the axle spacings shown in the previous figures. It is worth noting that these results are consistent with the information obtained in the data collection effort and the NCHRP Report 575 results. Also, the axle spacing variation was lesser than the one observed for GVWs and axle weights. Therefore, the average values obtained in this analysis suggested for further analysis.

Table 3.33: Axle spacing of SHV from WIM data

Configuration	No. Axles	Sp. 1-2 (ft)	Sp. 2-3 (ft)	Sp. 3-4 (ft)	Sp. 4-5 (ft)	Sp. 5-6 (ft)	Sp. 6-7 (ft)	Spacing Total (ft)
X-X-OO	4	12.66	4.27	4.42	-	-	-	21.35
X-OO-X	4	12.50	4.37	10.14	-	-	-	27.01
X-XX-OO	5	11.25	4.11	4.07	4.35	-	-	23.78
X-X-OO-X	5	13.35	4.24	4.47	10.90	-	-	32.96
X-XXX-OO	6	11.10	3.76	3.79	3.83	4.46	-	26.94
X-XX-OO-X	6	10.36	3.92	4.22	4.40	11.81	-	34.71
X-XXX-OO-X	7	8.67	3.53	3.52	3.55	4.42	11.69	35.37

3.4 Summary

This chapter serves to describe the research efforts that went into the data collection and evaluation of SHVs, and is divided into two major sections: data collection activities, and characterization of GVW, axle weights, and axle spacing. First, CTR collected data and evaluated its potential to serve as an input for the pavement and bridge consumption analyses. Then, based on the data collection findings, CTR proceeded to characterize SHVs in terms of their GVW, axle weights, and axle spacing, which were identified as the key parameters to understand the effect of these trucks on the Texas infrastructure.

The purpose of the first section was to identify SHV configurations and types operating in Texas, sorted by truck type/function/weight/spacing/tire designs, estimating the number of SHVs operating in Texas, and serving as a foundation off of which further analysis on pavement impacts, bridge impacts, and safety impacts could be performed. Furthermore, all of the various data collection activities performed were described, including the truck photographic library, public agency databases, project site visits, company site visits, on-route data collection, TxDOT MVC data, online truck sale data, survey, and training received. Each data collection activity has been described in this chapter, as well as connected to overall project objectives. Details of the analysis performed with this data have also been described.

Based on the findings of the first section of this chapter, CTR found that the gathered information fails to provide the input parameters to conduct a comprehensive analysis of the impact of SHVs on pavements and bridges. For this reason, the TxDPS and the WIM data sets were used to generate these input parameters as shown in the previous sections. SHV records extracted from these data set were used to estimate the GVWs, axle weight, and axle spacing. This information is summarized in this chapter.

By examining the results, the following important observations can be obtained from the TxDPS weight enforcement data:

- The values presented in Tables 3.28 through 3.32 provide an initial characterization of the typical SHV configurations, axle weights, and GVWs traveling through the state. It is worth noting that the difference between the 5th and the 95th percentile of the GVW ranged from 9,900 lbs to 28,100 lbs. The variations found in this analysis are expected, and CTR suggests utilizing the developed distributions instead of deterministic values for further analyses.

- The average GVWs for all three commodities and their respective typical configurations tend to be slightly greater than the Texas legal weight limits discussed in Chapter 1. However, as mentioned in previous sections, the TxDPS data is biased toward overloaded trucks. CTR suggests that the average GVW and axle weights are representative of SHVs traveling in Texas. It is noted that not every truck weighed by DPS was in fact overloaded.
- By observing the number of data points in each table, the most common SHV configurations were identified. From the total data set extracted and analyzed, 73% were identified as dump trucks, 14% as ready-mix trucks, and the remaining 12% as garbage trucks. Furthermore, 93% of the records corresponded to SU4.
- Ready-mix trucks showed higher GVWs when compared to dump and garbage trucks. This trend was expected given the legal GVW and axle weight exemptions in Texas. The GVWs of dump trucks and garbage trucks showed similar values.
- It was observed that as additional lift axles were added, there was an incremental increase of about 6,000 to 8,000 lbs in the GVW for dump trucks and ready-mix trucks.
- It is interesting to notice that the configurations with booster axles tend to present higher steering axle weights compared to those configurations without booster axles. These results illustrate how a booster axle enables operators to increase the steering axle weight without exceeding the Texas weight limits. The results suggest that these configurations are more common on ready-mix trucks, less common on dump trucks, and not yet implemented on garbage trucks. Though certain TxDPS configurations are shown as X-00-X, the last X is not a booster axle, but rather a tag axle.

Similarly, the following important observations can be obtained from the WIM data analysis:

- As expected, the WIM results show lower GVW for all configurations. This data set includes loaded and unloaded trucks; therefore, the WIM data set is less conservative than the TxDPS data set when considering truck consumption rates of bridges and pavements.
- It is important to note that CTR was unable to extract the type of commodity being transported by each truck using WIM data; thus, the records were not disaggregated as for the analysis performed using the TxDPS data set. For this reason, the GVWs and the axle weights show higher variations than those obtained from the TxDPS data set.
- Of the total number of records (~2,000,000), only 1% was identified as an SHV. Of the SHVs, approximately 60, 16, 23, and 1% were identified as SU4, SU5, SU6, and SU7, respectively. Interestingly, this distribution follows the same pattern as the one obtained from the TxDPS data analysis.

Chapter 4. SHV Pavement Analysis and Impacts

Texas maintains a highway system of approximately 85,000 center-line miles, which includes about 16,000 miles of load-posted roadways. These roadways were posted in the late 1950s at 58,420 lb GVW, which was the legal weight limit in Texas at that time. The roadways were load-posted to protect them from accelerated deterioration due to a nationwide increase in the truck GVW limit to 73,280 lbs. Currently, truck loads are limited in terms of both axle loads and GVW by federal and state regulations (generally, 20,000 lbs. for single axle, 34,000 lbs. for tandem axles, 42,000 lbs. for tridem axles, and 80,000 lbs. GVW). Specifically, in the federal regulations, the relationship between the maximum allowable load, axle spacing, and number of axles is tabulated using the FBF:

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right] \tag{4-1}$$

where
W: overall gross weight on any group of two or more consecutive axles;
L: distance in feet between the outer axles of any group of two or more consecutive axles;
N: represents the number of axles under consideration.

The FBF's purpose is to regulate the weight that a truck can carry—not to provide guidelines for developing new truck configurations to carry more weight. However, the FBF's structure implies that the load capacity of a truck can be increased by adding more axles. Over the past decades, many new truck configurations with closely spaced axles were developed to increase load capacity and transportation efficiency, including SHVs. Although those trucks meet the requirements of the federal and state regulations, their effect on pavements compared with the conventional trucks is unknown. Moreover, it is unknown whether the currently posted roadways are adequate for these new truck configurations.

Previous national research (Sivakumar 2007) has thoroughly investigated the load effects of SHVs with multiple axles and increased weights on bridges; however, no studies have specifically considered the effect of SHVs on pavements. For this reason, SHVs operating in Texas present a new challenge in terms of determining the allowable axle and GVW limits for the state. There is little or no information currently available about the actual weight carried by the fixed and liftable axles, tire sizes, and numbers of SHVs operating in various regions of the state, which suggest a need for a comprehensive study to obtain this information for policy and decision-making processes regarding the operation of SHVs.

Thus, the research team conducted extensive data collection efforts (detailed in Chapter 3) to obtain the necessary information about the SHVs operating in Texas. These efforts included studying data from available agency databases; visiting various project sites to collect 2-hour truck traffic data; observing and measuring SHV dimensions and weights at operational sites and companies; collecting on-route truck data; analyzing TxDOT 24-hour video MVC data; reviewing online truck sale data; and communicating with industry to gather information. Specifically, by analyzing the axle load data from the TxDPS weight enforcement database, and TxDOT WIM data, a comprehensive database of the load distributions for various SHV configurations was established, which was essential for both the pavement and bridge analyses.

Using the data mentioned above, the research team evaluated the pavement impacts due to SHV operations on the state-maintained highway system in terms of accelerated consumption. Various factors were considered during the analysis, such as types of SHVs (dump truck, ready-mix trucks, or others), SHV configurations, axle spacing, and distributions of axle load. This chapter covers the following topics:

- Section 4.1 presents a brief introduction of the background and objective of the pavement consumption analysis.
- Section 4.2 includes a review of the methodology of pavement consumption analysis, challenges for the analysis of SHV, and the proposed method for the analysis of SHVs.
- Section 4.3 conveys the experimental design.
- Section 4.4 first introduces the axle load data used in the analysis, then provides the analysis results for typical configurations of dump trucks, ready-mix trucks, and garbage trucks.
- Section 4.5 summarizes the major findings of the pavement analysis.

4.1 Pavement Consumption Analysis

The basis of the methodology adopted in this project for the pavement consumption analysis was developed in previous work performed under TxDOT Research Project 0-6736, *Rider 36 OS/OW Vehicle Fees Study*, and TxDOT Research Project 0-6817, *Review and Evaluation of Current Gross Vehicle Weights and Axle Load Limits*. Adopting the same methodology will help ensure consistency and coherence with previous work in this area sponsored by TxDOT. This will also facilitate the understanding by the Texas State Legislature and TxDOT Administration as they are familiar with the previous work and the methodology adopted. This methodology is also consistent with the AASHTO and FHWA standards and methods.

In the Rider 36 study by Prozzi et al. (2012), the authors presented a methodology to evaluate pavement consumption caused by OW loads through establishing equivalencies between different axle loads and configurations that result in the same level of pavement distress, pavement performance, or pavement consumption. In the proposed method, a standard 18-kip single axle was used as a frame of reference, and the time (or traffic) of a pavement structure to reach a certain failure criterion was obtained using mechanistic-empirical pavement analysis, which was then used to establish equivalencies. In terms of pavement failure, three terminal performance indicators values for rutting, cracking, and roughness were selected as criteria after taking into consideration common practices on pavement design and management. These three criteria are given as follows:

(1) 0.5 inches of rutting (surface deformation) at the end of the design life;

(2) 10% of the cracked area (fatigue cracking associated with load) at the end of the design life;

(3) 125 inches/mile of roughness in terms of the International Roughness Index (IRI) at the end of the design life (an initial IRI of 63 inches/mile was used in the analysis).

The methodology proposed in the Rider 36 study represents a significant enhancement over previous procedures. This methodology provides a modular approach towards the calculation of the overall load equivalency for any given truck configuration. Thus, the overall pavement consumption due to a combination of different axles is equivalent to the sum of the consumption caused by each individual axle.

4.1.1 Equivalent Consumption Factor (ECF)

As previously discussed, the fundamental principle behind the pavement consumption analysis methodology involves the assumption of equivalency between different axle loads and configurations that result in the same level of pavement distress, pavement performance, or pavement consumption. In establishing such equivalency, a standard 18-kip single axle was used as the reference. Recent studies have also shown that the equivalency factors for different axle loads and configurations are partially governed by the bearing capacity of the pavement structure and the environmental conditions (Prozzi and De Beer 1997; Prozzi et al., 2007). Therefore, it is essential to determine ECFs for different axle loads over a spectrum of pavement structures.

In Texas, pavements are designed to reach a terminal distress condition under the given traffic and environmental conditions at the end of its 20-year design period. However, due to inherent differences in the failure mechanisms, it is impossible to reach each of the three terminal distress values simultaneously at the end of the design period. Therefore, it becomes necessary to determine the required traffic volume that would result in the associated terminal distress under each of the failure criteria. Thus, the calculated traffic volume will depend on the distress mechanism being considered. Once the design traffic volumes are determined, the next step involves analyzing each of the pavement structures for a range of different axle loads and configurations and to determine the time (or traffic) to reach each of the aforementioned failure criteria. The ECF in this study is calculated as follows:

$$ECF = \frac{T_{18}}{T_L} \tag{4-2}$$

where

T_{18}: time to failure under "*N*" repetitions of a standard 18-kip axle; and
T_L: time to failure under "*N*" repetitions of any given axle load "*L*".

Therefore, the ECF represents the relative pavement life for any given pavement structure under given environmental conditions under the 18-kip single standard axle over the life of the same pavement under the same conditions under any given load and configuration. It is important to note that in this process, one would develop separate ECFs based on each of the distress criteria above-mentioned. From a practical standpoint, a given axle configuration loaded to "L" kips should have a single ECF. For this reason, it is important to establish a weighting mechanism to be applied to the individual ECFs (i.e., rutting, cracking, and roughness) for establishing the combined and unique ECF for the particular axle load and configuration. The weighting mechanism should be devised such that it takes into account fundamental engineering principles. For example, it is known that rutting is more critical in warm climatic regions, while cracking is the dominant distress mechanism in colder climatic regions. For simplification, in this study, the averaged ECF for rutting, cracking, and roughness was used to represent relative consumption of SHVs with respect to the 18-kip single standard axle.

4.1.2 Consumption Rates

The consumption rate ($/VMT) was also implemented to represent the pavement consumption of SHVs in a more quantitative way. The consumption rate is calculated based on the cost (per unit mile) of adding additional pavement structure to achieve the pavement design life considering increased loads associated with the specific vehicle configuration. Let us assume two pavement structures as shown in Figure 4.1, and that the pavement structure (left) has a design life of 20 years under the applications of 18-kip single standard axle. Also, let us assume that that the pavement structure fails before the 20-year design life under the application of a specific truck configuration. To achieve the design life of 20 years, an additional HMA overlay might be required as shown by the pavement structure on the right side. The cost of this additional HMA overlay is used to estimate the pavement consumption rate of the assumed truck configuration in terms of $/VMT.

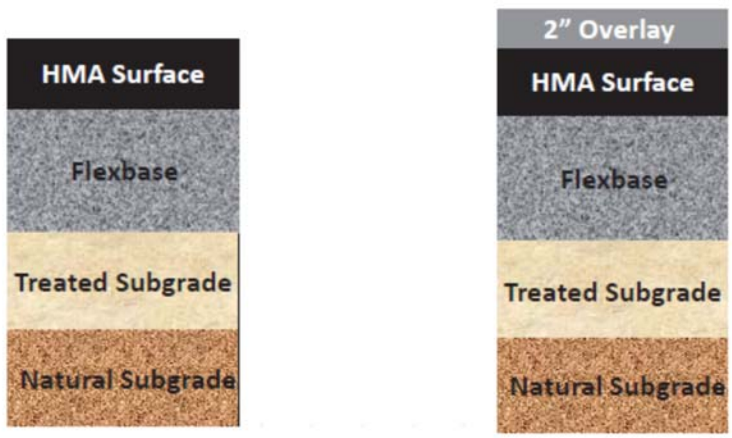


Figure 4.1: Illustration of consumption rate (left: as design; right: as required)

4.1.3 Mechanistic-Empirical Pavement Analysis

Pavement mechanistic-empirical (ME) analyses were performed using the AASHTOWare Pavement ME Design software, whose theory and concept originates from the Mechanistic-Empirical Pavement Design Guide developed under the NCHRP. The methodology has been approved by AASHTO and supported by the FHWA. In an ME flexible pavement analysis, fundamental pavement responses under repeated traffic loadings are calculated using a multi-layer linear elastic approach. Although this approach assumes that a flexible pavement is a multi-layered structure and that each layer exhibits a linearly elastic response to traffic loads, which is not the case, this assumption is reasonable at the low strain levels typical of highway traffic. The method computes stresses and strains borne by pavement layers due to traffic loadings. These critical pavement responses are then related to field distresses using empirical relationships or transfer functions that are calibrated based on field performance data.

4.2 Equivalent Configurations of SHVs

Although the methodology adopted by the AASHTOWare Pavement ME Design is applied, it should be noted that the software assumes that the weight of an axle group is equally distributed over the axles in the group as shown in Figure 4.2 (a). Thus, in the situations where one liftable axle is very close to the fixed tandem axle group, it is suitable to treat them as one tridem axle group. However, since the AASHTOWare Pavement ME does not enable the user to input the different axle loads within an axle group, it is not possible to directly model a liftable axle as part of tridem axle group. In addition, Pavement ME does not enable the user to specify difference in distance between axles within the group. Thus a liftable axle that is located 8' from the lead tandem axle which has a 4' tandem axle spacing, cannot be modelled as part of the group, Pavement ME applies the same axle spacing between axles of a group. Further, if the liftable axle and fixed tandem axle group are treated as separate axle groups (i.e., one single axle plus one tandem axle group), then the influence between these two axle groups would not be modeled since these axles would be analyzed in separate program runs, not within a single run with the axles adjacent to each other. This limitation of the AASHTOWare Pavement ME software means that the pavement consumption for the configuration (b) in Figure 4.2 would be the same as configuration (c), and as clearly stated by pavement analysis experts, this is not the case for actual truck loads. Given this limitation, AASHTOWare Pavement ME cannot be directly used for the analysis of SHVs.

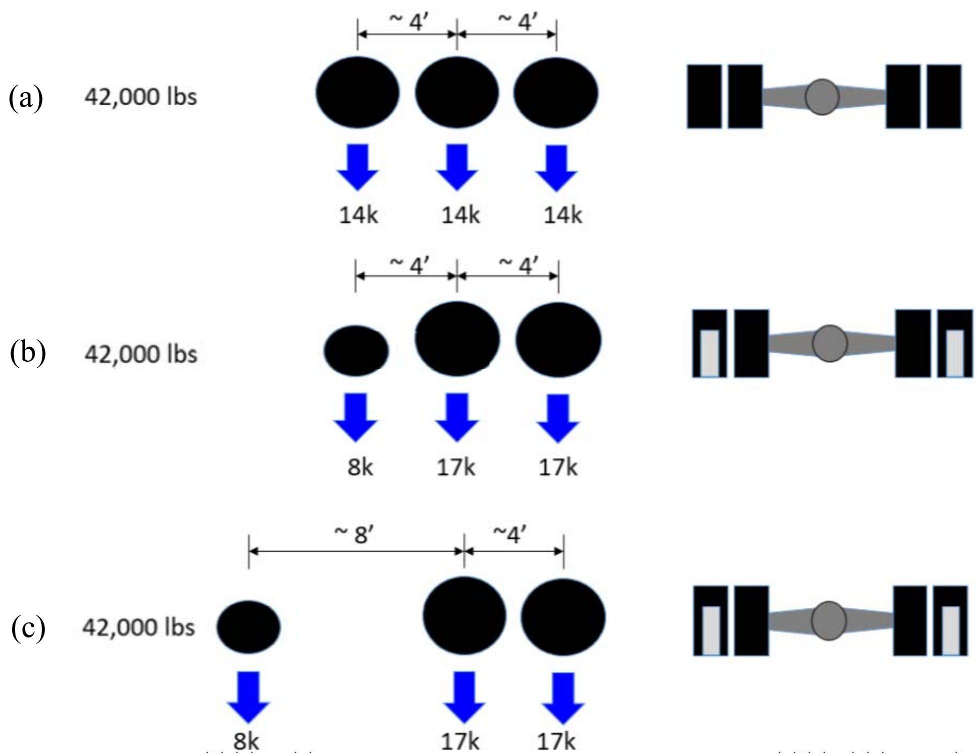


Figure 4.2: Challenges for the analysis of SHVs

To overcome this issue, the research team proposed three methods for the analysis of SHVs. The purpose of these three methods is to arrive at the real pavement consumption rate through the evaluation of a range of possible simulated configurations that generate the same consumption as the actual configuration. A detailed review of these three methods is presented in the following section. This analysis is based on an SU four-axle truck, which has one 12-kip single steering axle, one eight-kip liftable axle, and one 34-kip tandem axle group. It is important to clarify that the proposed equivalent configurations are hypothetical configurations, and their only purpose is to generate similar pavement responses as the configuration being considered. This analysis is performed to generate simulated configurations that can be analyzed using the AASHTOWare Pavement ME. CTR does not intend to suggest these hypothetical configurations are "better" or "worse" than the SHVs operating in the state; they are not being considered as potential configurations. In addition, CTR is not proposing these hypothetical configurations for potential adoption by trucking companies, or for consideration in any proposed future Texas State legislation regarding lift axles. These methods were developed solely to address the described limitations of the Pavement ME program in modeling SHVs.

4.2.2 Method 1

In this method, the liftable axle and the fixed tandem axle group are treated as separate groups, and each axle carries the same loads as the tridem axle shown in figure b). Though each axle carries the same load as the tridem axle group in b); this method might underestimate the consumption of SHVs. This configuration omits the influence between the liftable axle and fixed tandem axles (Figure 4.3). Therefore, Method 1 failed to correctly model the original tridem axle and underestimated the critical strains.

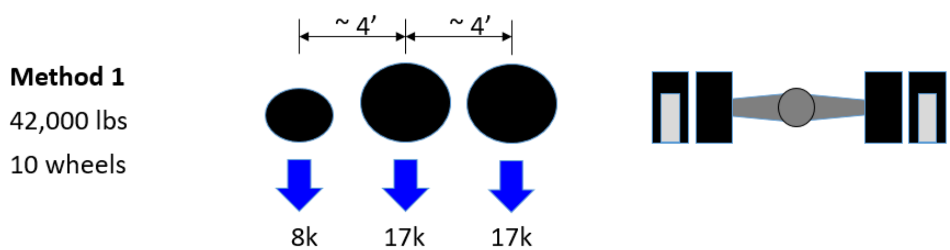


Figure 4.3: Equivalent configuration for Method 1

4.2.3 Method 2

In this method, the liftable axle and the fixed tandem axle group are treated as separate groups as shown in Figure 4.4. However, in this configuration two hypothetical wheels were added to the liftable axle. This addition converts the liftable axle from a single tire axle into a dual tire axle, carrying twice the load as the original load. For the fixed tandem axle group, no changes were implemented. CIRCLY, a multi-layer linear elastic approach software, was used to analyze this configuration. The critical strains generated by this hypothetical equivalent configuration were compared to those generated by the original tridem axle configuration b). Thus, it was found that by adding a hypothetical wheel on the liftable axle, the critical strains for hypothetical and the original tridem axle configurations were the approximately the same. It is important to notice that each tire in the fixed tandem axle carries approximately 4,250 lbs., which is similar to the tire weight of 4,000 lbs. of the liftable axle.

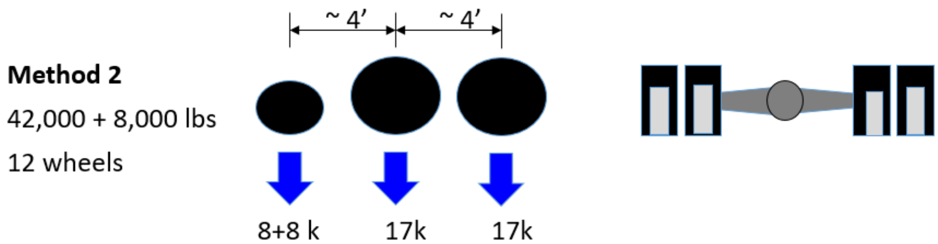


Figure 4.4: Equivalent configuration for Method 2

4.2.4 Method 3

In this method, the liftable axle and the fixed tandem axle group are combined as one tridem axle group as shown in Figure 4.5. To achieve this configuration, two hypothetical wheels were added to the liftable axle. If the axle loads are modeled as shown for the tridem axle group b) this method tends to overestimate the effect of the axle group on the pavement structure, meaning that strains and stresses are larger. For this reason, the wheel loads for each axle of the tridem axle group used in Method 3 must be adjusted to produce equivalent stresses and strains thus eliminating an analysis that is too conservative.

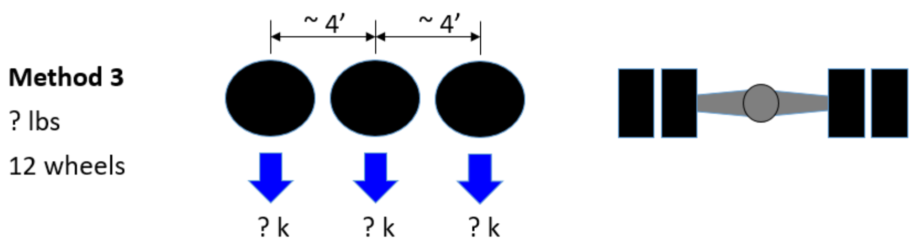


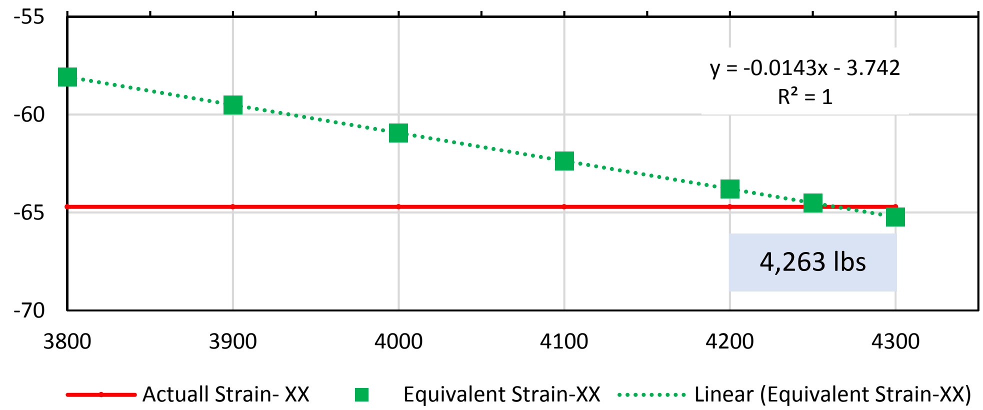
Figure 4.5: Equivalent configuration for Method 3 (unknown wheel loads)

The reasonable equivalent load wheels for Method 3 were estimated for the selected pavement structure using the multi-layer linear elastic approach software CIRCLY. The critical strains generated by the Method 3 configuration were compared to those generated by the original configuration. The Method 3 tire loads were adjusted until the critical strains for both configurations were approximately the same. To conduct this pavement analysis, a simple pavement structure with one AC layer directly placed over the subgrade was selected. The detailed properties are listed in Table 4.1.

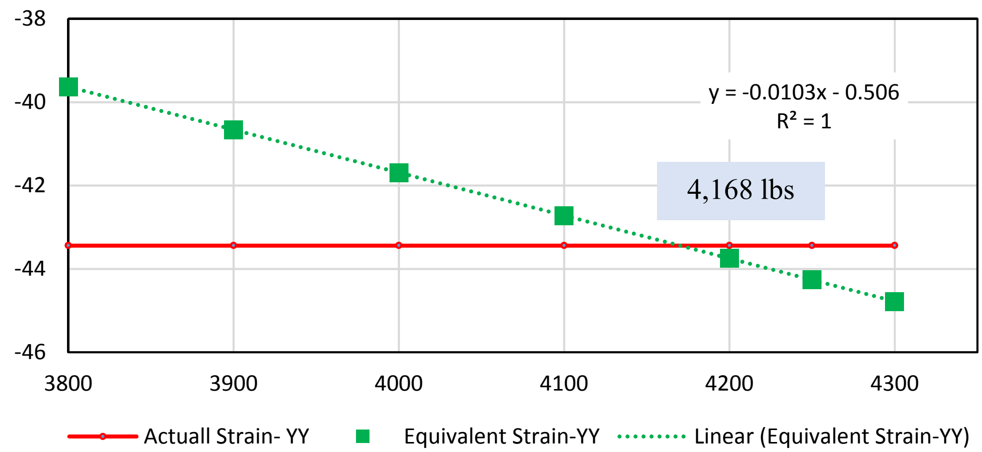
Table 4.1: Properties of selected pavement structure

Layer	Thickness (inch)	Modulus (psi)	Poisson Ratio
AC	10	500,000	0.35
Subgrade	Semi-infinite	50,000	0.35

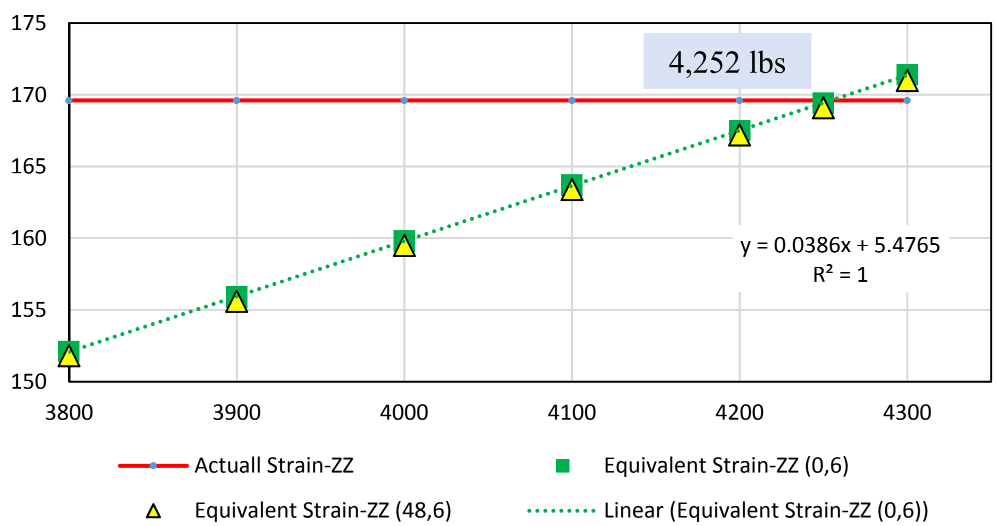
Considering the relationship between pavement distresses, for fatigue cracking, the maximum tensile strains under the bottom of AC layer along both the longitudinal and transverse directions was selected as critical strains. For rutting, the maximum compressive strain at the surface of the subgrade was selected as the critical strain. The analysis results obtained from a multi-layer linear elastic software are shown in Figure 4.6.



a) Longitudinal Strain – XX (10^{-6})



b) Transverse Strain – YY (10^{-6})



c) Vertical Strain – ZZ (10^{-6})

Figure 4.6: Critical strains produced by different wheel loads (Method 3)

As shown in Figure 4.6, the relationship between the critical strains and the wheel load is linear (R^2=1); an increase in the wheel load generates higher critical strains. In terms of the sensitivity of the pavement performance parameters to the wheel load, rutting (vertical strains) shows the highest sensitivity, followed by longitudinal and transverse strains. As seen in Figure 4.6, different equivalent loads per wheel are generated by each critical strain. However, the objective of the "hypothetical configuration in Method 3 is to use only one equivalent load. Weighting methods are unavailable and selection of the equivalent load is solely based on subjective judgment. Even if a reasonable method can be used to combine these three values, the relationship between the resulted equivalent load and the real wheel load will become a very challenging task. The proposed equivalent load per wheel is based on the real total load of the liftable axle and fixed tandem axle. Then, a load equal to the load carried by the liftable axle is added. The sum of those two quantities is divided equally among the axles within the tridem axle group as shown in Figure 4.7.

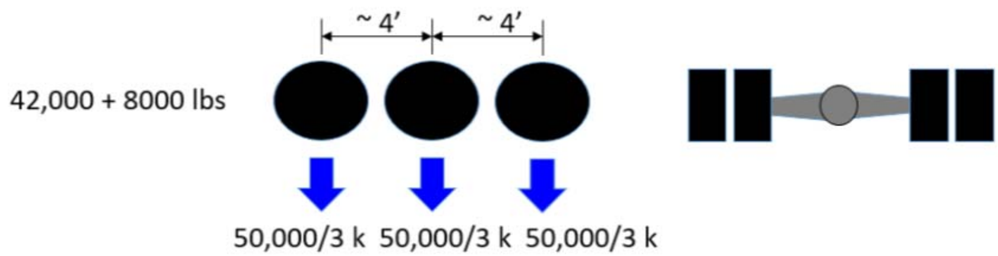


Figure 4.7: Equivalent configuration for Method 3 (Final)

To validate the solution, a comparison between the critical strains generated by the real configuration and the proposed equivalent configuration (Figure 4.7) was performed. As shown in Table 4.2, the differences between the equivalent and real strains are all below 5 x 10^{-6}, and 3%. Therefore, the proposed equivalent load per tire is considered reasonable

Table 4.2: Comparison between real and equivalent critical strains

Strains	Equivalent Strain	Real Strain	Difference	Relative Difference
ε_{XX}	-63.33	-64.71	1.38	2.14%
ε_{YY}	-43.42	-43.44	0.02	0.04%
ε_{ZZ}	166.31	169.6	3.29	1.94%

As previously discussed, the purpose of the aforementioned three methods is to estimate the real pavement consumption rate through the evaluation of a range of possible simulated configurations that generate the same consumption as the real configuration. In Method 1, the influence between the liftable axle and the fixed tandem axle group is neglected. Therefore, the pavement consumption rate is expected to be lower than the actual consumption. In Method 2, the influence between the liftable axle and the fixed tandem axle group is also neglected; however, the additional load in the liftable axle deals with the issue of this omission. It is difficult to determine whether it will generate underestimated or overestimated pavement consumption rates. In Method

3, since the liftable axle and fixed tandem axle group are treated as one tridem axle group, and additional load is added, the expected consumption will be higher than the real consumption.

To determine the range of the actual pavement consumption rates, the ECFs and consumption rates for these three methods were computed and the results are shown in Figure 4.8. As Figure 4.8 depicts, Method 2 shows the lowest ECF and consumption among the three methods, while Methods 1 and 3 generate nearly the same results. Therefore, both Method 1 and Method 3 can provide reasonable estimates of the actual consumption of SHVs. In this study, Method 3 was adopted based on the higher value of ECF, which corresponds to the most conservative case.

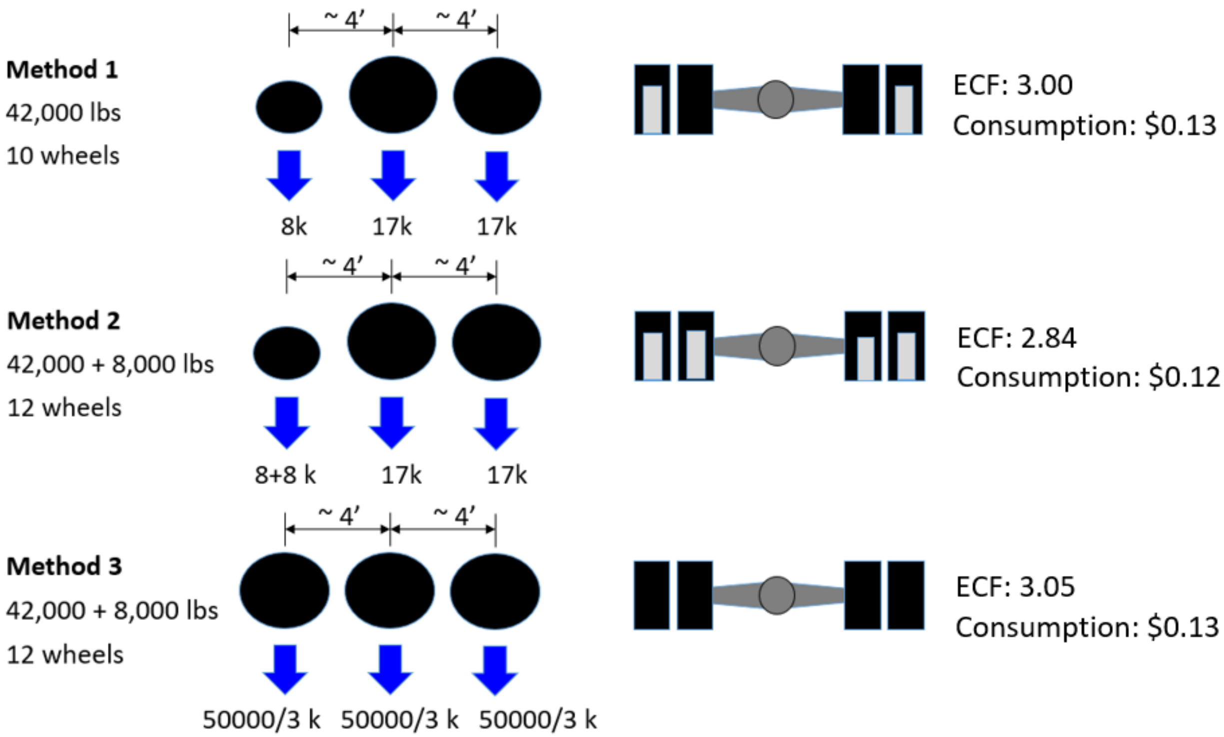


Figure 4.8: Consumption for different equivalent configurations

The pavement consumption analysis previously discussed served to validate the hypothesis that by adding additional wheels to the liftable axles, and treating the liftable and tandem axles as one axle group, a conservative but reasonable estimation of the true consumption of a given SHV can be obtained. Thus, the following equivalency methods were used in this study for the consumption analysis of SHVs:

(1) For pusher axles, if only one pusher axle exists, two additional wheels were added to its original configuration. For this reason, the modified pusher axle and the fixed axle were treated as one tridem axle group; if more than one pusher axle exists, two additional wheels were added to each of them. Therefore, the modified pusher axles were treated as one axle group.
(2) For booster axles, two additional loads were added to the axle and the axle was treated as a single axle group due to its relatively great distance from the other axles.

4.3 Experimental Design

Based on the findings of the previous chapters, the research team selected the most popular routes used by SHVs in Texas. Once the routes were selected, typical pavement structures were obtained from TxDOT's Plans Online with the assistance of relevant TxDOT personnel. This information consisted of typical pavement structures (layer thicknesses and materials) as well as subgrade conditions and environmental characteristics. This information was essential for pavement modeling and analysis. The second component of the experimental design is traffic characterization. Typical SHVs were sampled and the most popular configurations were selected and evaluated.

4.4 Analysis Results

4.4.1 Review of the Axle Load Data

The axle data required to perform the pavement analysis in this study was obtained from TxDPS, in the form of a sample of weigh enforcement activities reported from 2010 to 2015 in Texas as described in Chapter 3. The data contains axle and weight information that served as a valuable resource in determining the most common SHV configurations in Texas, and their respective axle weights. Around 3,000 SHVs were identified out of the total number of 292,000 records.

In addition to the TxDPS weight enforcement data, the research team also proposed four three-axle SU truck weight configurations: 1) maximum legal load, 2) realistic load based on legal considerations and results from the previous analysis, 3) permit/exemption load, and 4) normal load under permit/exemption. Details of the base cases are shown in Figures 4.10, 4.11/4.12, and 4.13 for dump trucks, ready-mix trucks, and garbage trucks, respectively.

4.4.2 Analysis of Dump Trucks

Five typical dump truck configurations were considered in this study. These configurations include one three-axle SU straight truck as base case truck configuration, one SU4, one SU5, one SU6, and one SU7; Figure 4.9 depicts the axle composition of these configurations.

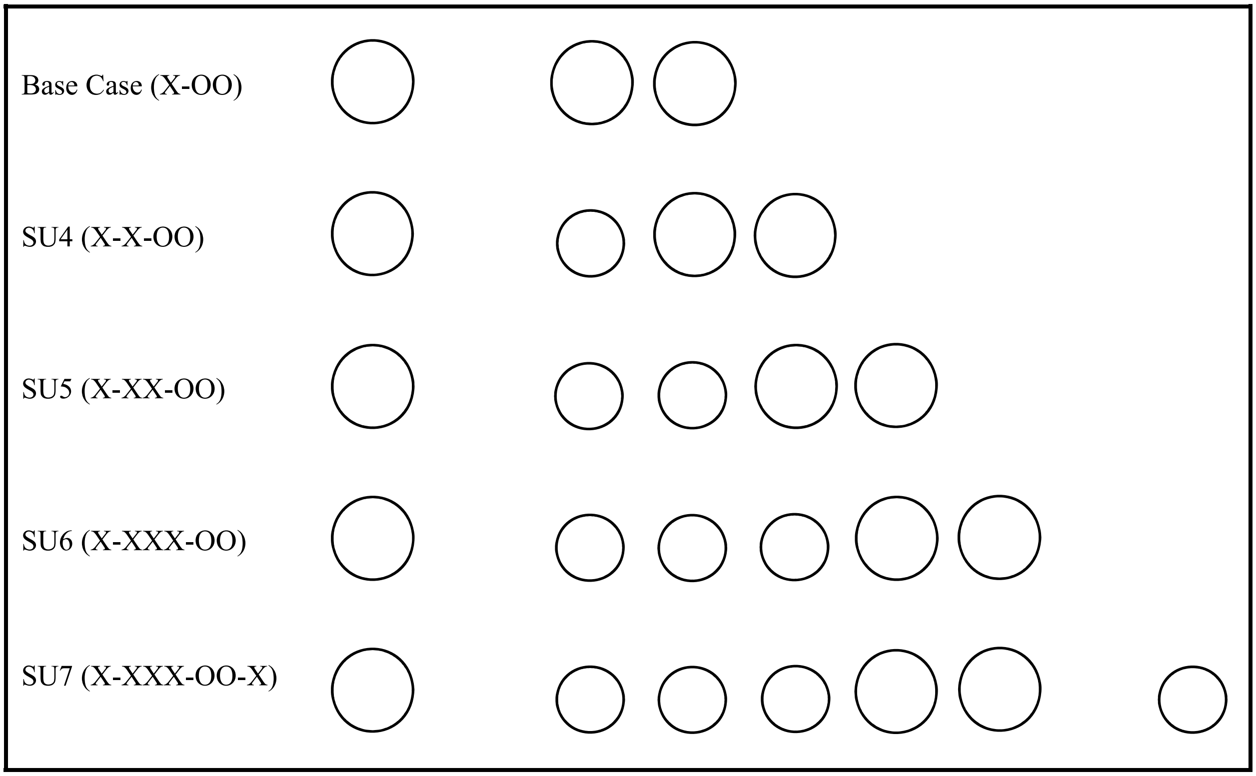


Figure 4.9: Analyzed dump truck configurations

The detailed values in terms of ECF and consumption rate are summarized in Tables 4.3 through 4.7. Comparisons between the pavement consumption rates of SHVs and the traditional three-axle SU straight trucks are shown in Figure 4.10. As that figure demonstrates, except for the 95th percentile of the load distribution, SHVs have higher pavement consumption rates when compared with the base case truck configuration. Moreover, the pavement consumption rate tends to increase as the number of axles increases, which can be explained by the increased payload for the configurations with more axles.

It is important to note that legal load limits or load limit exemptions might not actually be achievable in actual practice (real case). Thus, the following tables provide several different base cases that are presented to maintain consistency with previous research conducted using the pavement and bridge consumption methodologies. However, CTR obtained additional analysis software, in particular the Load Xpert analysis system, that provides a means for modeling different truck configurations. Load Xpert was used to determine the estimated actual axle loads for a given truck configuration (number and spacing of axles, tare weight of truck and distribution of tare weight to the axles, cargo compartment dimensions, cargo weight and distribution to axles). Thus, it was found that though a truck can legally carry 20,000 lbs on the steering axle, and 34,000 lbs on the tandem axle, in actual practice this weight distribution cannot be accomplished. Typically, the tandem axle load allowable maximum will be reached prior to the steer axle load maximum, which results in a lower GVW weight than is hypothetically legal under Texas weight laws. This also applies to special weight exemptions for ready-mix and garbage trucks. A ready-mix truck, by state exemption, can carry up to 23,000 lbs on the steer axle and 46,000 lbs on the drive tandem axle. However, the 46,000 lb limit will be reached before the 23,000 lb steer axle maximum. Thus, although legal, the 69,000 lb GVW limit cannot be achieved without purchasing a ready-mix truck permit. The permit allows a ready-mix truck to operate with a 25,300 lb steer axle and a 50,600 lb drive tandem axle, though the 69,000 lb GVW maximum cannot be exceeded. Thus, the higher tandem axle load allows the steer axle load to increase such that the 69,000 lb GVW can be achieved. Garbage trucks are granted a state exemption to operate at a 21,000 lb steer axle and a 44,000 lb tandem axle load. However, it should be noted that the state exemption allows a 64,000 lb maximum GVW (not 65,000 lbs). Again, based on analysis of three-axle garbage truck configurations using Load Xpert, the researchers found that the 44,000 lb tandem axle exemption is reached before the steer axle exemption of 21,000 lbs, thus resulting in a ‘real case’ load with a lower-than-allowable steer axle weight and, thus, lower than the allowable exemption of 64,000 lbs GVW.

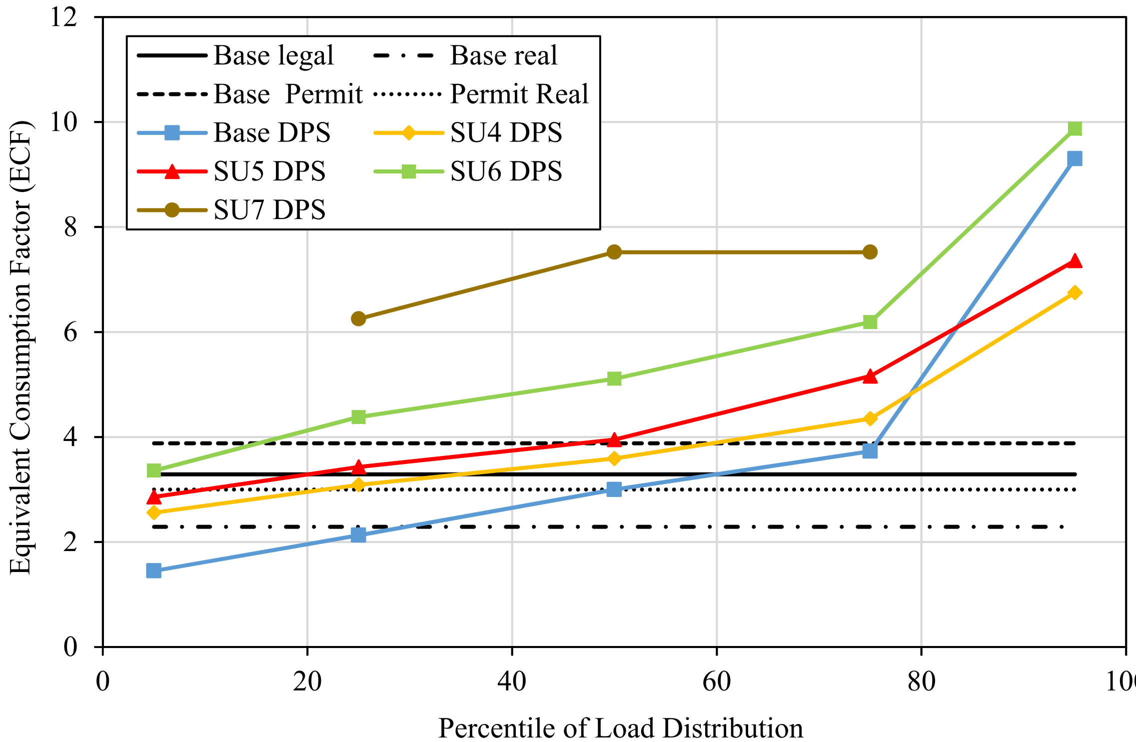


Figure 4.10: Consumption for different percentiles of load distribution (dump truck)

Table 4.3: Consumption for base cases dump truck

Base Cases	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
Base legal	20,000	17,000	17,000					54,000	3.29	$0.14
Base real	14,000	17,000	17,000					48,000	2.29	$0.10
Base + Permit	19,300	18,700	18,700					56,700	3.88	$0.17
Permit Real Case	13,000	18,700	18,700					50,400	3.00	$0.13
DPS Data	**Axle 1**	**Axle 2**	**Axle 3**	**Axle 4**	**Axle 5**	**Axle 6**	**Axle 7**	**GVW**	**ECF**	**Consumption Rate $/VMT**
5th Percentile	11,026	14,915	14,915					40,857	1.45	$0.06
25th Percentile	12,468	16,866	16,866					46,200	2.13	$0.09
50th Percentile	13,755	18,607	18,607					50,968	3.00	$0.13
75th Percentile	14,600	19,750	19,750					54,100	3.73	$0.16
95th Percentile	18,405	24,897	24,897					68,200	9.30	$0.41
Sample Mean	13,332	18,034	18,034					49,400	2.67	$0.12

Table 4.4: Consumption for SU4 dump truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile	11,931	7,245	16,620	16,704				52,500	2.56	$0.11
25th Percentile	12,647	7,680	17,617	17,707				55,650	3.09	$0.14
50th Percentile	13,249	8,045	18,456	18,550				58,300	3.59	$0.16
75th Percentile	13,988	8,494	19,485	19,584				61,550	4.35	$0.19
95th Percentile	15,701	9,534	21,872	21,983				69,090	6.75	$0.29
Sample Mean	13,408	8,142	18,678	18,773				59,002	3.76	$0.16

Table 4.5: Consumption for SU5 dump truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile	14,715	6,919	6,828	15,994	15,994			60,350	2.86	$0.12
25th Percentile	15,544	7,309	7,213	16,895	16,895			63,750	3.43	$0.15
50th Percentile	16,214	7,624	7,524	17,624	17,624			66,500	3.95	$0.17
75th Percentile	17,455	8,207	8,100	18,972	18,972			71,588	5.16	$0.23
95th Percentile	19,157	9,008	8,890	20,823	20,823			78,570	7.36	$0.32
Sample Mean	16,456	7,738	7,636	17,887	17,887			67,492	4.16	$0.18

Table 4.6: Consumption for SU6 dump truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile	12,831	5,931	5,361	5,456	18,061	18,061		65,700	3.36	$0.15
25th Percentile	13,837	6,395	5,781	5,883	19,477	19,477		70,850	4.38	$0.19
50th Percentile	14,452	6,680	6,038	6,145	20,343	20,343		74,000	5.11	$0.22
75th Percentile	15,204	7,027	6,352	6,464	21,401	21,401		77,850	6.19	$0.27
95th Percentile	17,147	7,925	7,164	7,291	24,137	24,137		87,800	9.87	$0.43
Sample Mean	14,565	6,732	6,085	6,193	20,503	20,503		74,581	5.26	$0.23

Table 4.7: Consumption for SU7 dump truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile										
25th Percentile	18,475	6,858	4,910	6,099	14,881	14,881	12,046	78,150	6.25	$0.27
50th Percentile	19,314	7,170	5,133	6,376	15,557	15,557	12,594	81,700	7.52	$0.33
75th Percentile	19,326	7,174	5,136	6,380	15,566	15,566	12,601	81,750	7.52	$0.33
95th Percentile										
Sample Mean	18,994	7,051	5,048	6,271	15,300	15,300	12,385	80,349	7.06	$0.31

4.4.3 Analysis of Ready-Mix Trucks

Three ready-mix truck configurations were considered in this study. Figure 4.11 depicts the axle composition of these configurations.

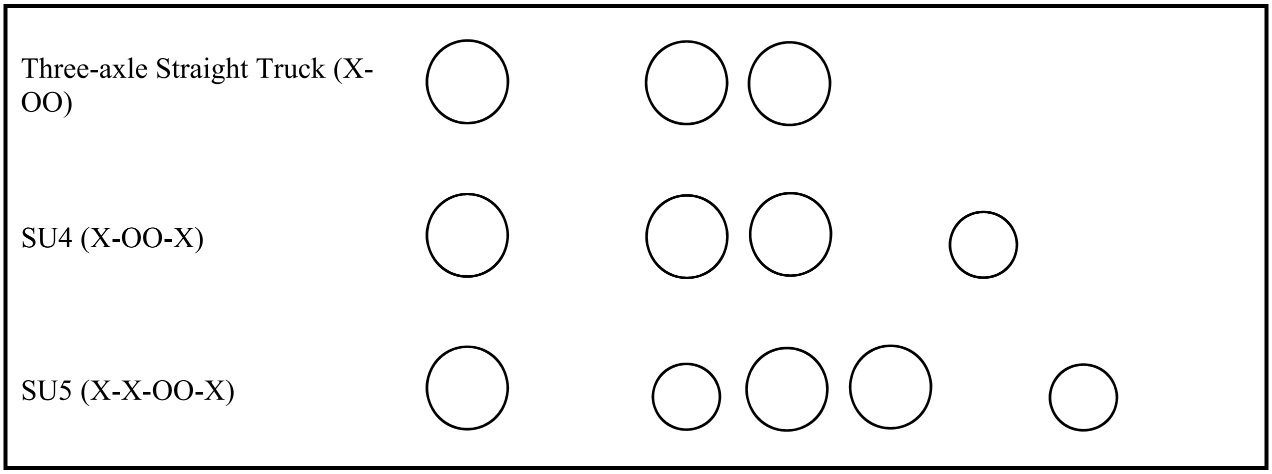


Figure 4.11: Analyzed configurations of ready-mix truck

The results of consumption analysis for different configurations of ready-mix trucks are presented in Figure 4.12; detailed information is tabulated in Tables 4.8 through 4.10. As shown in this figure, for ready-mix trucks, the normal three-axle straight truck tends to have a higher rate of consumption than SHVs (unlike dump trucks). This tendency is explained by the exemptions for ready-mix trucks in Texas. Moreover, the two SHV configurations investigated have very similar values of consumption regardless of the weight allocation. Because the analysis results for the base truck carrying legal and permit/exemption allowable load are still pending, the comparison between them and the consumption of SHVs is not presented here, but will be included in the final report.

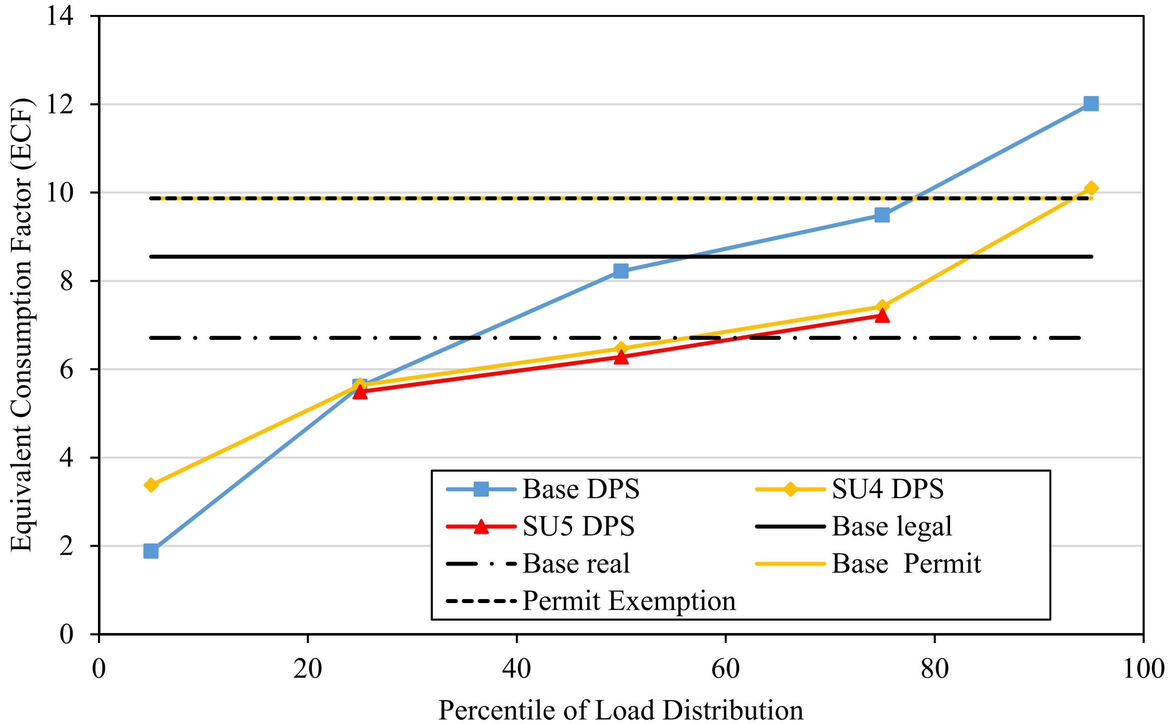


Figure 4.12: Consumption for different percentiles of load distribution (ready-mix truck)

Table 4.8: Consumption for base cases ready-mix truck

Base Cases	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
Base legal	23,000	23,000	23,000					69,000	8.55	$0.37
Base real	16,800	23,000	23,000					62,800	6.71	$0.29
Base + **Permit**	18,400	25,300	25,300					69,000	9.87	$0.43
Permit + Exemption	18,400	25,300	25,300					69,000	9.87	$0.43
DPS Data	**Axle 1**	**Axle 2**	**Axle 3**	**Axle 4**	**Axle 5**	**Axle 6**	**Axle 7**	**GVW**	**ECF**	**Consumption Rate $/VMT**
5th Percentile	12,660	16,095	16,095					44,850	1.88	$0.08
25th Percentile	17,162	21,819	21,819					60,800	5.61	$0.25
50th Percentile	18,842	23,954	23,954					66,750	8.22	$0.36
75th Percentile	19,533	24,833	24,833					69,200	9.49	$0.42
95th Percentile	20,652	26,256	26,256					73,164	12.01	$0.53
Sample Mean	18,000	22,884	22,884					63,768	6.81	$0.30

Table 4.9: Consumption for SU4 ready-mix truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile	15,565	17,234	17,234	8,548				58,580	3.38	$0.15
25th Percentile	17,908	19,828	19,828	9,835				67,400	5.64	$0.25
50th Percentile	18,559	20,549	20,549	10,193				69,850	6.47	$0.28
75th Percentile	19,223	21,285	21,285	10,557				72,350	7.42	$0.32
95th Percentile	20,740	22,964	22,964	11,390				78,058	10.1	$0.44
Sample Mean	18,528	20,515	20,515	10,176				69,733	6.41	$0.28

Table 4.10: Consumption for SU5 ready-mix truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile										
25th Percentile	17,570	6,167	20,090	20,090	8,320			72,238	5.49	$0.24
50th Percentile	18,230	6,398	20,845	20,845	8,632			74,950	6.28	$0.27
75th Percentile	18,944	6,649	21,662	21,662	8,971			77,888	7.22	$0.32
95th Percentile										
Sample Mean	18,258	6,408	20,877	20,877	8,646			75,067	6.34	$0.28

4.4.4 Analysis of Garbage Trucks

In this study, four configurations were identified for the consumption analysis of garbage trucks, as shown in Figure 4.13. These configurations include one base-case three-axle SU straight truck, two SU4 configurations (one with pusher axle, other one with tag axle), and one SU5 with one pusher and one tag axle.

Figure 4.14 and Tables 4.11 through 4.14 provide the consumption for garbage truck configurations.

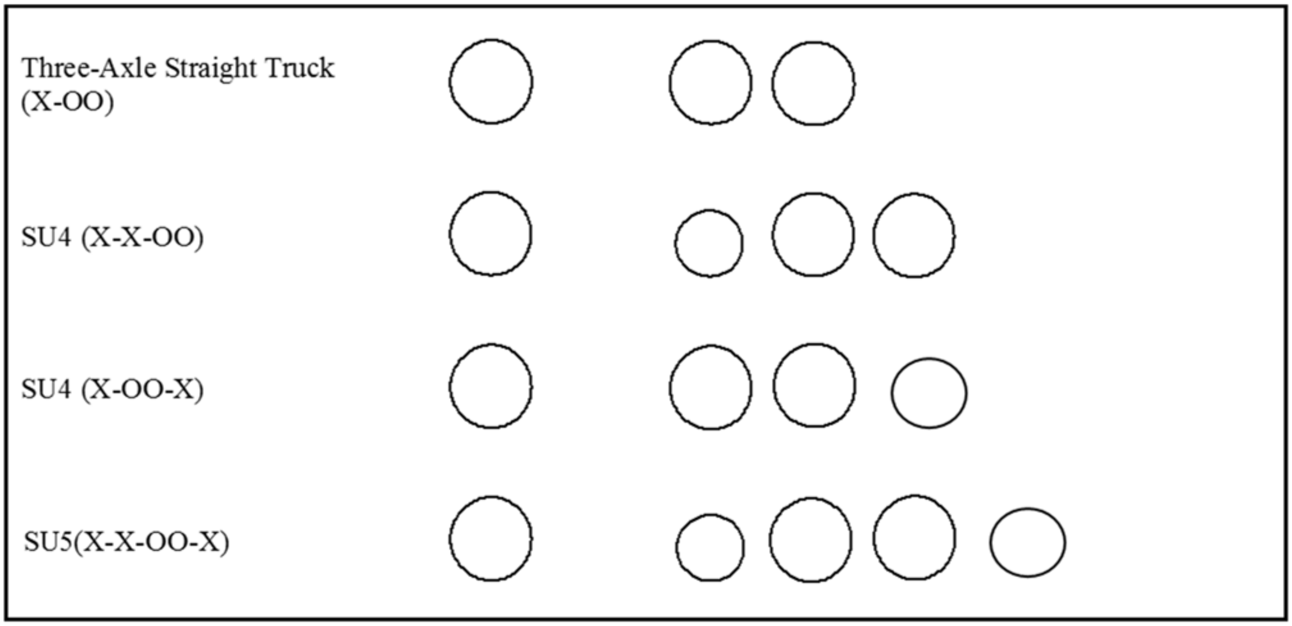


Figure 4.13: Analyzed configurations of garbage truck

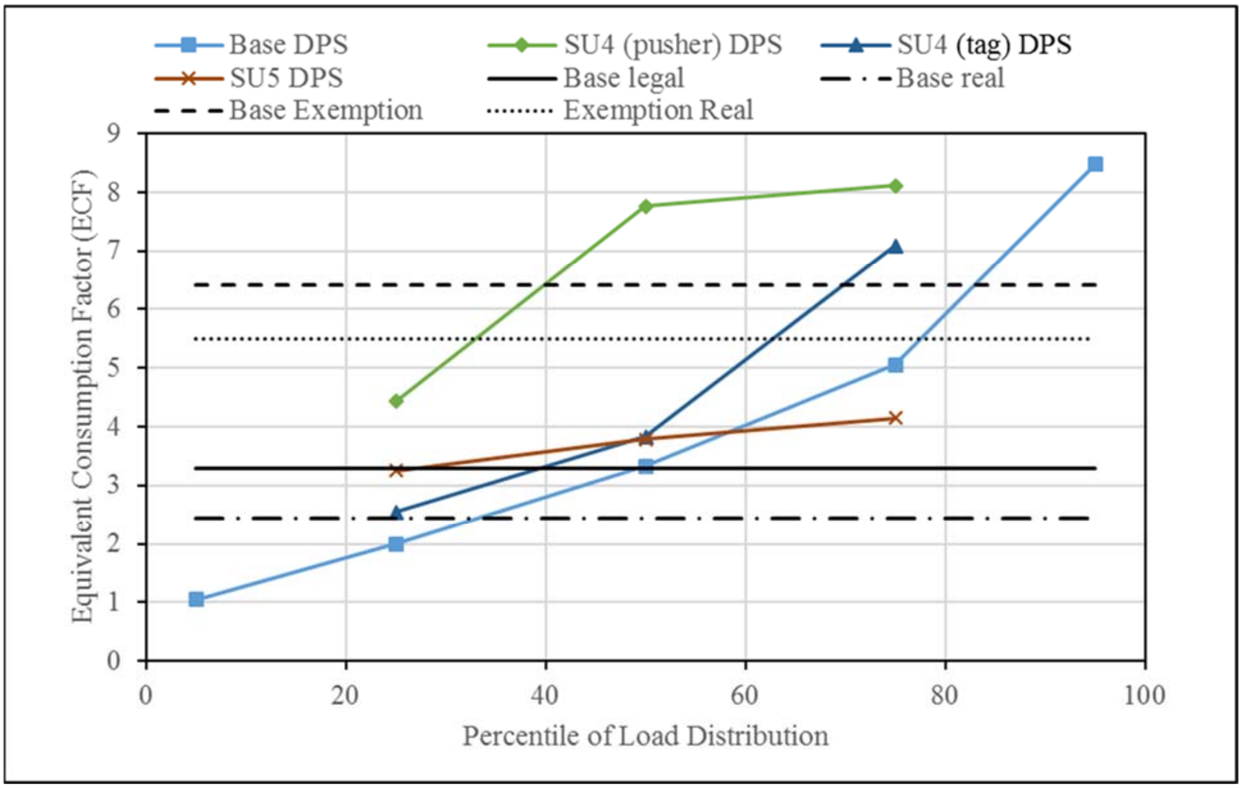


Figure 4.14: Consumption for different percentiles of load distribution (garbage truck)

Table 4.11: Consumption for base cases garbage trucks

Base Cases	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
Base legal	20,000	17,000	17,000					54,000	3.29	$0.14
Base real	15,500	17,000	17,000					49,500	2.43	$0.11
Base + Exemption	21,000	22,000	22,000					64,000	6.41	$0.28
Exemption Real Case	15,000	22,000	22,000					59,000	5.50	$0.24
DPS Data	**Axle 1**	**Axle 2**	**Axle 3**	**Axle 4**	**Axle 5**	**Axle 6**	**Axle 7**	**GVW**	**ECF**	**Consumption Rate $/VMT**
5th Percentile	10,729	12,985	12,985					36,700	1.04	$0.05
25th Percentile	13,477	16,311	16,311					46,100	1.99	$0.09
50th Percentile	15,611	18,894	18,894					53,400	3.33	$0.15
75th Percentile	17,424	21,088	21,088					59,600	5.05	$0.22
95th Percentile	19,821	23,989	23,989					67,800	8.47	$0.37
Sample Mean	15,427	18,671	18,671					52,770	3.17	$0.14

Table 4.12: Consumption for SU4 (pusher axle) garbage trucks

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile										
25th Percentile	11,421	5,598	20,643	20,643				58,305	4.43	$0.19
50th Percentile	13,245	6,492	23,939	23,939				67,615	7.76	$0.34
75th Percentile	13,368	6,553	24,163	24,163				68,246	8.11	$0.35
95th Percentile										
Sample Mean	12,508	6,131	22,608	22,608				63,855	6.25	$0.27

Table 4.13: Consumption for SU4 (tag axle) garbage trucks

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile										
25th Percentile	17,202	15,956	15,956	4,342				53,455	2.54	$0.11
50th Percentile	19,430	18,022	18,022	4,904				60,379	3.83	$0.17
75th Percentile	22,816	21,164	21,164	5,759				70,904	7.08	$0.31
95th Percentile										
Sample Mean	19,799	18,365	18,365	4,997				61,525	4.12	$0.18

Table 4.14: Consumption for SU5 garbage truck

DPS Data	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	GVW	ECF	Consumption Rate $/VMT
5th Percentile										
25th Percentile	16,920	8,007	15,252	15,252	7,340			62,770	3.25	$0.14
50th Percentile	17,730	8,390	15,982	15,982	7,691			65,775	3.79	$0.17
75th Percentile	18,215	8,620	16,419	16,419	7,902			67,575	4.15	$0.18
95th Percentile										
Sample Mean	17,682	8,368	15,939	15,939	7,671			65,599	3.77	$0.16

4.5 Summary of Findings

The research team evaluated the pavement impacts of SHV operations on the state-maintained highway system in terms of pavement consumption. Various factors were considered during the analysis, such as types of SHVs (dump trucks, ready-mix trucks, or others), SHV configurations, and distributions of the axle load. The major findings are listed here:

- The limitations of the AASHTOWare Pavement ME software prevent its use as means to directly model SHVs since the software assumes equal axle load distribution for an axle group; however, the research team developed three methods to approximate typical SHV configurations and related consumption rates. For this purpose, an extensive pavement analysis was performed. A liftable axle together with a tandem axle was modeled in multi-layer linear elastic software to match their response in terms of strain to existent configurations in AASHTOWare Pavement ME. Then, these equivalent configurations were used as input parameters in the pavement consumption analysis.
- For dump trucks, SHVs have higher consumption rates than the base configuration. As expected among SHVs, the consumption increases as the number of axles increase. Compared with the consumption caused by the dump base legal load case, the research team found the following consumption rate factors: SU4 (1.14), SU5 (1.26), SU6 (1.60), and SU7 (2.15). Considering the consumption of the dump base legal load plus permit case, the research team the following consumption rate factors: SU4 (0.97), SU5 (1.07), SU6 (1.36), and SU7 (1.82).
- In contrast to dump trucks, ready-mix trucks (configured as normal three-axle straight trucks) tend to produce higher consumption rates than do SHVs, which is due to the current axle and GVW exemptions for ready-mix trucks in Texas. Comparison with the legal (exemption) base case the research team found the following consumption rate factors: SU4 (0.75) and SU5 (0.74). Comparison with the legal (exemption) base case plus permit, the research team found the following consumption rate factors: SU4 (0.68) and SU5 (0.67).
- For garbage trucks, SHVs yield lower pavement consumption rates than the state base plus exemption, base case for the three-axle truck configuration. The research team found the following consumption rate factors: SU4 pusher (0.98), SU4 tag (0.64), and SU5 with pusher and tag axles (0.59). With regard to the state exemption 'real' base case—that is, the axle loads that can actually operate legally under the state exemption—the research team found the following consumption rate factors: SU4 pusher (1.14), SU4 tag (0.75), and SU5 with pusher and tag axles (0.69).

4.6 References

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Chapter 5. SHV Impacts on Bridges

5.1 Background and Objective

This chapter documents our efforts to analyze the SHV bridge impacts. The analysis results consist of consumption rates in dollars per VMT ($/VMT) for the SHV configurations selected. This analysis was conducted at two levels:

1. A complete network-level analysis of each configuration impact on all bridges in Texas, on- and off-system, and
2. A project-level analysis of a sample of bridges, conducted to inform recommendations for bridge posting signage strategies.

Results from the network-level analysis were used to evaluate the magnitude of the potential bridge rerating effort faced by TxDOT's Bridge Division in order to meet FHWA requirements if the studied configurations are approved. These configurations are based on the analysis of their impacts on every bridge in Texas (21,722 on-system and 11,515 off-system bridges). The analysis was performed with necessary data pulled from TxDOT's two bridge databases: PonTex (a system developed in-house to manage bridge inspection data) and the older BRINSAP (Bridge Inventory, Inspection and Appraisal Program). Results from the project-level analysis of a sample of bridges were used as an input to create signage compliant with the MUTCD for bridge load posting.

5.2 SHV Bridge Consumption Analysis: Theory and Analysis Methodology

Bridge consumption may be understood as a fatigue process in which each load pass over a given bridge consumes part of the bridge design life. AASHTO bridge design specifications include fatigue curves that imply a certain number of stress cycles that define the bridge design life (AASHTO 1990). The generic mathematical formulation of the bridge fatigue curves is presented in Equation 5.1.

$$\log N = C - m \log S \qquad (5.1)$$

Where:

N – Number of cycles or load applications
S – Stress range
m – Constant: material dependent
C – Constant

Figure 5.1 illustrates one of the fatigue curves included in the AASHTO bridge design specifications. This set of curves is specific for steel bridge details and is in a logarithmic scale. It is evident from this set of curves that 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.

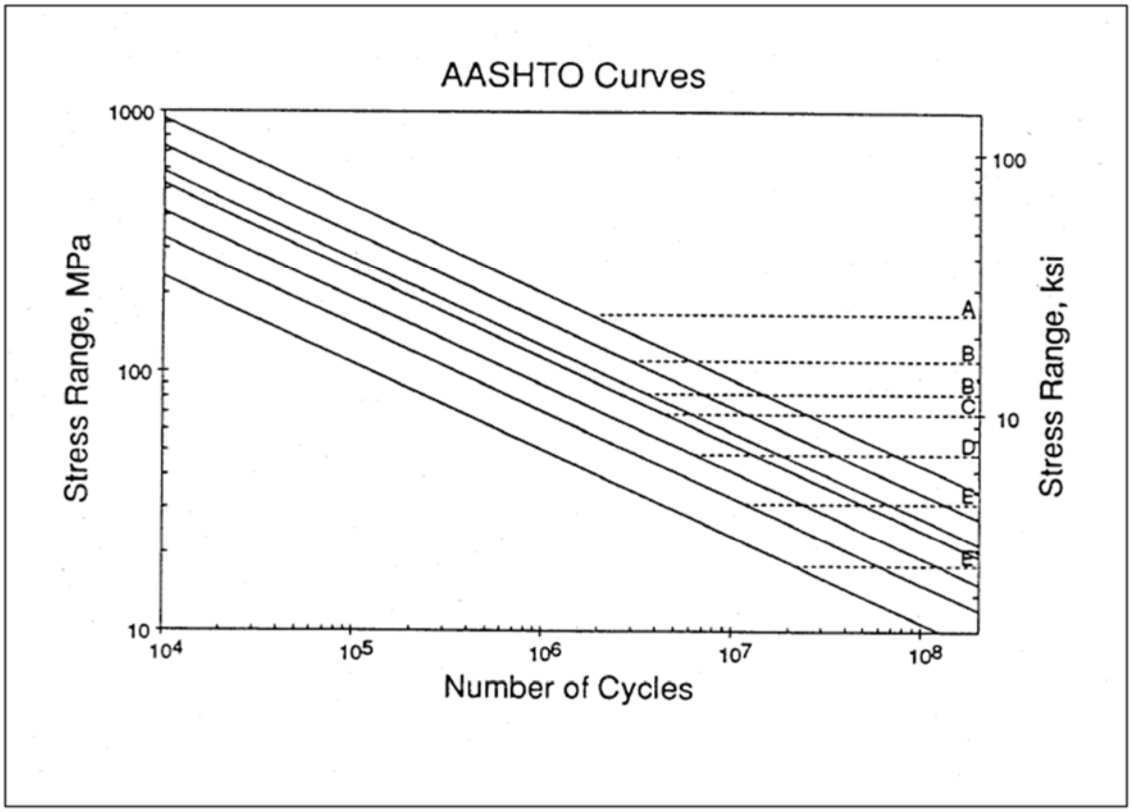


Figure 5.1: AASHTO bridge fatigue curves – steel bridges

AASHTO specifies a 75-year design life or two million applications of the design load. Design loads are specific load configurations with defined axle spacing and axle loads. The PonTex/BRINSAP/National Bridge Inventory (NBI) database contains data that allows for the application of simplified methodologies to estimate bridge consumption for load configurations at the policy level. The following PonTex/NBI data items are of particular importance to the bridge consumption analysis:

Operating rating load: maximum permissible live load that can be placed on a bridge. Allowing unlimited use of the operating rating load will reduce the bridge life.

Inventory rating load: live load that can safely utilize the bridge for an indefinite period of time. This load causes stresses equivalent to those caused by the design load, but reflect the current load rating for a given bridge.

HS20-44 load: AASHTO standard 72 kip truck (AASHTO 1990).

Applying Equation 5.1 twice, one for the inventory rating load and one for the SHV configuration of interest, then subtracting one result from the other, one obtains Equation 5.2.

$$\frac{N_{Inventory}}{N_{OSOW}} = \frac{S^{m}_{OSOW}}{S^{m}_{Inventory}} \qquad (5.2)$$

Where:

$N_{inventory}$ – Number of load applications for the inventory rating load
N_{OSOW} – Number of load applications for the OS/OW or SHV load
$S_{inventory}$ – Stress range for the inventory load
S_{OSOW} – Stress range for the OS/OW or SHV load
m – Constant: material dependent

At the network/policy level, it is not feasible to calculate actual stress ranges for bridge details for the following reasons: (1) digital descriptions of bridge cross sections and other characteristics are not available; (2) even if they were, the data mining effort and computational demands would make this task unfeasible within this project's time frame.

An acceptable method, successfully used in previous OS/OW studies, involves using live load bending moments as surrogates for the stress range (Imbsen and Schomber 1987; Weissmann and Harrison 1992; Weissman et al. 2002). This approach substitutes the stress ranges in Equation 5.2 with bending moments, defining the bridge consumption ratio as depicted in Equation 5.3. Simply put, Equation 5.3 states that the bridge consumption ratio induced by a bending moment of an inventory rating load passing on a given bridge is equal to one. Loads inducing bending moments twice as large as the inventory rating bending moment lead to a bridge consumption ratio of two to the power "m," where *m* is a function of the bridge material. Table 5.1 presents the *m* values recommended in the literature for the corresponding PonTex/BRINSAP structure type codes (Overman 1984). The structure type codes are stored in the third and fourth digits of the PonTex values for data item 43 – Structure Type.

$$ConsumptionRatio = \left(\frac{M_{OSOW}}{M_{Inventory}} \right)^m \qquad (5.3)$$

Where:

$M_{inventory}$ – Live load bending moment for the inventory rating load
M_{OSOW} – Live load bending moment for the OS/OW or SHV load
m – Constant: material dependent

The computer program Moment Analysis of Structures (MOANSTR) can then be used to calculate live load moments depicted in Equation 5.4 for every bridge recorded in the PonTex's on- and off-system statewide inventories. The MOANSTR program's core is a finite differences routine that calculates the live load moment envelopes generated by the SHV configurations and the PonTex/BRINSAP rating loads. The MOANSTR routine incorporates previous research by Matlock (Matlock and Taylor 1968) and others (Weissmann and Harrison 1992, Weissmann et al. 2002). MOANSTR calculates moment envelopes and identifies the maximum live load bending moments (positive and negative) induced by the SHV configuration and the inventory rating load for the consumption calculations. For the posting calculations discussed later in this chapter, MOANSTR was coded with the operating rating. Mileage by county is then applied to arrive to a consumption calculation in dollars per mile driven.

Table 5.1: Values of "m" constant for bridge fatigue analysis

Structure Type	m
Concrete Slab	4.1
Concrete Girders	3.5
Concrete T Beam	4.1
Concrete Box Beam	4.1
Concrete Continuous Slab	4.1
Concrete Continuous T Beam	4.1
Steel Girder	3.0
Steel Continuous Girders	3.0
Steel Continuous Girder	3.2
Steel Continuous Box Beam	3.2
Steel Continuous Box Beam	3.2
Prestressed Concrete	3.5
Prestressed Concrete Slab	3.5
Prestressed Concrete Girder	3.5
Prestressed Concrete Box Beam	3.5
Prestressed Concrete Continuous	3.5
Prestressed Concrete Continuous	3.5

The bridge consumption (in dollars) due to a given load pass is estimated by using Equation 5.3 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 is $190/sq ft of deck area (Texas 2030 Committee 2009). Updating these values for the year 2017 leads to $235/sq ft. Previous federal highway cost allocation studies established that the asset value of a bridge should be allocated according to the schedule summarized in Table 5.2, with 11% of the bridge asset value attributable to loads that are over HS20-44 (USDOT 2000). HS20-44 is a standardized bridge design load, and current bridge inventory ratings are usually recorded as multiples of the HS20-44 design load in PonTex/BRINSAP. The inventory rating is coded in PonTex data item 66. SHVs are expected to generate force effects in excess of inventory rating loads.

Table 5.2: Bridge asset value percentages for GVW categories

Vehicle Class	Percent Allocation
Passenger Vehicles	65.02%
Trucks	
Single Unit	7.67%
Combinations	
under 50 kips	2.68%
50 - 70 kips	5.15%
70 - 75 kips	8.41%
Over HS20-44 Loading	11.08%
TOTAL =	**100.00%**

With the help of computerized routines, Equation 5.4 was applied, on a bridge by bridge basis, to every on- and off-system bridge in PonTex. The bridge asset consumption results for each bridge were summarized and aggregated to determine an overall cost for each SHV configuration, which was divided by the mileage to get to a cost per mile for bridge consumption.

$$Consumption_{OSOW} = [(Area)(235)(0.11)\left(\frac{M_{OSOW}}{M_{Inventory}}\right)^m] \div (2{,}000{,}000) \qquad (5.4)$$

Where:

$M_{inventory}$ – Live load bending moment for the inventory rating load for each bridge in the permit dataset

M_{OSOW} – Live load bending moment for the OS/OW or SHV load for each bridge in the permit dataset

m – Constant: material dependent

235 – Asset value for a bridge in dollars per bridge deck square foot

0.11 – The bridge asset value responsibility for heavy trucks (see Table 5.2).

2,000,000 – Number of allowable load cycles that define bridge design life according to AASHTO

The latest version of the RHINO (Road-Highway Inventory Network) GIS file was processed with the objective of obtaining the on- and off-system center miles by county. The on- and off-system mileages by county were then exported to the Statistical Analysis System (SAS) for further processing, in order to obtain centerline mileage totals by county to be used in the bridge consumption calculation mentioned above.

It is important to note that, for a significant number of the bridges, particularly those off-system, that the moment ratio in Equation 5.4 was capped at 1.36. The moment ratio of 1.36 is an approximation of the operating rating limit. It is meant to reflect the fact that configurations that induce a moment ratio above the operating rating will be allowed to cross that specific bridge, which will have to be posted for that specific configuration.

5.3 SHV Bridge Consumption Analysis

5.3.1 Overview

This section documents the consumption analysis for the four-, five-, six- and seven-axle configurations, determined through extensive field and data surveys, discussed in previous chapters. The analysis also includes the three-axle configurations for dump, ready-mix, and garbage trucks, respectively. These three-axle configurations represent the commonly used configurations of these three truck types. They can be used for comparison and for incremental consumption analysis.

The configurations are depicted in Figure 5.2 through Figure 5.11. The base case dump, ready-mix, and garbage trucks are represented schematically in Figure 5.2. The remaining figures also contain a picture of the truck type. Bridge consumption results by county and statewide are provided in Table 5.2 through Table 5.26 for the top 12 bridge consumption counties. Excel files with complete results by county are available upon request. Table 5.27 has a summary of statewide consumption for each configuration, and Figure 5.12 shows the statewide summary in graph format, organized by type of truck.

5.3.2 Base Case: Three-Axle Trucks

Figure 5.2 shows the base case three-axle configurations, and Table 5.3 through Table 5.8 show consumption results for the dump, ready-mix, and garbage trucks respectively. There are always two tables for each truck, one for off-system and the other for on-system bridges.

Table 5.3 and Table 5.4 illustrate the consumption calculations for the base case three-axle dump truck, respectively, for the off-system and on-system bridges.

The following description applies to subsequent chapter tables. All unit costs are in dollars, except the cost per mile, which is displayed in cents per mile for convenience. As previously explained in the methodology section, all consumption values come from bridge-by-bridge bending moment calculations used to obtain the moment ratios in Equation 5.4. The results tables' columns are explained below.

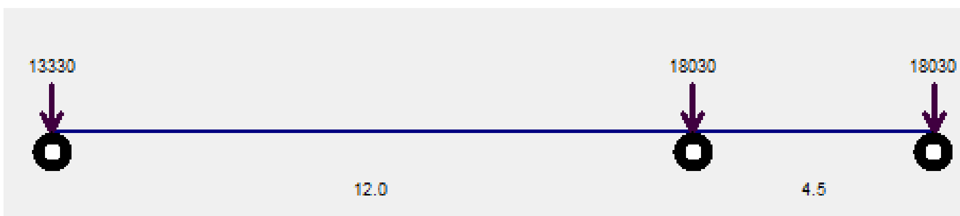
- First column: county name.
- Second column: number of on/off-system bridges in the county.
- Third column: total on/off-system centerline mileage in the county.
- Fourth column: bridge density in the county (bridges per centerline mile).
- Fifth column: total bridge consumption in the county (dollars per county per configuration pass).
- Sixth column: average consumption per bridge in the county (dollars per bridge per configuration pass).
- Seventh column: average consumption per mile in the county (CENTS per mile per configuration pass).

- Last row: statewide results.

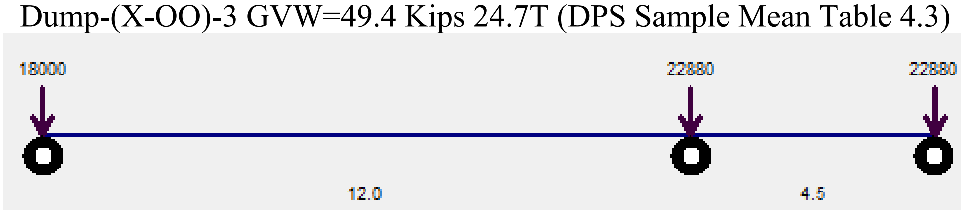
The results in all tables are limited to the 12 counties with the highest consumption costs per mile. The totals summarized at the bottom of the table are the statewide results. On- and off-system results of all configurations for every county statewide are available on supporting Excel spreadsheets.

The totals summarized in Table 5.3 show that the statewide off-system consumption per mile for the three-axle dump truck base case configuration is 0.31 cents per mile. This low number is caused by extensive mileage encompassed by the off-system roads and streets in Texas, which adds up to a total of 215,340 center line miles.

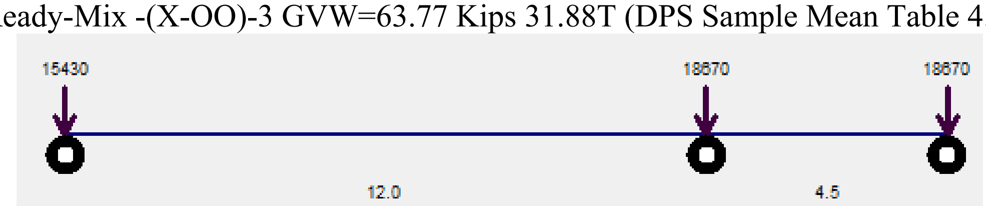
Table 5.4 summarizes the consumption calculations for the three-axle, base case dump truck for the on-system bridges. Consumption values for the on-system bridges are much higher than for the off-system bridges due to the higher number of bridges and lower on-system mileage: 21,717 bridges over 79,217 center miles, leading to an average statewide consumption of 3.41 cents per mile. This disparity between on- and off-system consumption costs is consistent for all truck configurations.



Dump-(X-OO)-3 GVW=49.4 Kips 24.7T (DPS Sample Mean Table 4.3)



Ready-Mix -(X-OO)-3 GVW=63.77 Kips 31.88T (DPS Sample Mean Table 4.8)



Garbage-(X-OO)-3 GVW=52.77 Kips 26.39T (DPS Sample Mean Table 4.11)

Figure 5.2: Base case three-axle configurations for dump, ready-mix and solid waste (garbage) trucks

Table 5.3: Off-system bridge consumption by county for the base-case dump truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13349.8	0.12	$170.61	$0.11	1.3
DALLAS	737	8176.8	0.09	$92.11	$0.12	1.1
TRAVIS	281	4235.4	0.07	$34.06	$0.12	0.8
COLLIN	317	4014.9	0.08	$24.87	$0.08	0.6
WILLIAMSON	197	2754.6	0.07	$16.32	$0.08	0.6
BEXAR	328	6313.6	0.05	$36.19	$0.11	0.6
WILLACY	49	527.4	0.09	$2.96	$0.06	0.6
FORT BEND	239	2801.6	0.09	$15.48	$0.06	0.6
HIDALGO	142	3548.8	0.04	$16.69	$0.12	0.5
TARRANT	434	7574.1	0.06	$33.97	$0.08	0.4
BRAZORIA	167	2253.0	0.07	$9.97	$0.06	0.4
MAVERICK	14	260.7	0.05	$1.10	$0.08	0.4
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$665.50*		*0.31*

Table 5.4: On-system bridge consumption by county for the base-case dump truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.592	$264.63	$0.18	28.7
HARRIS	1,820	1380.7	1.318	$384.36	$0.21	27.8
TARRANT	1,076	987.3	1.090	$127.83	$0.12	12.9
TRAVIS	574	652.5	0.880	$82.29	$0.14	12.6
BEXAR	917	1066.0	0.860	$120.38	$0.13	11.3
COLLIN	312	554.7	0.562	$53.35	$0.17	9.6
EL PASO	369	506.6	0.728	$44.07	$0.12	8.7
WILLIAMSON	298	586.4	0.508	$45.46	$0.15	7.8
ORANGE	77	235.9	0.326	$18.01	$0.23	7.6
JEFFERSON	210	377.8	0.556	$27.82	$0.13	7.4
MONTGOMERY	200	488.5	0.409	$35.32	$0.18	7.2
DENTON	320	557.2	0.574	$39.94	$0.12	7.2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,722*	*79,217.4*		*$2,700.67*		*3.41*

Table 5.5: Off-system bridge consumption by county for the base-case ready-mix truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$359.75	$0.23	2.7
DALLAS	737	8,176.8	0.09	$201.87	$0.27	2.5
TRAVIS	281	4,235.4	0.07	$73.04	$0.26	1.7
COLLIN	317	4,014.9	0.08	$58.86	$0.19	1.5
WILLIAMSON	197	2,754.6	0.07	$38.32	$0.19	1.4
BEXAR	328	6,313.6	0.05	$80.58	$0.25	1.3
FORT BEND	239	2,801.6	0.09	$33.81	$0.14	1.2
HIDALGO	142	3,548.8	0.04	$36.03	$0.25	1.0
TARRANT	434	7,574.1	0.06	$74.06	$0.17	1.0
WILLACY	49	527.4	0.09	$5.01	$0.10	1.0
MAVERICK	14	260.7	0.05	$2.40	$0.17	0.9
BRAZORIA	167	2,253.0	0.07	$20.70	$0.12	0.9
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,512*	*215,340.1*		*$1,391.84*		*0.65*

Table 5.6: On-system bridge consumption by county for the base-case ready-mix truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
DALLAS	1,466	920.8	1.59	$607.63	$0.41	66.0
HARRIS	1,820	1,380.7	1.32	$888.51	$0.49	64.4
TARRANT	1,076	987.3	1.09	$299.42	$0.28	30.3
TRAVIS	574	652.5	0.88	$192.97	$0.34	29.6
BEXAR	917	1,066.0	0.86	$282.48	$0.31	26.5
COLLIN	312	554.7	0.56	$122.32	$0.39	22.1
EL PASO	369	506.6	0.73	$103.65	$0.28	20.5
WILLIAMSON	298	586.4	0.51	$105.59	$0.35	18.0
ORANGE	77	235.9	0.33	$41.67	$0.54	17.7
MONTGOMERY	200	488.5	0.41	$81.17	$0.41	16.6
JEFFERSON	210	377.8	0.56	$61.62	$0.29	16.3
DENTON	320	557.2	0.57	$90.73	$0.28	16.3
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,720*	*79,217.4*		*$6,013.49*		*7.59*

Table 5.7: Off-system bridge consumption by county for the base-case garbage truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$206.48	$0.13	1.5
DALLAS	737	8,176.8	0.09	$112.36	$0.15	1.4
TRAVIS	281	4,235.4	0.07	$41.38	$0.15	1.0
COLLIN	317	4,014.9	0.08	$30.62	$0.10	0.8
WILLIAMSON	197	2,754.6	0.07	$20.01	$0.10	0.7
BEXAR	328	6,313.6	0.05	$43.94	$0.13	0.7
WILLACY	49	527.4	0.09	$3.58	$0.07	0.7
FORT BEND	239	2,801.6	0.09	$18.81	$0.08	0.7
HIDALGO	142	3,548.8	0.04	$20.46	$0.14	0.6
TARRANT	434	7,574.1	0.06	$40.93	$0.09	0.5
BRAZORIA	167	2,253.0	0.07	$12.06	$0.07	0.5
MAVERICK	14	260.7	0.05	$1.32	$0.09	0.5
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$799.47*		*0.37*

Table 5.8: On-system bridge consumption by county for the base-case garbage truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
DALLAS	1,466	920.8	1.59	$323.99	$0.22	35.2
HARRIS	1,820	1,380.7	1.32	$472.00	$0.26	34.2
TARRANT	1,076	987.3	1.09	$157.28	$0.15	15.9
TRAVIS	574	652.5	0.88	$101.36	$0.18	15.5
BEXAR	917	1,066.0	0.86	$147.12	$0.16	13.8
COLLIN	312	554.7	0.56	$65.32	$0.21	11.8
EL PASO	369	506.6	0.73	$53.92	$0.15	10.6
WILLIAMSON	298	586.4	0.51	$55.75	$0.19	9.5
ORANGE	77	235.9	0.33	$22.07	$0.29	9.4
JEFFERSON	210	377.8	0.56	$33.67	$0.16	8.9
MONTGOMERY	200	488.5	0.41	$43.44	$0.22	8.9
DENTON	320	557.2	0.57	$48.60	$0.15	8.7
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,722*	*79,217.4*		*$3,270.42*		*4.13*

5.3.3 Four-Axle Trucks

Figure 5.3 through Figure 5.6 show the four-axle truck configurations selected for analysis. They include dump, garbage, and ready-mix trucks. Table 5.9 through Table 5.16 show the top 12 bridge consumption costs, first for off-system, then for on-system bridges. The table formats and organization are the same as those discussed for the base case dump truck.

Dump-(X-X-OO)-4 GVW=59Kips 29.5T

Figure 5.3: Four-axle dump truck configuration (DPS Sample Mean Table 4.4)

Table 5.9: Off-system bridge consumption by county for the four-axle dump truck configuration

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$280.03	$0.18	2.1
DALLAS	737	8,176.8	0.09	$154.75	$0.21	1.9
TRAVIS	281	4,235.4	0.07	$56.59	$0.20	1.3
COLLIN	317	4,014.9	0.08	$42.68	$0.13	1.1
WILLIAMSON	197	2,754.6	0.07	$27.90	$0.14	1.0
BEXAR	328	6,313.6	0.05	$60.87	$0.19	1.0
WILLACY	49	527.4	0.09	$4.82	$0.10	0.9
FORT BEND	239	2,801.6	0.09	$25.57	$0.11	0.9
HIDALGO	142	3,548.8	0.04	$28.43	$0.20	0.8
TARRANT	434	7,574.1	0.06	$55.55	$0.13	0.7
BRAZORIA	167	2,253.0	0.07	$16.34	$0.10	0.7
MAVERICK	14	260.7	0.05	$1.80	$0.13	0.7
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,077.96*		*0.50*

Table 5.10: On-system bridge consumption by county for the four-axle dump truck configuration

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$451.32	$0.31	49.0
HARRIS	1,820	1,380.7	1.32	$658.24	$0.36	47.7
TARRANT	1,076	987.3	1.09	$220.64	$0.21	22.3
TRAVIS	574	652.5	0.88	$142.29	$0.25	21.8
BEXAR	917	1,066.0	0.86	$205.57	$0.22	19.3
COLLIN	312	554.7	0.56	$90.98	$0.29	16.4
EL PASO	369	506.6	0.73	$75.95	$0.21	15.0
WILLIAMSON	298	586.4	0.51	$77.92	$0.26	13.3
ORANGE	77	235.9	0.33	$30.99	$0.40	13.1
MONTGOMERY	200	488.5	0.41	$60.41	$0.30	12.4
JEFFERSON	210	377.8	0.56	$46.51	$0.22	12.3
DENTON	320	557.2	0.57	$66.64	$0.21	12.0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,720*	*79,217.4*		*$4,479.52*		*5.65*

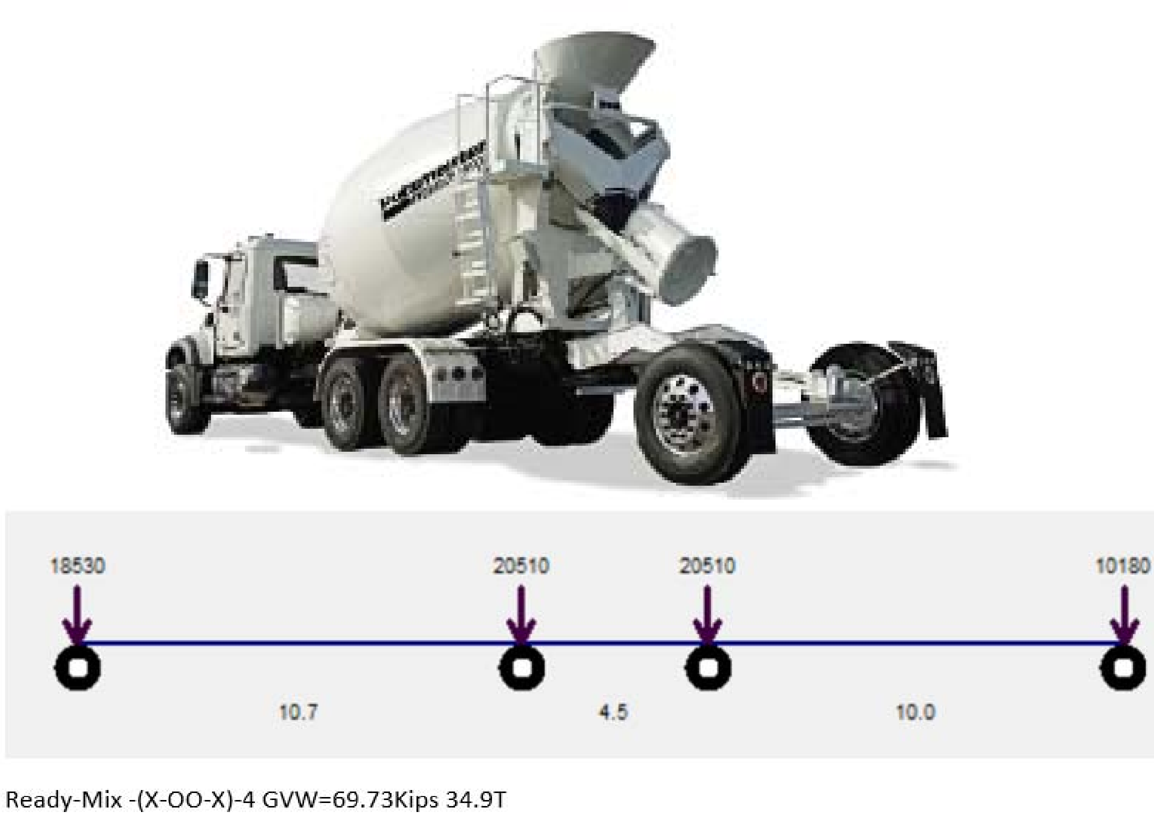


Figure 5.4: Four-axle ready-mix truck (DPS Sample Mean Table 4.10)

Table 5.11: Off-system bridge consumption by county for the four-axle ready-mix truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$392.93	$0.25	2.9
DALLAS	737	8,176.8	0.09	$222.87	$0.30	2.7
TRAVIS	281	4,235.4	0.07	$80.85	$0.29	1.9
COLLIN	317	4,014.9	0.08	$67.77	$0.21	1.7
WILLIAMSON	197	2,754.6	0.07	$44.10	$0.22	1.6
BEXAR	328	6,313.6	0.05	$86.56	$0.26	1.4
FORT BEND	239	2,801.6	0.09	$37.08	$0.16	1.3
HIDALGO	142	3,548.8	0.04	$41.13	$0.29	1.2
TARRANT	434	7,574.1	0.06	$83.14	$0.19	1.1
MAVERICK	14	260.7	0.05	$2.77	$0.20	1.1
BRAZORIA	167	2,253.0	0.07	$22.01	$0.13	1.0
WILLACY	49	527.4	0.09	$4.96	$0.10	0.9
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,505.77*		*0.70*

Table 5.12: On-system bridge consumption by county for the four-axle ready-mix truck

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$726.09	$0.50	78.9
HARRIS	1,820	1,380.7	1.32	$1,075.48	$0.59	77.9
TARRANT	1,076	987.3	1.09	$361.94	$0.34	36.7
TRAVIS	574	652.5	0.88	$234.82	$0.41	36.0
BEXAR	917	1,066.0	0.86	$325.31	$0.35	30.5
COLLIN	312	554.7	0.56	$147.31	$0.47	26.6
EL PASO	369	506.6	0.73	$121.06	$0.33	23.9
WILLIAMSON	298	586.4	0.51	$127.01	$0.43	21.7
ORANGE	77	235.9	0.33	$47.78	$0.62	20.3
MONTGOMERY	200	488.5	0.41	$96.35	$0.48	19.7
DENTON	320	557.2	0.57	$105.72	$0.33	19.0
JEFFERSON	210	377.8	0.56	$68.69	$0.33	18.2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,720*	*79,217.4*		*$6,774.17*		*8.55*

Garbage-(X-X-OO)-4 GVW=63.86Kips 31.9T

Figure 5.5: Four-axle solid waste (garbage) truck with pusher liftable axle (DPS Sample Mean Table 4.12)

Table 5.13: Off-system bridge consumption by county for the four-axle garbage truck with pusher liftable axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$359.04	$0.23	2.7
DALLAS	737	8,176.8	0.09	$201.72	$0.27	2.5
TRAVIS	281	4,235.4	0.07	$72.93	$0.26	1.7
COLLIN	317	4,014.9	0.08	$58.57	$0.18	1.5
WILLIAMSON	197	2,754.6	0.07	$38.29	$0.19	1.4
BEXAR	328	6,313.6	0.05	$81.36	$0.25	1.3
FORT BEND	239	2,801.6	0.09	$33.73	$0.14	1.2
HIDALGO	142	3,548.8	0.04	$36.08	$0.25	1.0
TARRANT	434	7,574.1	0.06	$73.95	$0.17	1.0
WILLACY	49	527.4	0.09	$5.02	$0.10	1.0
BRAZORIA	167	2,253.0	0.07	$20.77	$0.12	0.9
MAVERICK	14	260.7	0.05	$2.39	$0.17	0.9
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,512*	*215,340.1*		*$1,394.10*		*0.65*

Table 5.14: On-system bridge consumption by county for the four-axle garbage truck with pusher liftable axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$608.27	$0.41	66.1
HARRIS	1,820	1,380.7	1.32	$886.91	$0.49	64.2
TARRANT	1,076	987.3	1.09	$298.93	$0.28	30.3
TRAVIS	574	652.5	0.88	$192.79	$0.34	29.5
BEXAR	917	1,066.0	0.86	$284.12	$0.31	26.7
COLLIN	312	554.7	0.56	$122.06	$0.39	22.0
EL PASO	369	506.6	0.73	$105.01	$0.28	20.7
WILLIAMSON	298	586.4	0.51	$105.40	$0.35	18.0
ORANGE	77	235.9	0.33	$41.86	$0.54	17.7
MONTGOMERY	200	488.5	0.41	$80.95	$0.40	16.6
JEFFERSON	210	377.8	0.56	$61.91	$0.29	16.4
DENTON	320	557.2	0.57	$90.47	$0.28	16.2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,720*	*79,217.4*		*$6,040.96*		*7.63*

Garbage-(X-OO-X)-4 GVW=61.53 Kips 30.8T

Figure 5.6: Four-axle garbage truck with tag liftable axle (DPS Sample Mean Table 4.13)

Table 5.15: Off-system bridge consumption by county for the four-axle garbage truck with tag liftable axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$313.85	$0.20	2.4
DALLAS	737	8,176.8	0.09	$173.98	$0.24	2.1
TRAVIS	281	4,235.4	0.07	$63.46	$0.23	1.5
COLLIN	317	4,014.9	0.08	$49.44	$0.16	1.2
WILLIAMSON	197	2,754.6	0.07	$32.02	$0.16	1.2
BEXAR	328	6,313.6	0.05	$67.79	$0.21	1.1
FORT BEND	239	2,801.6	0.09	$29.06	$0.12	1.0
WILLACY	49	527.4	0.09	$4.87	$0.10	0.9
HIDALGO	142	3,548.8	0.04	$31.40	$0.22	0.9
TARRANT	434	7,574.1	0.06	$62.62	$0.14	0.8
BRAZORIA	167	2,253.0	0.07	$18.05	$0.11	0.8
MAVERICK	14	260.7	0.05	$2.04	$0.15	0.8
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,197.76*		*0.56*

Table 5.16: On-system bridge consumption by county for the four-axle garbage truck with tag liftable axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
DALLAS	1,466	920.8	1.59	$513.96	$0.35	55.8
HARRIS	1,820	1,380.7	1.32	$754.74	$0.41	54.7
TARRANT	1,076	987.3	1.09	$253.31	$0.24	25.7
TRAVIS	574	652.5	0.88	$163.29	$0.28	25.0
BEXAR	917	1,066.0	0.86	$233.12	$0.25	21.9
COLLIN	312	554.7	0.56	$104.34	$0.33	18.8
EL PASO	369	506.6	0.73	$85.74	$0.23	16.9
WILLIAMSON	298	586.4	0.51	$89.30	$0.30	15.2
ORANGE	77	235.9	0.33	$34.91	$0.45	14.8
MONTGOMERY	200	488.5	0.41	$69.32	$0.35	14.2
DENTON	320	557.2	0.57	$76.14	$0.24	13.7
JEFFERSON	210	377.8	0.56	$51.58	$0.25	13.7
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,720*	*79,217.4*		*$5,021.55*		*6.34*

5.3.4 Five-Axle Trucks

Figure 5.7 through Figure 5.9 show the five-axle truck configurations selected for analysis. They include dump, garbage, and ready-mix trucks. Table 5.17 through Table 5.22 show the top 12 bridge consumption costs, first for off-system, then for on-system bridges. The table formats and organization are the same as those discussed for the base case dump truck.

Garbage-(X-X-OO-X)-5 GVW=65.6 Kips 32.8T

Figure 5.7: Five-axle garbage truck with pusher and tag liftable axles (DPS Sample Mean Table 4.14)

Table 5.17: Off-system bridge consumption by county for the five-axle garbage truck with pusher and tag liftable axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$331.95	$0.21	2.5
DALLAS	737	8,176.8	0.09	$184.65	$0.25	2.3
TRAVIS	281	4,235.4	0.07	$67.61	$0.24	1.6
COLLIN	317	4,014.9	0.08	$54.16	$0.17	1.3
WILLIAMSON	197	2,754.6	0.07	$35.28	$0.18	1.3
BEXAR	328	6,313.6	0.05	$71.03	$0.22	1.1
FORT BEND	239	2,801.6	0.09	$30.71	$0.13	1.1
HIDALGO	142	3,548.8	0.04	$33.86	$0.24	1.0
TARRANT	434	7,574.1	0.06	$67.52	$0.16	0.9
WILLACY	49	527.4	0.09	$4.58	$0.09	0.9
MAVERICK	14	260.7	0.05	$2.25	$0.16	0.9
BRAZORIA	167	2,253.0	0.07	$18.69	$0.11	0.8
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,256.43*		*0.58*

Table 5.18: On-system bridge consumption by county for the five-axle garbage truck with pusher and tag liftable axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$583.42	$0.40	63.4
HARRIS	1,820	1,380.7	1.32	$863.41	$0.47	62.5
TARRANT	1,076	987.3	1.09	$289.06	$0.27	29.3
TRAVIS	574	652.5	0.88	$187.35	$0.33	28.7
BEXAR	917	1,066.0	0.86	$259.02	$0.28	24.3
COLLIN	312	554.7	0.56	$118.44	$0.38	21.4
EL PASO	369	506.6	0.73	$96.52	$0.26	19.1
WILLIAMSON	298	586.4	0.51	$101.62	$0.34	17.3
ORANGE	77	235.9	0.33	$38.54	$0.50	16.3
MONTGOMERY	200	488.5	0.41	$77.58	$0.39	15.9
DENTON	320	557.2	0.57	$84.60	$0.26	15.2
JEFFERSON	210	377.8	0.56	$56.06	$0.27	14.8
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Statewide Total	*21,720*	*79,217.4*		*$5,477.72*		*6.91*

Table 5.19: Off-system bridge consumption by county for a ready-mix truck with one pusher and one booster axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption		
				Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$416.13	$0.26	3.1
DALLAS	737	8,176.8	0.09	$241.61	$0.33	3.0
TRAVIS	281	4,235.4	0.07	$84.75	$0.30	2.0
COLLIN	317	4,014.9	0.08	$74.87	$0.24	1.9
WILLIAMSON	197	2,754.6	0.07	$50.42	$0.26	1.8
BEXAR	328	6,313.6	0.05	$95.94	$0.29	1.5
FORT BEND	239	2,801.6	0.09	$40.58	$0.17	1.4
HIDALGO	142	3,548.8	0.04	$47.48	$0.33	1.3
MAVERICK	14	260.7	0.05	$3.24	$0.23	1.2
TARRANT	434	7,574.1	0.06	$94.04	$0.22	1.2
WEBB	28	1,137.5	0.02	$11.99	$0.43	1.1
BRAZORIA	167	2,253.0	0.07	$23.05	$0.14	1.0
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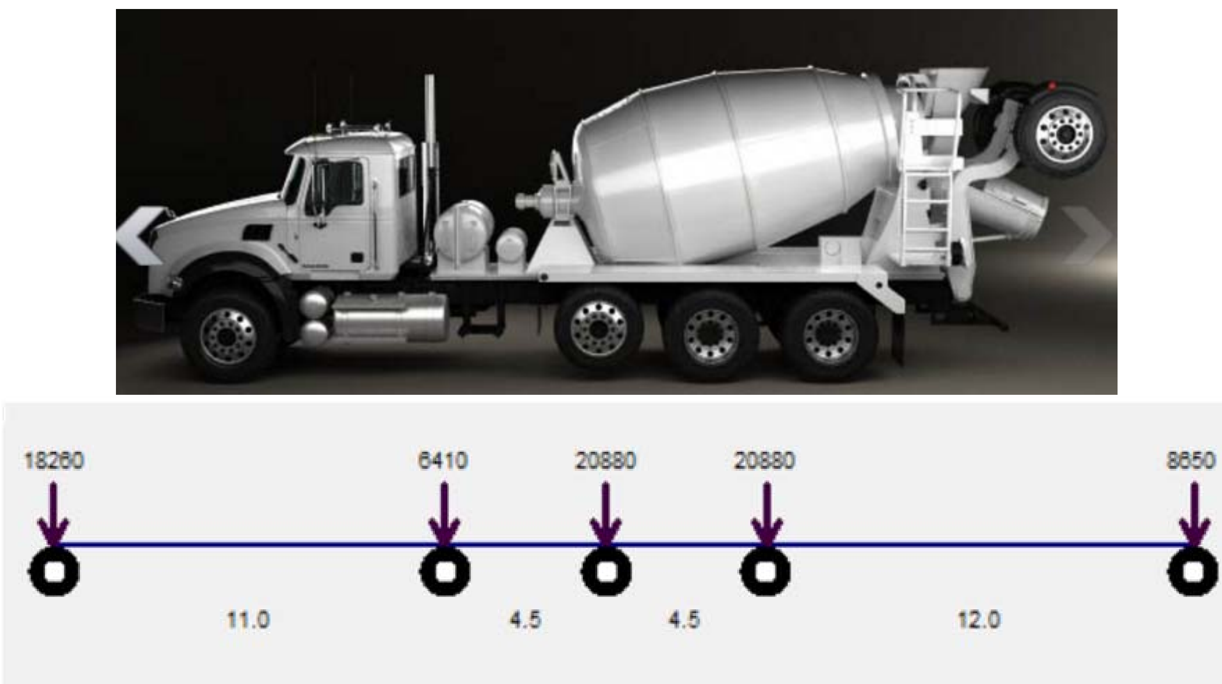
Statewide Total	*11,514*	*215,340.1*		*$1,628.05*		*0.76*



Ready-Mix -(X-X-OO-X)-5 GVW=75.07 Kips 37.54T

Figure 5.8: Five-axle ready-mix truck with one pusher and one booster axle (DPS Sample Mean Table 4.10)

Table 5.20: On-system bridge consumption by county for the five-axle ready-mix truck with one pusher and one booster axle

				Consumption		
County	Total Bridges	Total Mileage	Bridges/ Mile	Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$864.09	$0.59	93.8
HARRIS	1,820	1,380.7	1.32	$1,285.27	$0.71	93.1
TARRANT	1,076	987.3	1.09	$435.60	$0.40	44.1
TRAVIS	574	652.5	0.88	$284.17	$0.50	43.6
BEXAR	917	1,066.0	0.86	$384.14	$0.42	36.0
COLLIN	312	554.7	0.56	$169.40	$0.54	30.5
EL PASO	369	506.6	0.73	$145.06	$0.39	28.6
WILLIAMSON	298	586.4	0.51	$152.88	$0.51	26.1
MONTGOMERY	200	488.5	0.41	$114.26	$0.57	23.4
ORANGE	77	235.9	0.33	$54.34	$0.71	23.0
DENTON	320	557.2	0.57	$124.56	$0.39	22.4
FORT BEND	225	434.9	0.52	$93.62	$0.42	21.5
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Statewide Total	*21,720*	*79,217.4*		*$7,853.37*		*9.91*

Dump-(X-XX-OO)-5 GVW=67.6 Kips 33.8T

Figure 5.9: Five-axle dump truck with two pusher liftable axles (DPS Sample Mean Table 4.5)

Table 5.21: Off-system bridge consumption by county for the five-axle dump truck with two pusher liftable axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$347.46	$0.22	2.6
DALLAS	737	8,176.8	0.09	$194.47	$0.26	2.4
TRAVIS	281	4,235.4	0.07	$71.18	$0.25	1.7
COLLIN	317	4,014.9	0.08	$57.12	$0.18	1.4
WILLIAMSON	197	2,754.6	0.07	$37.60	$0.19	1.4
BEXAR	328	6,313.6	0.05	$75.65	$0.23	1.2
FORT BEND	239	2,801.6	0.09	$32.16	$0.13	1.1
HIDALGO	142	3,548.8	0.04	$36.17	$0.25	1.0
TARRANT	434	7,574.1	0.06	$71.36	$0.16	0.9
WILLACY	49	527.4	0.09	$4.89	$0.10	0.9
MAVERICK	14	260.7	0.05	$2.37	$0.17	0.9
BRAZORIA	167	2,253.0	0.07	$19.56	$0.12	0.9
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Statewide Total	*11,515*	*215,340.1*		*$1,323.49*		*0.61*

Table 5.22: On-system bridge consumption by county for the five-axle dump truck with two pusher liftable axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.59	$624.45	$0.43	67.8
HARRIS	1,820	1,380.7	1.32	$923.99	$0.51	66.9
TARRANT	1,076	987.3	1.09	$309.07	$0.29	31.3
TRAVIS	574	652.5	0.88	$201.11	$0.35	30.8
BEXAR	917	1,066.0	0.86	$277.20	$0.30	26.0
COLLIN	312	554.7	0.56	$126.56	$0.41	22.8
EL PASO	369	506.6	0.73	$103.83	$0.28	20.5
WILLIAMSON	298	586.4	0.51	$108.62	$0.36	18.5
ORANGE	77	235.9	0.33	$41.76	$0.54	17.7
MONTGOMERY	200	488.5	0.41	$82.37	$0.41	16.9
DENTON	320	557.2	0.57	$89.92	$0.28	16.1
JEFFERSON	210	377.8	0.56	$59.61	$0.28	15.8
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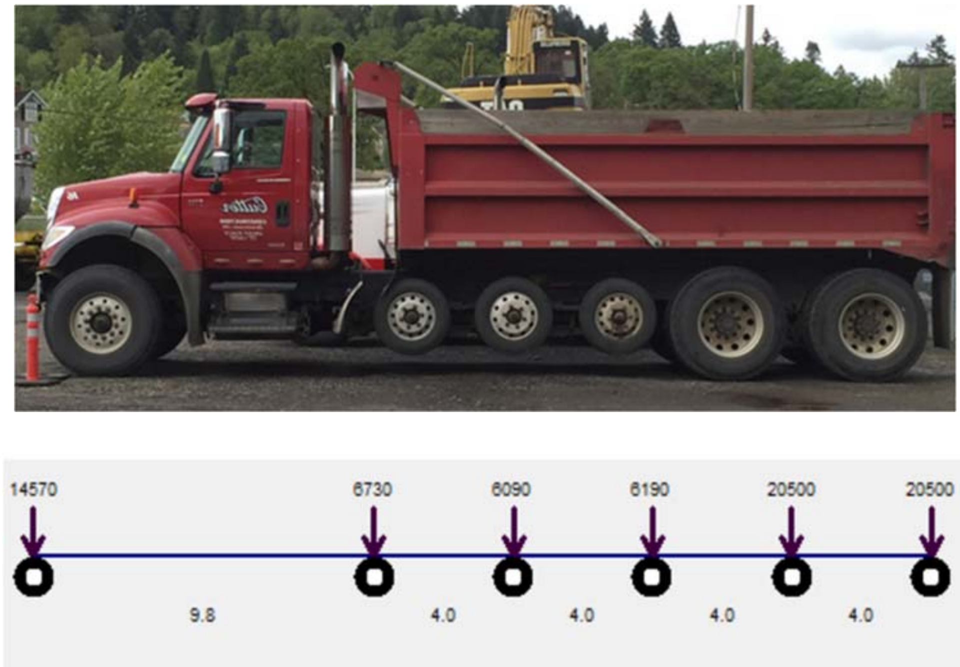
.	.	.	.	.	.	.
Statewide Total	*21,722*	*79,217.4*		*$5,868.99*		*7.41*

5.3.5 Six-Axle Truck

Figure 5.10 shows the six-axle truck configuration selected for analysis, a dump truck. Table 5.23 and Table 5.24 show the top 12 bridge consumption costs, respectively for off-system, then for on-system bridges. The table formats and organization are the same as those discussed for the base case dump truck.



Dump-(X-XXX-OO)-6-Average GVW= 37.29 T

Figure 5.10: Six-axle dump truck configuration with three pusher axles (DPS Sample Mean Table 4.6)

Table 5.23: Off-system bridge consumption by county for the six-axle SHV dump truck configuration with three pusher axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
HARRIS	1,579	13349.8	0.12	$411.80	$0.26	3.1
DALLAS	737	8176.8	0.09	$237.57	$0.32	2.9
TRAVIS	281	4235.4	0.07	$84.40	$0.30	2.0
COLLIN	317	4014.9	0.08	$73.00	$0.23	1.8
WILLIAMSON	197	2754.6	0.07	$49.19	$0.25	1.8
BEXAR	328	6313.6	0.05	$94.18	$0.29	1.5
FORT BEND	239	2801.6	0.09	$39.70	$0.17	1.4
HIDALGO	142	3548.8	0.04	$45.99	$0.32	1.3
TARRANT	434	7574.1	0.06	$91.44	$0.21	1.2
MAVERICK	14	260.7	0.05	$3.10	$0.22	1.2
BRAZORIA	167	2253.0	0.07	$22.97	$0.14	1.0
WEBB	28	1137.5	0.02	$11.46	$0.41	1.0
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.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,606.68*		*0.75*

Table 5.24: On-system bridge consumption by county for the six-axle SHV dump truck configuration with three pusher axles

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Dollars/ Bridge	Cents/ Mile
DALLAS	1,466	920.8	1.592	$264.63	$0.18	28.7
HARRIS	1,820	1380.7	1.318	$384.36	$0.21	27.8
TARRANT	1,076	987.3	1.090	$127.83	$0.12	12.9
TRAVIS	574	652.5	0.880	$82.29	$0.14	12.6
BEXAR	917	1066.0	0.860	$120.38	$0.13	11.3
COLLIN	312	554.7	0.562	$53.35	$0.17	9.6
EL PASO	369	506.6	0.728	$44.07	$0.12	8.7
WILLIAMSON	298	586.4	0.508	$45.46	$0.15	7.8
ORANGE	77	235.9	0.326	$18.01	$0.23	7.6
JEFFERSON	210	377.8	0.556	$27.82	$0.13	7.4
MONTGOMERY	200	488.5	0.409	$35.32	$0.18	7.2
DENTON	320	557.2	0.574	$39.94	$0.12	7.2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,722*	*79,217*		*$7,668.77*		*9.68*

5.3.6 Seven-Axle Truck

Figure 5.11 shows the seven-axle truck configuration selected for analysis, a dump truck. Table 5.25 and Table 5.26 show the top 12 bridge consumption costs, first for off-system, then for on-system bridges. The table formats and organization are the same as those discussed for the base case dump truck.

Dump-(X-XXX-OO-X)-7-Average GVW= 40.175 T

Figure 5.11: Seven-axle dump truck configuration with three pusher axles and one booster axle (DPS Sample Mean Table 4.7)

Table 5.25: Off-system bridge consumption by county for the seven-axle SHV dump truck configuration – three pusher axles and one booster axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
HARRIS	1,579	13,349.8	0.12	$372.75	$0.24	2.8
DALLAS	737	8,176.8	0.09	$217.18	$0.29	2.7
TRAVIS	281	4,235.4	0.07	$76.84	$0.27	1.8
WILLIAMSON	197	2,754.6	0.07	$47.42	$0.24	1.7
COLLIN	317	4,014.9	0.08	$68.07	$0.21	1.7
BEXAR	328	6,313.6	0.05	$84.75	$0.26	1.3
FORT BEND	239	2,801.6	0.09	$35.41	$0.15	1.3
HIDALGO	142	3,548.8	0.04	$43.22	$0.30	1.2
MAVERICK	14	260.7	0.05	$3.01	$0.22	1.2
TARRANT	434	7,574.1	0.06	$86.41	$0.20	1.1
WEBB	28	1,137.5	0.02	$10.58	$0.38	0.9
BRAZORIA	167	2,253.0	0.07	$19.19	$0.11	0.9
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*11,515*	*215,340.1*		*$1,419.58*		*0.66*

Table 5.26: On-system bridge consumption by county for the seven-axle SHV dump truck configuration – three pusher axles and one booster axle

County	Total Bridges	Total Mileage	Bridges/ Mile	Consumption Dollars/ County	Consumption Dollars/ Bridge	Consumption Cents/ Mile
HARRIS	1,820	1,380.7	1.32	$1,311.51	$0.72	95.0
DALLAS	1,466	920.8	1.59	$874.42	$0.60	95.0
TRAVIS	574	652.5	0.88	$289.80	$0.50	44.4
TARRANT	1,076	987.3	1.09	$433.34	$0.40	43.9
BEXAR	917	1,066.0	0.86	$369.68	$0.40	34.7
COLLIN	312	554.7	0.56	$165.05	$0.53	29.8
EL PASO	369	506.6	0.73	$140.41	$0.38	27.7
WILLIAMSON	298	586.4	0.51	$151.22	$0.51	25.8
MONTGOMERY	200	488.5	0.41	$109.41	$0.55	22.4
ORANGE	77	235.9	0.33	$52.77	$0.69	22.4
DENTON	320	557.2	0.57	$116.69	$0.36	20.9
FORT BEND	225	434.9	0.52	$90.67	$0.40	20.8
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Statewide Total	*21,722*	*79,217.4*		*$7,305.12*		*9.22*

5.3.7 Summary and Conclusions

Table 5.27 shows a summary of the statewide bridge consumption for the on- and off-system bridges. It also shows the percent increase with respect to the base case, calculated for the same type of truck (ready-mix, dump, and garbage). Figure 5.12 shows the same data in graphical format.

The on-system consumption increases are consistently greater than the increases in off-system consumption, due to the greater number of on-system bridges and smaller on-system mileage. The two largest increases in statewide consumption were both on-system. The greatest increase is caused by the six-axle dump truck (183.9%), followed by the seven-axle dump truck (170.4%).

Table 5.27: Statewide bridge consumption overview

Configuration	Axle Layout (X=single,OO=tandem)	Highway System	Statewide Consumption (cents/mile)	Percent increase from base case
3-Axle Dump Truck	Dump-(X-OO)-3	OFF	0.31	-
(Base Case)		ON	3.41	-
3-Axle Ready Mix	Ready-Mix -(X-OO)-3	OFF	0.65	-
(Base Case)		ON	7.59	-
3-Axle Solid Waste (Garbage)	Garbage -(X-OO)-3	OFF	0.37	-
(Base Case)		ON	4.13	-
4-Axle Ready Mix	Ready-Mix -(X-OO-X)-4	OFF	0.70	7.7%
		ON	8.55	12.6%
5-Axle Ready Mix	Ready-Mix -(X-X-OO-X)-5	OFF	0.76	16.9%
		ON	9.91	30.6%
4-Axle Solid Waste (Garbage)	Garbage-(X-X-OO)-4	OFF	0.65	75.7%
		ON	7.63	84.7%
4-Axle Solid Waste (Garbage)	Garbage-(X-OO-X)-4	OFF	0.56	51.4%
		ON	6.34	53.5%
5-Axle Dump Truck	Dump-(X-XX-OO)-5	OFF	0.61	96.8%
		ON	7.41	117.4%
5-Axle Solid Waste (Garbage)	Garbage-(X-X-OO-X)-5	OFF	0.58	56.8%
		ON	6.91	67.3%
4-Axle Dump Truck	Dump-(X-X-OO)-4	OFF	0.50	61.3%
		ON	5.65	65.7%
6-Axle Dump Truck	Dump-(X-XXX-OO)-6	OFF	0.75	141.9%
		ON	9.68	183.9%
7-Axle Dump Truck	Dump-(X-XXX-OO-O)-7	OFF	0.66	112.9%
		ON	9.22	170.4%

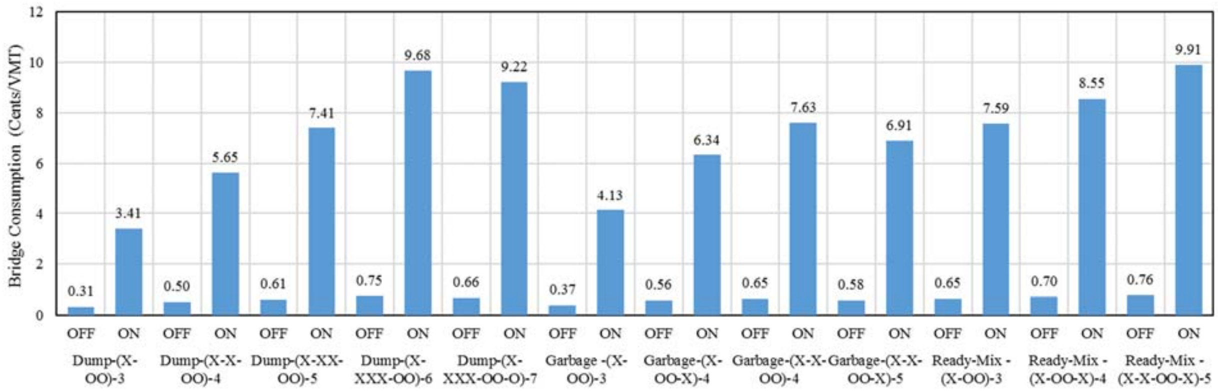

Figure 5.12: Statewide bridge consumption overview

5.4 SHV Bridge Posting

5.4.1 Background

The trucking industry continues to seek out new truck designs, axle configurations, and methods of operation that meet federal and state laws while improving efficiency and increasing company profits. During the past several years, multiple-axle SHVs have been developed to increase the load-carrying capacity of SU trucks. SHVs are designed for specific applications, such as dump trucks, ready-mix concrete trucks, construction material transportation, garbage trucks, and other such applications. This project extensively researched SHV configurations operating in Texas, as discussed in previous chapters.

Although SHVs meet the loading requirements of the FBF (also referred to as “Bridge Formula B”), national studies sponsored by AASHTO have shown that these short, heavy trucks can produce higher stresses in certain bridge designs. AASHTO has funded studies through the NCHRP, published in NCHRP 575 and NCHRP 700. NCHRP 575 specifically documents the results of a national survey of SHV operations and configurations that resulted in five new SHV bridge load rating vehicles for evaluating bridge load capacities. The notional rating vehicle load is used as a screening tool to access bridge load ratings and to identify bridges that may require further assessment using one of the four SHV loadings (SU4, SU5, SU6, and SU7). AASHTO SHV/SU configurations are depicted in Figure 5.13.

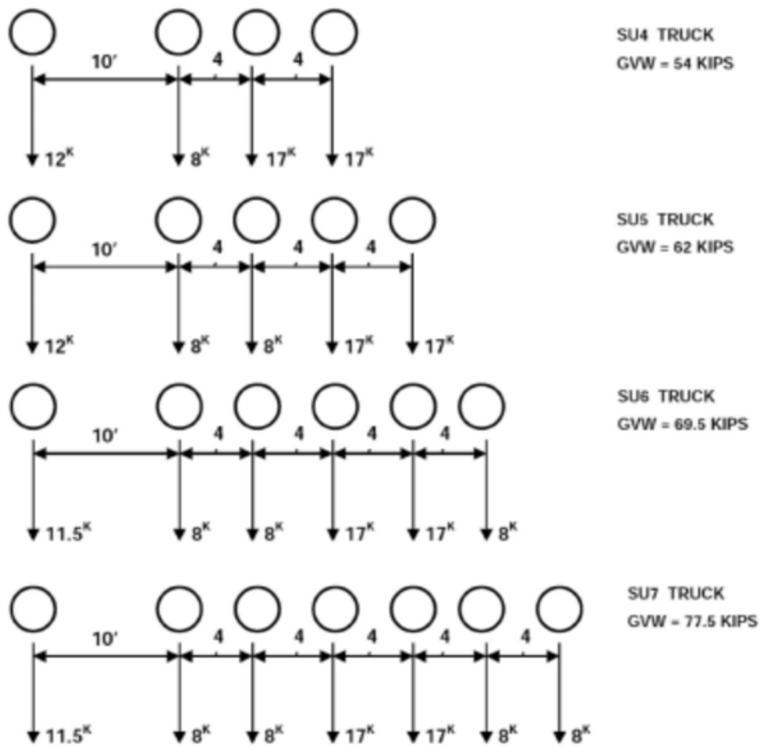

Figure 5.13: AASHTO SU configurations for bridge rating

The FHWA's November 2013 memo requires the states to rerate bridges with spans less than 200 ft in span by December 2017 to address SHV impacts. This raises particular concerns about off-system bridges, which generally have shorter spans and lower load ratings due to the age of the bridge stock.

The posting analysis presented in the next section of this chapter compares the AASHTO configurations with the configurations selected for analysis, such as the previously discussed four, five, six, and seven-axle SHV configurations.

5.4.2 Posting Signs and the MUTCD

When a load rating analysis shows that a bridge does not have sufficient load capacity for either the SHVs identified by this research project or the ones specified by AASHTO, the bridge must be posted for load. Posting signs must conform to the MUTCD. The MUTCD has only one sign (R12-5) that depicts silhouettes of trucks for load posting; these silhouettes represent the three standard legal vehicles. The MUTCD does not allow any other truck silhouettes to be used on signs, so there will be no new silhouettes depicting the SHVs on a posting sign. This makes sense, considering that there is a safety issue of having truck drivers attempting to count the number of axles depicted on a sign while traveling at highway speeds.

Several states are in the process of developing bridge posting signs for regulating SHV operations. Sign designs developed by Virginia, Oregon, Ohio, Delaware, and Kentucky DOTs that provide weight limits for SHVs have one thing in common: they tie an allowable GVW to the number of axles on the SU truck. The Oregon DOT (ODOT) seems to be very active on this issue and has several recommendations for SHV posting signs.

ODOT's proposed posting signs consider that there is a possibility that a bridge has sufficient capacity for legal axle weights and 80,000 lbs GVW for routine commercial traffic, but does not have sufficient capacity for the different SHV configurations. Instead of penalizing all 80,000 lbs trucks from using the bridge, the posting sign depicted in Figure 5.14 was developed to restrict SU vehicles to a lower GVW. Figure 5.15 depicts a proposed sign that restricts SHV operations but allows other commercial traffic to operate.

The posting sign depicted in Figure 5.15 is intended to be used without any other posting signs when a bridge has sufficient capacity for routine commercial traffic and permit loads, but does not have sufficient capacity for the different SHV configurations.

The methodology discussed later in this chapter takes into consideration these proposed signing approaches and is directed at calculating a GVW limit for the different SHV axle configurations.

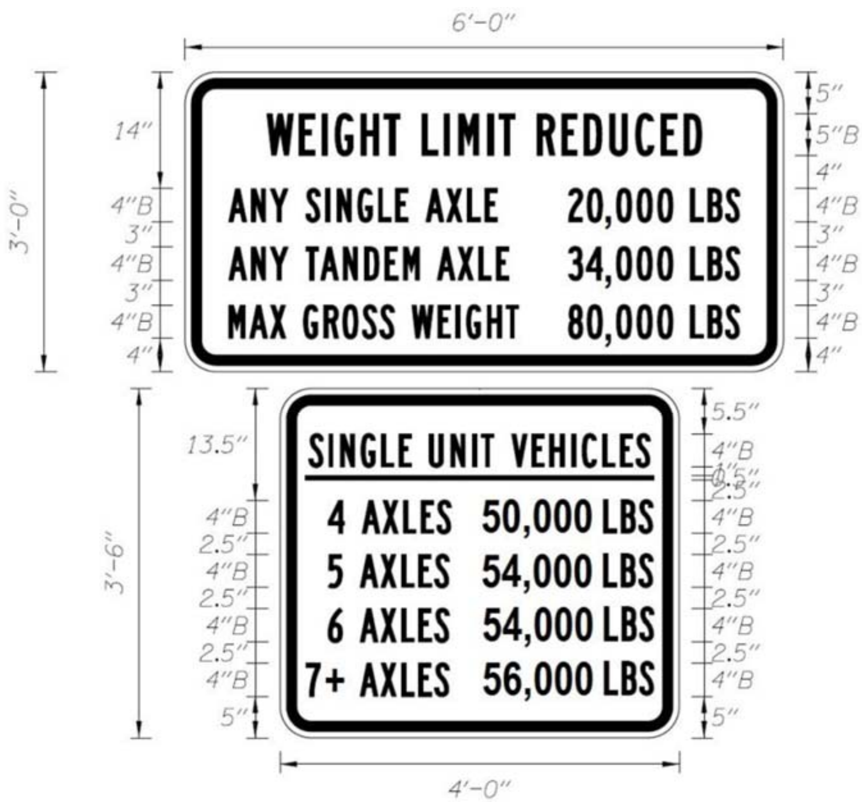

Figure 5.14: ODOT SHV posting sign for bridges posted for other legal loads

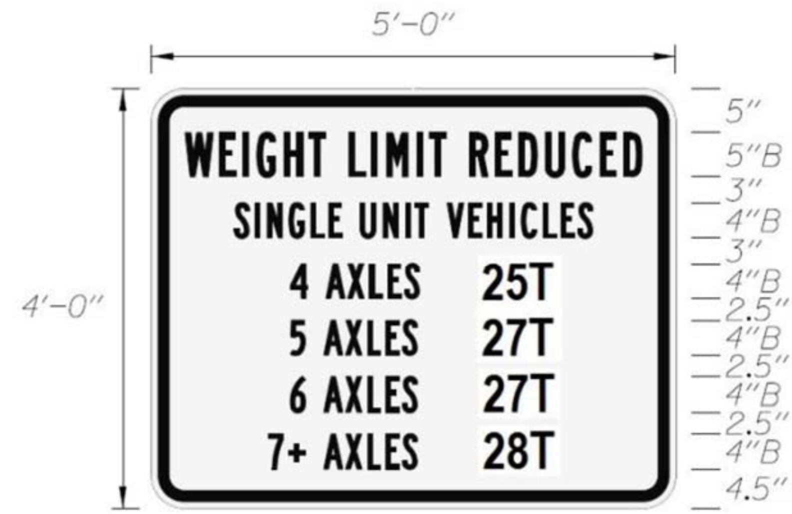

Figure 5.15: ODOT SHV posting sign for bridges posted for SHVs only

5.5 Recommended GVW Limits for Posting Texas Bridges for SHVs

5.5.1 Background

The recommended posting analysis for Texas' on and off-system bridges is based on moment ratios calculated for every on- and off-system bridge statewide. The denominator of these ratios is always the bending moment induced by the operating rating load recorded in PonTex/BRINSAP. The numerator is the moment induced by each SHV configuration analyzed in this study, in addition to the SU/SHV configurations proposed by AASHTO.

The AASHTO configurations described in the November 2013 FHWA memo also require a comprehensive analysis of SHV impacts and associated posting requirements. The SHV configurations recommended by the FHWA in its memo are also included in the latest AASHTO bridge load rating recommendations and were discussed previously in this chapter (see Figure 5.13).

5.5.2 Methodology and Results

The analyses of the six- and seven-axle configurations depicted in Figure 5.10 and Figure 5.11, together with the six- and seven-axle configurations defined by AASHTO and depicted in Figure 5.13, are used to illustrate the bridge rating analysis methodology. The four, five, and six-axle SHV configurations are presented in the next section as results.

The first step of the analysis consisted of running the MOANSTR network bridge analysis program to calculate moment ratios for the configurations under study for all on- and off-system bridges statewide. For the posting analysis, these moment ratios are calculated based on the operating rating load recorded in PonTex. This assumes that the TxDOT Bridge Division uses the operating rating as a limit when it comes to bridge posting decisions.

Table 5.28 and Table 5.29 illustrate the number of bridges exceeding operating rating for the AASHTO SU6 configuration depicted in Figure 5.13, respectively for the off and on-system bridges. These tables present only the highest number of bridges above operating rating counties. Complete tables are available in separate spreadsheets. It may be observed that, as expected, the highest number of bridges exceeding operating rating are located off-system, with 5,436 out of 12,210 exceeding operating rating for the AASHTO SU6 configuration. The same analysis for the on-system bridges statewide shows that, as expected, a much smaller percentage of the on-system bridges will experience moment ratios exceeding operating rating, for the same AASHTO SU6 configuration: 1,262 bridges out of 21,789 bridges.

Figure 5.16 and Figure 5.17 present the cumulative frequency distribution of the moment ratios for the AASHTO SU6 configuration for the on- and off-systems respectively. For example, if TxDOT's Bridge Division would accept moment ratios of 1.05 for the AASHTO SU6 configuration, Figure 5.16 shows that the resulting cumulative frequency would be 27%. Consequently, the 5,436 off-system posted bridges for the SU6 configuration (moment ratio≥1) summarized in Table 5.28 would be reduced to 63% of the set, resulting in 3,424 posted bridges.

From Figure 5.17, if TxDOT's Bridge Division would accept moment ratios of 1.05 for the AASHTO SU6 configuration, the resulting cumulative frequency would be 43% and the number of on-system posted bridges to the SU6 would decrease to 719 bridges, or 57% of the 1,262 bridges with moment ratio≥1 summarized in Table 5.29.

Table 5.28: Bridges exceeding operating rating by county for the AASHTO SU6 off-system

County	Off Sys Bridges	% Above Oper	Count Abpove Oper
HARRIS	1,633	69.1	1,128
DALLAS	740	45.8	339
TRAVIS	292	65.8	192
FORT BEND	278	48.2	134
BEXAR	336	35.4	119
BRAZORIA	220	50.5	111
LIMESTONE	146	71.2	104
TARRANT	438	22.4	98
HIDALGO	143	67.1	96
HILL	125	74.4	93
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.	.	.	.
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	12,210		**5,436**

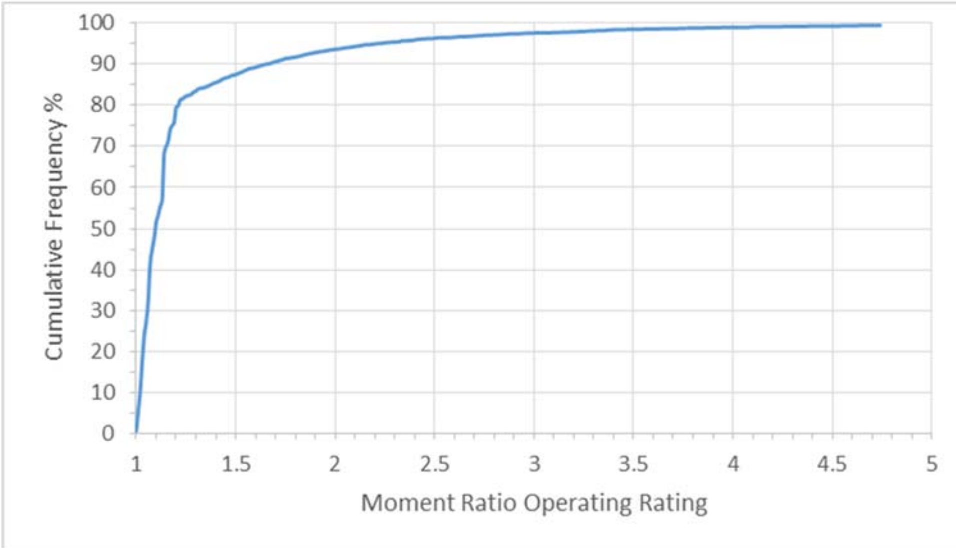

Figure 5.16: Cumulative frequency distribution for moment ratios for the AASHTO SU6 off-system

Table 5.29: Bridges exceeding operating rating by county for the AASHTO SU6 on-system

County	On Sys Bridges	% Above Oper	Count Above Oper
HARRIS	1,827	2.7	49
COLLIN	312	15.4	48
DALLAS	1,466	3.1	45
TAYLOR	178	20.2	36
NOLAN	81	39.5	32
SUTTON	55	54.5	30
JEFFERSON	213	13.6	29
KARNES	53	47.2	25
KAUFMAN	226	11.1	25
HUNT	198	10.1	20
.	.	.	.
.	.	.	.
.	.	.	.
	21,789		**1,262**

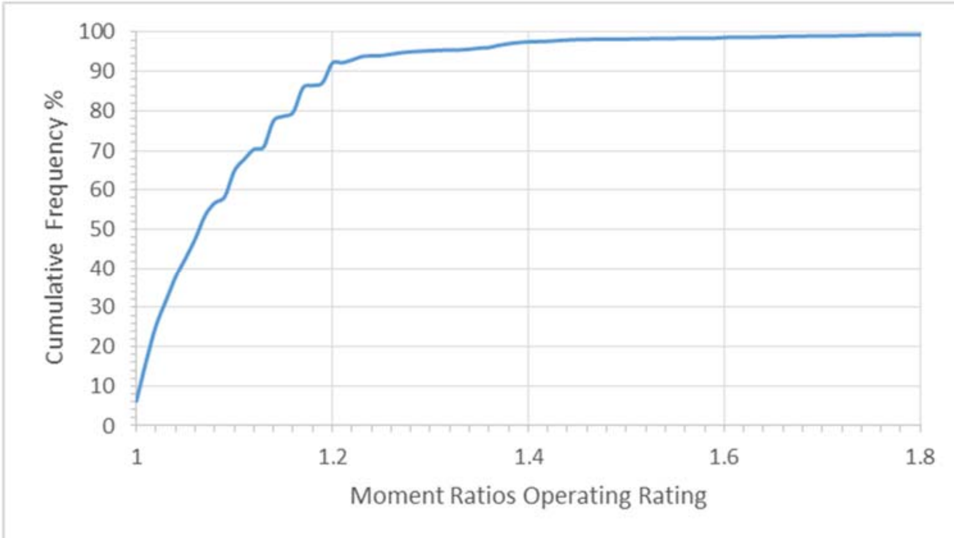

Figure 5.17: Cumulative frequency distribution for moment ratios for the AASHTO SU6 on system

The same moment ratios were calculated for all other four, five, six, and seven-axle SHV configurations analyzed in this project, and depicted in Figure 5.3 through Figure 5.11. These results are discussed later in this section.

SAS computer code was written to compare the proposed rating GVW for all these configurations in tons, taking into account any existing possible GVW limitations already recorded in PonTex items 41.1 and 41.2, respectively “Loading Restriction” and “Load Restriction in Thousands of Pounds.” Codes 3 and 9 for item 41.1 are of particular interest for the posting analysis, since these codes represent bridges that are already posted for GVW. Existing postings need to be compared with the SHV calculated postings to check if they may control the GVW posting. There are 492 off-system bridges and 48 on-system bridges with a code of 3 or 9 for item 41.1 in PonTex (September 2016 version).

A specific off-system bridge (Structure ID=121020AA2241001) is used to illustrate the computerized calculations performed for all on- and off-systems bridges statewide. Figure 5.18 show the GIS map of this bridge location. Figure 5.19 depicts the street view from Google Maps and the bridge data block. This bridge is located in Harris County with a structure length of 75 ft and three simply supported spans of 25 ft each. This bridge is already posted for GVW, as may be observed in Figure 5.20, with a limit of 36 tons. The operating rating recorded in PonTex for this bridge is also 36 tons, represented by a HS load configuration.

Table 5.30 summarizes the computerized calculations to determine the posting load for bridge 121020AA2241001, for the six- and seven-axle configurations summarized in Figure 5.10 and Figure 5.11 and for the AASHTO configurations in Figure 5.13. This process was repeated thousands of times by the computerized routines developed during this research project for all the bridges statewide for both the on- and off-systems.

For the calculations summarized in Table 5.30, it may be noted that moment ratios exceeding operating rating were calculated for the six- and seven-axle AASHTO SHV configurations and for the six-axle SHV configuration identified in this project and summarized in Figure 5.10. The seven-axle SHV configuration did not induce moments above operating rating on this bridge, so these calculations are not included in Table 5.30.

Recommended posting tons for the six- and seven-axle configurations were then calculated using the following approach: GVW for each configuration should be capped to operating rating moment values. In other words, the GVW limit for a given configuration is calculated by dividing the GVW for the configuration by the operating rating moment ratio so as to reduce the GVW for the SHV configuration to operating rating levels.

For example, the recommended posting GVW tons for the AASHTO SU6 vehicle for this particular bridge is calculated by dividing the GVW of the AASHTO SU6 vehicle, which is 34.75 tons, by 1.199, the moment ratio. This resulted in the recommended 29 tons posting GVW for the AASHTO SU6 vehicle.

The same process was implemented for the six-axle SHV (see Figure 5.10). Dividing this truck's 37.29 tons of GVW by the operating rating moment ratio for this load, which is 1.243, results in a recommended posting load of 30 tons. Therefore, the recommended load that should appear on the bridge posting sign for the six-axle SU truck should be the lowest value of 29 tons, which is determined by the AASHTO SU6 configuration. Note that 29 tons is also lower than the existing posting for this bridge (36 tons GVW as recorded in PonTex item 41.2).

The same procedure was followed for the only seven-axle configuration exceeding operating rating, the AASHTO SU7. The recommended posting load for the seven-axle SU truck for this bridge should be 32 tons. This value is the AASHTO SU7 GVW (38.75 tons) divided by its moment ratio 1.221. This is the controlling load for the seven-axle SHV posting and it is determined by the AASHTO SU7 configuration.

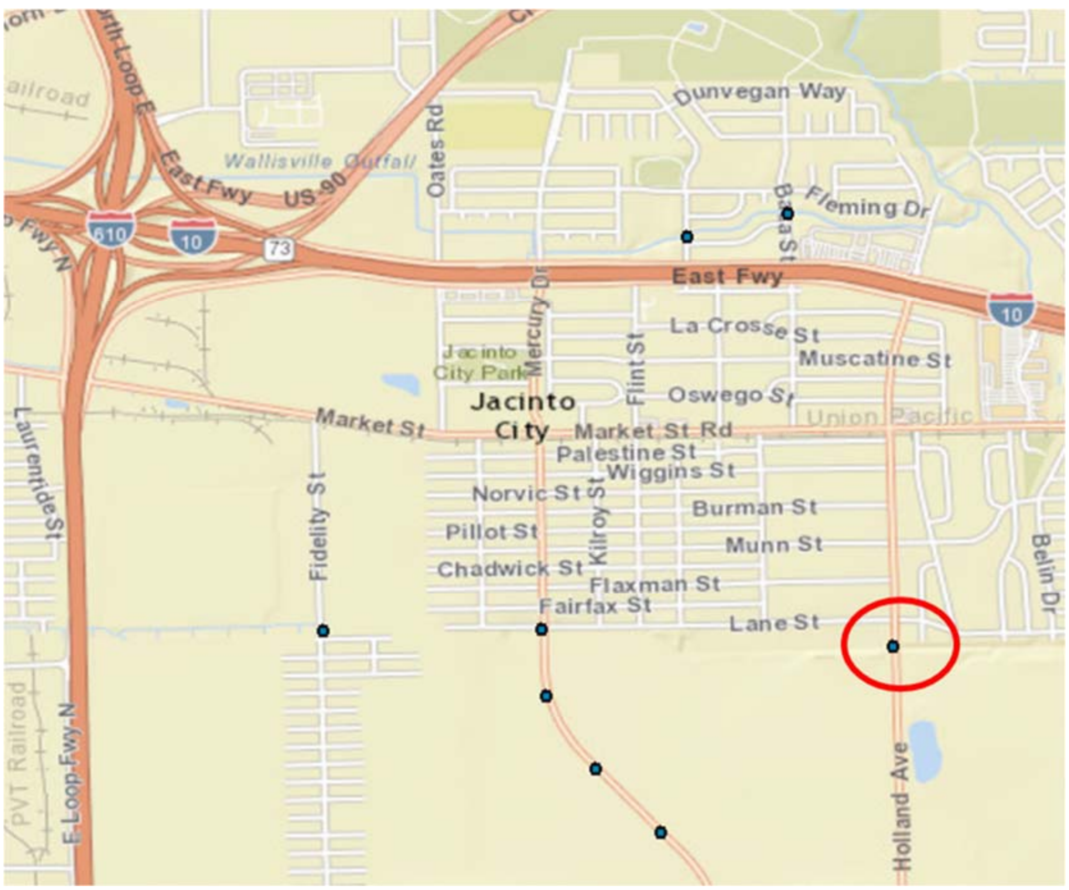

Figure 5.18: GIS snapshot of off-system bridge 121020AA2241001

0000_StructureID	7 Fac Carried	41 1 Load Type	41 2 Load 1000 lb	latitude	longitude
121020AA2241001	HOLLAND AVE	9	72	29.7593	-95.2337

Figure 5.19: Street view and basic information for off-system bridge 121020AA2241001

Table 5.30: Rating calculations for off-system bridge 121020AA2241001

Six Axle SHV	Moment ratio AASHTO SU6	1.199
	Recommended Posting tons AASHTO SU6	29
	Moment ratio X-XXX-OO 6-axle dump truck	1.243
	Recommended posting X-XXX-OO-6-axle dump truck	30
	Item 41.2 Pontex tons	36
	Lowest tons	29
	Governing Rating Load	SU6 AASHTO
Seven Axle SHV	Moment Ratio AASHTO SU7	1.221
	Recommended Posting tons AASHTO SU7	31.7
	Moment Ratio X-XXX-OO-X 7-axle dump truck	N/A
	Recommended Posting tons CTR 7 axle SHV	N/A
	Item 41.2 Pontex tons	36
	Lowest tons	31.7
	Governing Rating Load	SU7 AASHTO

Figure 5.20 shows the recommended posting sign for this bridge. The limits for the four- and five-axle SHVs were calculated in an analogous manner and the full summary of the results for this specific bridge are summarized in Table 5.31, which includes the data field values, variable names, and definitions. A Microsoft Access data base is available summarizing the calculations for all on- and off-system bridges that presented bending moment ratios above one, as previously discussed. The on-system data table of recommended SHV postings encompasses 1,956 bridge records whereas the off-system table encompasses 6,081 bridge records. The Access data set contains all the necessary information to identify a specific bridge in the system, including its

geographic coordinates, enabling an easy display of the results using a geo-referenced computerized environment such as ArcMap.

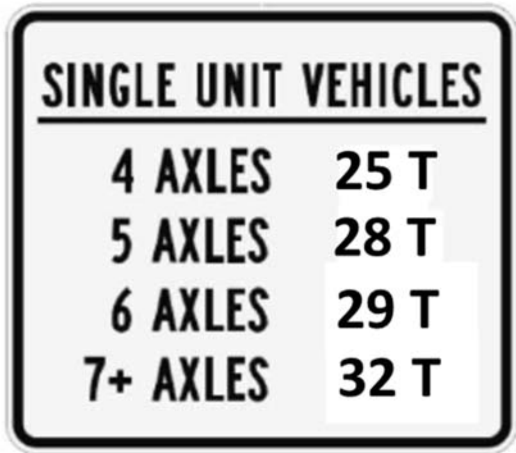

Figure 5.20: Recommended posting sign for off-system bridge 121020AA2241001

Table 5.31: Recommended posting tons for off-system bridge 121020AA2241001

SHV Type	Variable Definition	Data Set Variable	Data Set Value
4 Axle	Recommended SHV GVW Posting (tons)	PostedTons4	25.1
4 Axle	Controlling Rating Load	RatingLoad4	Garbage_x_x_oo_4postedtons
4 Axle	Bending Moment Ratio for Rating Load	Garbage_x_x_oo_4ratio	1.274
5 Axle	Recommended SHV Posting	PostedTons5	27.9
5 Axle	Controlling Rating Load	RatingLoad5	AASHTOSU5postedtons
5 Axle	Bending Moment Ratio for Rating Load	AASHTOSU5ratio	1.112
6 Axle	Recommended SHV Posting	PostedTons6	29
6 Axle	Controlling Rating Load	RatingLoad6	AASHTOSU6postedtons
6 Axle	Bending Moment Ratio for Rating Load	AASHTOSU6ratio	1.199
7 Axle	Recommended SHV Posting	PostedTons7	31.7
7 Axle	Controlling Rating Load	RatingLoad7	AASHTOSU7postedtons
7 Axle	Bending Moment Ratio for Rating Load	AASHTOSU7ratio	1.221

Table 5.32 through Table 5.39 summarize the statistics for the controlling posting load for the on- and off-system bridges and the four, five, six, and seven-axle SHV configurations analyzed in this chapter. The AASHTO SU6 configuration drives the posting load for most off- and on-system bridges. The AASHTO SU7 configuration drives almost the totality of the on- and off-system postings. The bulk of the postings for the four-axle SHV configurations for both on- and off-system bridges is driven by the garbage truck depicted in Figure 5.5. The recommended load postings for the five-axle configurations are split between the AASHTOSU5 and the ready-mix configuration depicted in Figure 5.8.

As expected, the existing GVW posting controls the limits on loading for a small percentage of the on- and off-system bridges—these are Type 3 or 9 postings for item 43.1 in PonTex.

Table 5.32: Controlling posting load for the four-axle configurations off-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU4	136	2.29
Garbage_x_oo_x_4	6	0.10
Garbage_x_x_oo_4	4,604	77.53
Readymix_x_oo_x_4	779	13.12
Pontex 41.1 Type 3 or 9	413	6.96
Total	**5,938**	

Table 5.33: Controlling posting load for the four-axle configurations on-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU4	14	0.84
Garbage_x_oo_x_4	1	0.06
Garbage_x_x_oo_4	1,372	82.25
Readymix_x_oo_x_4	264	15.83
Pontex 41.1 Type 3 or 9	17	1.02
Total	**1,668**	

Table 5.34: Controlling posting load for the five-axle configurations off-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU5	2,703	46.75
Dump_x_xx_oo_5	172	2.97
Garbage_x_x_oo_x_5	165	2.85
Readymixx_x_oo_x_5	2,314	40.02
Pontex 41.1 Type 3 or 9	428	7.40
Total	**5,782**	

Table 5.35: Controlling posting load for the five-axle configurations on-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU5	560	38.07
Dump_x_xx_oo_5	107	7.27
Garbage_x_x_oo_x_5	15	1.02
Readymixx_x_oo_x_5	768	52.21
Pontex 41.1 Type 3 or 9	21	1.43
Total	**1,471**	

Table 5.36: Controlling posting load for the six-axle configurations off-system

Controlling Posting Load	Number of Bridges	Percent
Dump-(X-XXX-OO)-6	881	15.0
AASHTOSU6	4,567	77.8
Pontex 41.1 Type 3 or 9	424	7.2
Total	**5,872**	

Table 5.37: Controlling posting load for the six-axle configurations on-system

Controlling Posting Load	Number of Bridges	Percent
Dump-(X-XXX-OO)-6	407	24.9
AASHTOSU6	1,203	73.7
Pontex 41.1 Type 3 or 9	22	1.4
Total	**1,632**	

Table 5.38: Controlling posting load for the seven-axle configurations off-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU7	5,289	92.4
Pontex 41.1 Type 3 or 9	432	7.6
	5,721	

Table 5.39: Controlling posting load for the seven-axle configurations on-system

Controlling Posting Load	Number of Bridges	Percent
AASHTOSU7	1,608	98.5
Pontex 41.1 Type 3 or 9	24	1.5
	1,632	

The Access data tables containing calculations of recommended posting loads for the four, five, six, and seven-axle configurations for both on- and off-system bridges are also available in a GIS map format. The data items summarized in Table 5.31 and those for the bridge posting calculation example are included in the GIS data block for the statewide on- and off-system bridges.

Figure 5.21 shows a snapshot of the GIS system developed for this research project. It highlights the data block for an off-system bridge in the outskirts of Kerrville, Kerr County—Structure ID 151330G00020001. This particular bridge is located 0.13 miles southwest of SH 16 and the recommended posted load for the six-axle SHV is controlled by the AASHTO SU6 configuration and limited to 31.9 tons, which should be rounded to 32 tons for the posting sign. The bending moment ratios for the AASHTO SU6 and the six-axle dump truck configurations are respectively 1.09 and 1.13, or 9% and 13% above the operating load recorded as an HS load with 36 tons of GVW. This bridge is not currently posted. The recommended posting load for the four-axle SHV is 28.6 tons, which should be rounded to 29 tons. The four-axle posting load is controlled by the garbage truck depicted in Figure 5.5. For the five-axle SHV configurations, the recommended posting load for this specific bridge is 32.4 tons and it is being controlled by the garbage truck depicted in Figure 5.7.

5.5.3 Summary of Electronic Deliverables

The electronic deliverables consist of:

1. Microsoft Access data base containing two data tables with bridge data and posting recommendations for the 6,081 off-system and 1,956 on-system bridges that experienced bending moment ratios above operating rating levels for any of the four, five, six, and seven-axle configurations defined previously.
2. A GIS map that can be opened in ArcMAP containing the same information included in the Microsoft Access data base.

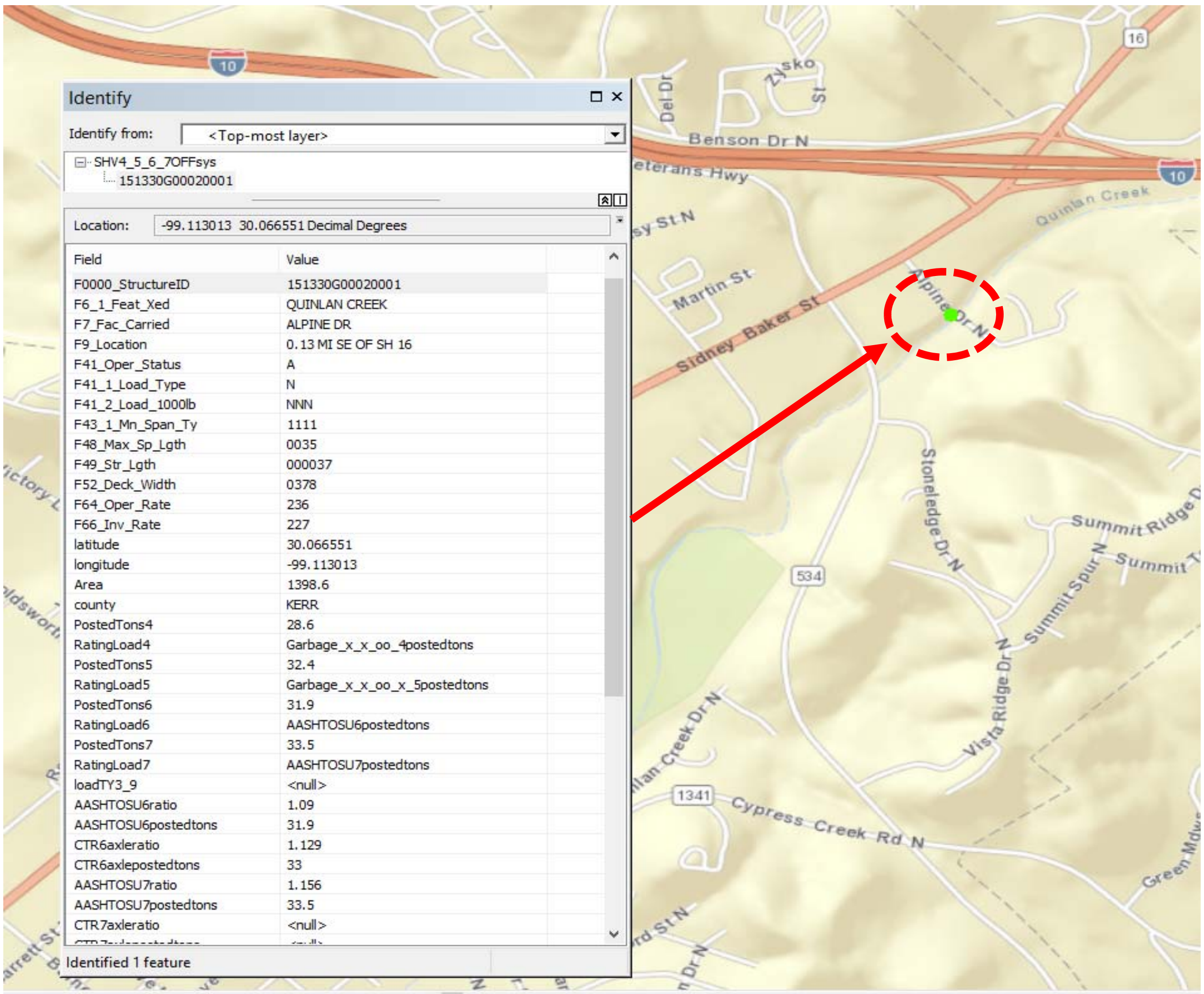

Figure 5.21: GIS system summarizing bridge recommended postings statewide

5.6 Implementation Recommendations

5.6.1 Consumption

Complete bridge consumption cost estimates for all counties statewide are available in Excel workbooks for on- and off-system bridges. The consumption values are invaluable results when used in a framework designed to recover some of the significant bridge consumption costs per mile that were documented in this chapter. The economics of SHV operations in Texas has to reflect infrastructure consumption in order to promote efficient transportation economics and preserve the significant investment in road infrastructure assets through a fine-tuned cost recovery process.

5.6.2 Posting

The computerized data sets for on- and off-system bridges documented in this chapter should be used to prioritize bridges for detailed posting analysis on a bridge-by-bridge basis, and subsequent implementation of adequate SHV posting signs. The computerized tools developed in this project provide an invaluable management tool for the TxDOT Bridge Division. They should be implemented in a timely manner in order to meet the tight deadlines for the review of bridge posting policies for SHVs established by the FHWA memo dated November 15, 2013.

One possible way of streamlining the task of evaluating thousands of bridges for posting could be by grouping these bridges in blocks segmented by the bending moment ratios available in the Access database and evaluating the posting for the highest moment ratios statewide first.

5.7 References

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Chapter 6. Safety Analysis of SHVs

6.1 Introduction

Straight trucks with no trailer (which include SHVs with liftable axles, among others) accounted for about 30% of trucks involved in fatal accidents in 2008 in the US. **In 2008, 10% of the total straight truck fatal accidents occurred in Texas**. Among straight truck fatal accidents in 2008 on a national level, about 20% were dump trucks, about 9% were garbage trucks, and about 4% were concrete mixer trucks (Jarossi et al., 2011).

6.2 Factors that Contribute to Truck Crashes

Various characteristics that can contribute to truck crashes include truck weight, load placement, load size, truck length, number of axles, type of brake system, speed, and truck driver's skill (Turner and Nicholson, 2009). Truck weight, load placement, and size can have an impact on the truck's acceleration, deceleration, and braking among others. Turner and Nicholson (2009) report that a high load increases the chance of rollover as it raises the center of gravity of the vehicle. Moreover, if the load's center of gravity is closer to one side of the truck compared to the other, the wheels on that side of the truck would bear higher load. This unequal load distribution between the two sides of the truck could result in unequal braking on the two sides of the vehicle, loss of control, and rollover. In addition, a loose, liquid, or semi-solid load such as ready-mix concrete could shift inside the vehicle during turning or braking, resulting in a greater amount of load on one side of the vehicle, which would change axle loads, adversely affect braking, and could contribute to rollover.

As the truck weight increases, the time and distance needed to stop increases. The report states that according to the Truck Safety Coalition (2007), at a specific speed, a truck weighing 100,000 lb took 25% more time to stop than an 80,000 lb truck. The stopping distance of a 120,000 lb truck was about 50% greater than the stopping distance of an 80,000 lb truck. The report further notes that in general, as the size and weight of commercial vehicles increases, crash rates decrease but crash severity increases. The report states that the length and type of the truck can have an impact on controlling and braking the truck—as the length of the truck and the number of axles increases, the additional steering and handling needed make braking more difficult (Turner and Nicholson, 2009).

The type of truck brake system can also influence the safety of the truck. The report notes that compared to car brakes, conventional truck brakes are more complex and less effective, and truck braking distances are larger than that of cars. Conventional truck brakes operate from air pressure, due to which they need to be adjusted regularly to maintain high braking efficiency. The report states that since conventional truck brakes are activated by air, a short delay occurs between the driver pushing the brake pedal, and operation of an individual brake. Antilock brakes, on the other hand, have better braking performance compared to conventional brakes. Due to the improved performance of antilock brakes, beginning 1998, federal regulations require SU trucks to be manufactured with antilock braking systems (Turner and Nicholson, 2009).

Fricke et al. performed studies regarding truck accident reconstruction, which state that, all other factors being equal, axles with lower loads will lock and skid before axles with higher loads. During skidding, there are no lateral friction forces available to prevent sliding of the tires due to curve super elevation or pavement cross slope. Anti-lock braking systems automatically compensate for differences in wheel loads, addressing the mentioned issue. The study also stated that, all other factors being equal, axles with smaller radius tires will lock before axles with larger radius tires (Fricke, 1990). This is because the maximum torque (rotational moment) of a wheel on a vehicle in motion is equal to the coefficient of friction of the tire on the road times the weight on the tire times the leverage (moment arm). The moment arm is the distance from the axle to the road—that is, the tire radius. With equal road friction, weight, and brake resistance to rotation, the wheel with the greatest moment arm can overcome brake resistance, while the wheel with the least moment arm might not. Thus, with increasing but equal brake effort, the wheel with the least radius (moment arm) will be the first to start sliding (Fricke, 1990). Both of these factors are relevant for SHVs, as liftable axles typically carry lower loads and implement tires with smaller radii, and these could be expected to lock before fixed axles, potentially resulting in yawing of the rear of the truck in the direction of pavement slope.

A representative for a liftable axle manufacturer was interviewed about lift axles and asked for details regarding liftable axle braking capacities. The representative, Justin Cravens of Ridewell Corporation, said:

> "Lift axles come in various weight capacities depending on what each state allows. Most common are 8k, 13k, and 20k lbs. Each of these has brakes equivalent to its carrying capacity. Brake capacity is determined by the size of the brake shoe, thickness, and material of the lining and stroke of the brake chamber. Timing of the brakes is determined by the brake valve. So, braking capacities match the carrying capacity of the axle, and vary SHV to SHV" (J. Cravens, personal communication, August 15, 2017).

Another factor that affects truck safety is speed—excess speed can contribute to truck crashes. In addition, the speed at which braking is initiated impacts the stopping distance—trucks traveling at higher speeds need longer stopping distances than those at lower speeds. Furthermore, the truck driver's skill, experience, and training are key factors in truck safety. Truck drivers could contribute to crashes through distracted driving, poor driving habits, impairment due to fatigue or substance abuse, and insufficient training (Turner and Nicholson, 2009).

6.3 Drawbacks of Liftable Axles

TRB's NCHRP Report 575: *Legal Truck Loads and AASHTO Legal Loads for Posting* discusses drawbacks of lift axles used in SHVs. The report notes that lowered lift axles reduce the turning capabilities of the SHV truck. On slippery roads, lowered lift axles may cause the truck to slide. The report discusses that if the lift axles are raised during the truck's turning movement, the stability of the truck is jeopardized, which contributes to an increased risk of rollover. The report further notes that enforcing compliance of lift axles with regulations is difficult. It has been observed that lift axles are lowered when the truck is approaching a weight facility, and later the lift axles are raised again after the truck clears the weight facility. To prevent this, some regulatory agencies require the controls for raising and lowering the lift axles to be placed outside the truck cab. Another drawback discussed in the report is that the proportion of the load carried by the lift axle varies based on how far the lift axle is deployed by the driver—if the lift axle is lowered too far, it may carry too much load, but on the other hand, if the lift axle is not lowered far enough, other axles of the truck may be overloaded.

6.4 Other Safety Considerations

SHVs require short wheelbases to be able to maneuver safely at construction sites, off-road locations, and narrow city streets (TRB, 1990). The 1990 TRB report further notes that due to the short wheelbase of SHVs, under the FBF requirements, the maximum legal weight allowed for SHVs is typically less than the maximum weight allowed for other longer commercial vehicles. Operators generally would not consider increasing the length of SHVs (to get additional weight allowance under the FBF) due to associated maneuverability problems.

The report notes that it was observed that in some cases, for their own benefit, SHV operators used lift axles that were lowered only when the truck was weighed by enforcement officials. SHV operators were also found in some cases to use "dummy" axles that helped increase the maximum legal weight allowed under the FBF by more than 5,000 lbs, though the axles were mostly non-load bearing, carrying little weight themselves. In these cases, the main purpose of adding non-load bearing axles to the vehicle was to gain additional weight allowance under the FBF; however, such axles create safety concerns.

6.5 Braking Distance

Information on braking distances of SU trucks, and some specific type of SHVs, was gathered from previous studies. In general, the braking distance of a vehicle depends on factors including speed, weight, and friction. The brake force required to stop a vehicle is directly proportional to its weight, and directly proportional to the square of the vehicle's speed (Yukon Air Brake Manual, n.d.). Stopping distance generally includes braking distance and distance traveled by the vehicle during the perception-reaction time of the driver. Braking distance is the distance traveled by the vehicle from the instant when the brakes are fully applied to the point when the vehicle comes to a complete stop.

Based on National Highway Traffic Safety Administration (NHTSA) research, the Code of Federal Regulation, CFC Title 49, Chapter 5 577.121 requires the following stopping distances for loaded and unloaded SU trucks, as shown in Table 6.1 and Figure 6.1. For speeds ranging from 20 to 60 mph, the stopping distance for loaded SU trucks ranges from 35 to 310 feet, and for unloaded SU trucks, the stopping distance ranges from 38 to 335 feet. In addition, the Code of Federal Regulations CFC Title 49 Volume 6, Section 393.52 specifies the minimum deceleration rate for an SU truck with service brake systems to be 14 feet per second.

Table 6.1: Stopping distances for loaded and unloaded SU trucks for different vehicle speeds

Vehicle Speed (mph)	Stopping Distance for Loaded SU Trucks (feet)	Stopping Distance for Unloaded SU Trucks (feet)
20	35	38
25	54	59
30	78	84
35	106	114
40	138	149
45	175	189
50	216	233
55	261	281
60	310	335

Source: NHTSA, DOT, Code of Federal Regulations, Title 49 Section 571.121 (n.d.)

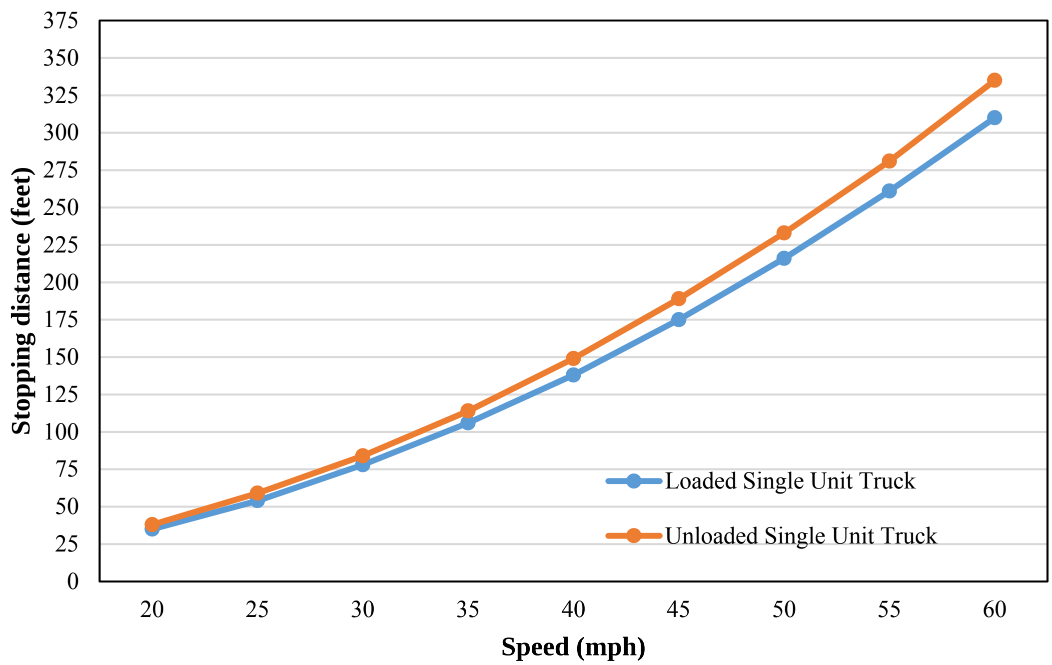

Figure 6.1: Stopping distances for loaded and unloaded SU trucks for different vehicle speeds

Bedsworth et al. conducted a study in which data from more than 200 deceleration tests on over 70 commercial vehicles, including SU dump and concrete mixing trucks, was analyzed. Data recorded during these tests includes truck skid distance (or braking distance), speed, weight, and friction factor, among others. This study used the average skid distance and the vehicle speed to calculate the vehicle's drag factor, *f*, which was equal to f = s*s/(30*d); where *s* is the speed of the vehicle in mph, and *d* is the vehicle's average skid distance. The drag factor times the acceleration due to gravity is equal to the deceleration rate of the vehicle. Among the different truck configurations tested, the configurations relevant to the SHV project are the dump trucks and concrete mixing trucks. Table 6.2 lists the number of test runs and average drag factor calculated for dump and concrete mixing trucks in the Bedsworth study.

Table 6.2: Number of test runs and average drag factor calculated for dump and concrete mixing trucks

Truck type	Number of test runs	Mean drag factor (f)
Dump trucks	16	0.59
Concrete mixing trucks	4	0.45

Source: Bedsworth et al., 2013

Figure 6.2 and Table 6.3 show the two concrete mixing trucks tested, and the truck skid distance, speed and weight measured, and the calculated drag factor during the four test runs. For these two concrete mixing trucks tested, the average drag factor was 0.45. The speed of the concrete trucks during the tests ranged between about 26 to 36 mph, and the measured skid distance or braking distance ranged between about 53 to 85 feet.

Figure 6.2: The two concrete mixing trucks tested in the Bedsworth et al. study

Table 6.3: Data collected for the two concrete mixing trucks tested in the Bedsworth et al. study

Truck type	Weight (lbs)	Test run number	Speed (mph)	Skid distance (ft)	Calculated drag factor (f)
Concrete mixer with two pusher axles and one booster axle	51,900	1	28.6	85.4	0.32
		2	26.4	56	0.41
Concrete mixer with three axles	27,250	1	28.7	53.67	0.51
		2	35.8	76	0.56

Source: Bedsworth et al., 2013

Six dump trucks were tested, two of which are shown in Figure 6.3. In addition, Table 6.4 shows the data for truck skid distance, speed and weight measured, and the calculated drag factor during the 16 test runs. The study computed the average drag factor for the dump trucks to be 0.59. The speed of the dump trucks during the tests ranged between about 25 to 40 mph, and the measured skid distance or braking distance ranged between about 35 to 83 feet.

Figure 6.3: Two (of the six) dump trucks tested in the Bedsworth et al. study

Table 6.4: Data collected for the six dump trucks tested in the Bedsworth et al. study

Truck type	Weight (lbs)	Test run number	Speed (mph)	Skid distance (ft)	Calculated drag factor (f)
Dump truck with 3 tag axles (34')	50,200	1	25.3	48.83	0.44
		2	32.3	82.92	0.42
		3	30.4	63	0.49
Dump truck with 1 tag axle	65,900	1	27	40.5	0.6
		2	29.1	47.8	0.59
		3	26.2	38.66	0.59
Dump truck with single rear axle (19')	unavailable	1	25.5	50.4	0.43
		2	40.1	78.58	0.68
Dump truck (28')	26,500	1	28.2	47.42	0.56
		2	38	77.67	0.62
Dump truck (25')	25,200	1	30	45.3	0.66
		2	34	81	0.48
		3	33	59.5	0.61
Dump truck (22')	21,800	1	32	43.4	0.79
		2	34	53.7	0.72
		3	29	35.66	0.79

Source: Bedsworth et al., 2013

Additional observations from this small set of data include:

1. These tests were performed on a dry pavement, which could result in quite different results than tests performed on a wet pavement. It is noted that ASTM locked wheel skid systems and other equipment used for collecting pavement friction data are conducted for wet pavement conditions. Professional, consulting accident investigators and law enforcement officials who conduct accident investigations use drag factor, skid distances and other factors to estimate the initial speed of the vehicle. In addition, devices such as a drag-sled or in-car computer that measures vehicle deceleration rates are used to measure factors such as pavement friction (*f*) and vehicle deceleration rate. Thus, the types of statistics and methods of measurement employed by NHTSA, law enforcement and professional accident investigators differ from equipment and methods used by pavement engineers to measure pavement skid resistance (Skid Number). Further work is needed to help understand these differences and create more coherent and unified approaches.

2. Multiple tests with the same truck, driver, and pavement yielded slightly different drag factors due to variability. This variability could be associated with small differences from test to test related to the rate at which the driver depressed the brake pedal, air pressure build up in the braking system, slight differences in the exact test location, which might result in different pavement texture conditions and other factors. It is noted that the dump truck with three pusher axles produced three slightly different drag factors: 0.44, 0.42, and 0.49. When multiplied by acceleration due to gravity, the deceleration rates are 14.1 ft/s^2, 13.5 ft/s^2, and 15.8 ft/s^2. Though the second test is actually below the deceleration rate required in the Code of Federal Regulations (14 ft/s^2), the average of the three tests is 14.5 ft/s^2, which is a compliant result.

6.6 Deflation of a Tire of a Booster Axle

Booster axles are often used to increase the payload capacity of SHVs, as they provide an additional axle to distribute the weight, and help increase the length of the wheelbase over which the total truck weight is distributed. Deflation of a tire of a booster axle of an SHV truck can likely contribute to a rollover crash—Larson and Cuadrado examined a rollover crash involving a seven-axle dump truck with three pusher axles and one booster axle. The dump truck was carrying a payload of dirt of about 50,000 lbs, and its GVW was estimated to be about 79,500 lbs. “The crash occurred on a straight, two-lane rural highway, with a two-way striped centerline, and a posted speed limit of 65 mph,” according to Larson and Cuadrado (2012). When the dump truck lost control and rolled over, it had been traveling on a level section of the highway. The reason for the rollover was not specified in the police accident report, but was hypothesized to be the deflation of the right tire of the booster axle (Larson and Cuadrado, 2012).

The photographs taken by the police at the accident scene (Figure 6.4) indicated that the truck suddenly went left and traveled across the opposite lane and went off the opposite side of the roadway. The tire marks indicated that gouge marks were created by the right tire of the booster axle. Figure 6.5 shows the tire marks of the dump truck before the accident occurred.

Figure 6.4: Photos taken by the police of the dump truck at its rest position after the accident

Figure 6.5: Photo taken by the police of tire marks of the dump truck, upstream from the location the truck went off the roadway.

Larson and Cuadrado investigated the cause of the dump truck's loss of control leading to the rollover, and the possible contribution of the deflation of the booster axle's tire, by conducting a series of tire deflation stability tests on a seven-axle dump truck with three pusher axles and one booster axle (as shown in Figure 6.6), which was configured identical to the dump truck involved in the accident.

Figure 6.6: The test seven-axle dump truck with a booster axle.

The tests helped evaluate the effect of booster axle tire deflation on the ability of the driver to control the truck. The test results indicate that the impact of a booster axle tire failure on the truck is different from other tire failures—other tire failures generally affect a truck's handling characteristics caused by increased drag at the failure location. However, test results indicated that booster axle tire failure resulted in steering of the axle, which generated forces and moment which would make it likely that a driver would lose control of the vehicle in such a case at highway speeds. Moreover, the tests indicated that the deflating booster axle tire did not cause any observable adverse effects until it was completely deflated. This implies that the driver may not be able to detect that the pressure in the booster axle tire is low until the tire completely deflates and contributes to destabilizing the truck (Larson and Cuadrado, 2012).

6.7 Example of SHV Truck Crash Likely due to Brake Failure

It is noted that Texas law enforcement officers who conduct crash investigations might or might not indicate whether an SU truck has lift or booster axles. If the crash investigator does note that the truck had liftable axles, there is typically no information regarding whether the lift axles were up or down at the time of the crash. Additional information related to the configuration of the truck at the time an accident occurred would be helpful during future analysis of SHV safety evaluations. In addition, it is apparent from discussions with professionals in the trucking industry, truck drivers, and businesses that are serviced by, or sell materials to, SHV operators do not use a common language when referring to SHV trucks.

In another example of a dump truck that met with an accident, brake failure was hypothesized to be the contributing factor. KXAN News reported in February 2016 that a dump truck crashed near a busy intersection on RM 2222, hit several vehicles on the road, and then went off a bridge (Jechow and Beausoleil, 2016). The dump truck was on its way to deliver a load from Georgetown to a location on Jester Boulevard in Austin. The news report stated that the dump truck had been involved in a crash in August 2015 too, but no injuries were reported. The article further noted that safety records showed that the company owning the truck had several violations between December 2014 and August 2015. The violations included inoperative head lamps, tail lamp, and turn signal; operating a commercial motor vehicle without proof of a periodic inspection; and oil and grease leak. Figure 6.7 shows the dump truck involved in the crash.

Source: Jechow and Beausoleil, 2016

Figure 6.7: Dump truck that met with an accident likely due to brake failure.

6.8 Information about Safety Considerations in Lift Axles from Lift Axle Patents

When reviewing various patents in the United States Patent and Trademark Office database, patents dated as far back as the 1950s were found, describing different lift axle systems. The earlier patents focused on the lift axle system which gave trucks the ability to “increase the truck capacity substantially within permissible highway axle loading limits” (Harbers, 1975). In later years, additional patents were filed that allowed for different lifting mechanisms, focusing on lower costs, higher efficiencies, fewer repair needs, and greater safety measures. Patents filed in the early 1990s provided for lift axle systems where the lifting mechanism is automatically "deactivated in overload conditions to prevent damage to the vehicle and to the lift axle assembly in bridging conditions" (Hauri, 1996). In the 2000s, patents were filed relating to the safety of the mechanism transferring air pressure between different air springs in the lift axle system (Fulton & Beaver, 2005). In the last few years, lift axle patents have provided details on safety benefits that lift axle systems can provide. A patent filed by Haldex Brake Products GmbH states

> "the lift axle might also be additionally used for keeping a required maximum of the brake force produced by a brake device with an increased load (and corresponding increased normal force between the wheels and the road) below an upper limit value. This is due to the fact that excess brake forces cannot be produced by brake force actuators or these excess brake forces cannot be held for long time periods. Accordingly, with an increase of the load without the additional lowering of the lift axle the brake device would be overloaded. It might also be impossible to produce the required brake force which might result in an increased braking distance" (Becke, Tschoke & Sulzyc, 2015).

6.9 Additional Truck Safety Considerations

Muthumani & Shi (2015) conducted a literature review on SHV safety considerations. The results, although pertaining primarily to general trucks, are synthesized below:

- Interviews with fifty transportation practitioners found that OS/OW vehicles were found to feature lower crash rates, but were generally involved in more severe crashes. This was also confirmed by another synthesis study (Turner & Nicholson, 2009). However, the relationship between size/weight and safety risks was deemed too complex to reach a definitive conclusion.
- Heavier trucks were found to generally take longer to stop and had more trouble operating during evasive maneuvers (OhioDOT, 2009).
- Adams et al. concluded that increasing the number of axles by 20% would reduce a truck's crash rate by 5% (Adams, Bittner & Wittwer, 2009).

6.10 Additional SHV Safety Considerations

Adams et al. (2009) also compared the safety impact of various truck configurations with increased weight on highway safety in the state of Wisconsin, using a five-axle tractor-trailer as the base case. The results, shown in Table 6.5, indicate that one type of SHV analyzed (seven-axle 80,000 lbs) slightly reduced the annual safety costs on highways, relative to the base case.

Table 6.5: Estimated safety costs for various truck configurations.

CONFIGURATION	ANNUAL SAFETY COSTS (million $)	
	Non-Interstate Only	Interstate and Non-Interstate
8-axle 108,000 lb. double	↓ $0.46	↓ $2.90
7-axle 97,000 lb. tractor semitrailer	↓ $0.70	↓ $4.43
7-axle 80,000 lb. single unit truck	*↓ $0.11*	*↓ $0.53*
6-axle 90,000 lb. tractor semitrailer	↓ $0.46	↓ $3.48
6-axle 98,000 lb. tractor semitrailer	↓ $1.52	↓ $9.40
6-axle 98,000 lb. straight truck-trailer	↓ $0.09	↓ $0.68

This paper also concluded that SHVs provide relatively increased operator safety as compared to other truck configurations, as SHVs are shorter and easier to maneuver. However, as is the general case, increasing weight limits for SHVs is likely to increase their crash risk.

6.11 SHV Registered Gross Weight, GVW Rating, and GVW

The many different lift axle designs and axle load limits are based on manufacturers' ratings, which range from 8,000 lbs per lift axle to over 20,000 lbs per lift axle. Manufacturers establish the lift axle maximum allowable load in relation to the design of the axle structural components, the brakes, and other factors. However, though SU trucks are sometimes retrofitted with lift axle(s) years after they were first manufactured, there is no current process in place to check the braking capacity of a lift axle or the entire loaded truck once additional axles have been fitted. This brings into question the overall braking efficiency of an SHV if the lift axle capacity and brakes have not been properly selected.

It is reasonable to assume that adding one or more lift axles to an existing three-axle SU truck implies that the owner plans to operate at a higher GVW. However, it is unclear if TxDMV requires that the original truck manufacturer's GVWR or the registered gross weight is changed in the truck registration data when a SU truck is modified by fitting one or more liftable axles. If additional axles are added, the allowable GVW of the truck can increase based on the FBF. However, based on TxDMV registration rules, the GVW cannot exceed the manufacturer's GVWR (TxDMV 2017). As previously mentioned, current registration requirements do not include data about the truck configuration (SU or tractor-trailer) or the number and types of axles. It is also unclear how the GVWR would be determined beyond merely considering the number of axles, axle spacing, axle load capacity, and tire rating. Other factors that could affect the weight a truck could safely transport include braking capacity, load distribution among all truck axles and the relationship between routine or permitted GVW and the modified GVWR of the SHV. The research team thinks that modification of a SU truck by adding lift or booster axles should require inspection by a truck specialist trained to make judgments about the GVWR of a truck that has been modified by adding one or more lift axles.

The allowable GVW is established by state laws based on truck configuration, number of axles and the FBF. The TxDMV's "Motor Vehicle Registration Manual" indicates that the truck should not be registered for more than the manufacturer's GVWR and the vehicle GVW should not exceed the GVWR. In addition, the Gross Registered Weight of a Commercial Vehicle is equal to the empty weight of the truck including permanently mounted equipment plus the weight of the heaviest load carried.

Truck manufacturers develop different truck designs in the medium, long haul and heavy or severe duty categories which typically relate to the operational use and amount of weight the truck will carry. The truck manufacturer indicates the truck load capacity based on the GVWR which is typically found on the truck door frame or on a stamped metal plate fixed inside the cab. The GVWR rating is directly related to truck components designed to transport heavy loads under severe duty conditions such as off-road use for dump, ready-mix, and garbage trucks. Increased GVWR may result in heavy duty chassis rails, heavier axles, different braking systems, and tire ratings, different engine designs and other features. Since each truck is custom tailored for the buyer, individual trucks of a given GVWR may vary in design component configuration.

OW permits may be purchased from the TxDMV to increase the truck GVW. In addition, state exemptions allow increased truck GVW for certain types of trucks or commodities. In a review of permitting practices and crash reports, the researchers did not find that the vehicle GVWR is required to be entered on a permit application; neither is it documented by the investigating law enforcement officer during a crash investigation.

It is noted that certain permits indicate that purchase of the permit does not authorize the permit holder to exceed tire load capacities based on the tire rating. In addition, most permits fix the maximum allowable GVW that can be operated with the permit. Thus, it appears that it is the truck driver or trucking company's responsibility not to exceed the GVWR if purchasing a permit. It is not clear how often a permitted vehicle GVW does in fact exceed the GVWR. As an example, though a permit may allow a truck to operate at 84,000 GVW, the actual GVWR for that truck might be 70,000 lbs suggesting that brakes, axles and other components are under-designed for the permitted load.

6.12 Summary

A review of SHV safety was conducted and the preliminary results summarized. Following are the key findings:

1. The vast majority of truck braking efficiency testing conducted by NHTSA, professional crash investigators, and law enforcement employs methods and statistics that differ from those used by DOTs for pavement design and data collection. These differences include:

    a. Truck brake and braking distance testing is typically conducted on a dry pavement surface with one or more vehicles of interest (dump truck, garbage truck, tractor–trailer unit). This testing is performed to determine vehicle drag factor, deceleration rate, braking distance, and skid distance.

    b. NHTSA has conducted testing used to develop Federal Regulations that establish the maximum allowable braking distances for truck tractors with no trailer and different GVWRs; truck tractors with an unloaded trailer; and a straight truck in either, loaded, or unloaded condition. This information has been incorporated in Code of Federal Regulations Title 49 Chapter 5; § 571.121. Tables listed in § 571.121 provide the maximum allowable braking distance for a given speed. For straight trucks there are no additional criteria for number of axles or GVWR, the criteria specified are for either a loaded or unloaded SU truck.

    c. Code of Federal Regulations Title 49 Chapter 6; § 393.53 has established the minimum deceleration rates for combination (truck tractor–trailer units) and straight trucks. There are no specific requirements for SHVs and thus minimum straight truck deceleration rates apply.

d. Code of Federal Regulations Title 49 Chapter 6, § 393.53 also specifies the minimum required braking force. Minimum required braking force is given as a percentage of the gross vehicle combination weight and varies depending on the type of truck; SU vehicles with a GVWR > 10,000 lbs must have a minimum braking force = 43.5% of the vehicle GVW.

e. NHTSA, professional crash investigators, and law enforcement typically conduct braking tests on a dry pavement (rather than a wet pavement) with a standard piece of equipment (ASTM locked wheel trailer) to determine skid resistance.

   The methods used to measure dry pavement friction (drag-sleds) are different from any methods employed by TxDOT and are the subject of debate since many different proprietary designs exist. Vericom manufactures a device than can be easily installed in a vehicle for use in directly measuring deceleration rates.

   Crash investigation researchers have published tables of expected pavement friction for different pavement conditions that might or might not agree with ASTM locked wheel, British pendulum, or other types of testing conducted by DOTs.

2. Though CTR was able to obtain some crash data for SHVs in published reports or news articles, SHVs are not specifically identified in TxDOT Crash Record Information System (CRIS) SU truck crash data. In addition, a law enforcement officer conducting a crash investigation might or might not indicate whether an SU truck had liftable or booster axles. Again, it is not currently required by state law that the investigating officer notes the presence of lift or booster axles or whether the axles were lifted or not.
3. TxDMV-VTR does not collect data on the number of axles or whether axles are liftable or not. State laws do not require this information to be collected and therefore it is not collected during truck registration.
4. The research team thinks that documenting the number and types of axles on each registered truck both during registration and during crash investigations would be extremely helpful in further evaluating safety impacts for SHVs as well as trucks in general.

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Chapter 7. The Economics of SHVs in Key Sectors of the US Economy

7.1 Background

Over the last four decades, U.S. transportation modes have gone through a series of legislative changes that removed or modified federal regulations to favor market-based operations. Box 1 summarizes the key Federal Legislative Acts (Bureau of Transportation Statistics, 2000) that deregulated U.S. transportation and underpin current operations in the various modes—air, trucking, rail, and buses. Succinctly, when applied to trucking, deregulation made the U.S. trucking sector a more easily entered and competitive industry[5].

Box 1. U.S. Transportation Deregulation

- Airlines, 1978
- Motor Carrier Act, (Trucks) 1980
- Staggers Act, (Rail) 1980
- Interstate Buses, 1982

This change altered the composition and strength of the trucking industry, one characteristic being the growth of large, publically quoted or listed companies[6] and numerous small companies with less than five trucks. This latter group, comprising over 80% of the trucking company sector, includes owner-drivers who operate single trucks either independently or within the fleet of large companies who provide loads and offer financial assistance in various forms. An owner-driver in this capacity follows company rules with respect to vehicle livery, safety standards, and good behavior on the roads, including adhering to highway laws—speed, safe driving—when operating the vehicle.

Trucking, in most countries, is not considered a glamorous and highly profitable industry, yet it is a key element of economic growth in all major nations, especially those that trade with the U.S. Furthermore, many citizens fail to perceive the connection between efficiently loaded/sized trucks and the many services and goods consumers expect to be efficiently provided when needed. This failure to appreciate trucks' crucial role stems from a variety of experiences, including the discomfort of sharing highways with large trucks, media coverage of truck accidents and safety issues, and environmental concerns. Nevertheless, what is less known is that the trucking sector does focus on safety[7] and returns a modest rate of return on capital expenditures. This suggests that fiscal conservatism is a principal component of the business model adopted by the successful trucking company. SHVs, however, can be significantly more expensive to purchase, which suggests, if the companies are rational, that the benefits from an SHV must be greater than the life cycle costs of their purchase and maintenance.

[5] Not all trucking deregulation created benefits and it can be argued that rural trucking services were adversely impacted.
[6] This allows investors to trade stock and offers pathways to raising capital to merge with or take over other companies, often medium-size regional companies.
[7] In Texas, the HEB grocery chain has over 750 drivers, of whom 325 have completed a million miles without any accident, reflecting 10 years of driving on some of the nation's busiest highways.

7.2 The Rise of the SHV

Class 8 five-axle articulated tractor trailers currently dominate U.S. heavy truck operations, including the haulage of solid construction materials like dirt, rock, sand, and gravel. The vehicles in this industry are termed *articulated dump trailers*. This project, however, has identified operational sectors where a range of SHVs have established a statistically significant presence in trucking operations (see Chapter 3). SHVs can be considered hybrids within a specific truck class, which allows the modified truck to legally carry a heavier load than the basic truck. In the same way that naval architects developed larger ship designs that could transit the original Panama Canal locks[8], trucks have been specified by operators and dealers to carry heavier legal loads than the basic design. SHVs are not confined to a specific commodity but are used to deliver a range of services over a relatively limited distance from their operating base. For example, while SHVs can be configured to use interstate highways, their annual VMT are significantly lower than most truckload and less-than-truckload carriers, reflecting metropolitan and limited statewide operations.

Box 2 offers some limitations on the three key dump truck designs and notes that large fleets—dump trucks in the excavation sector, for example—use a mix of articulated and three-axle single dump trucks. In 2017 the articulated dump trailer is the workhorse of the sector and will remain so for the next five years unless increases in size and weight favor a tridem trailer. If reliable maintenance, reduced downtime, and higher productivity can be established in the SHV class, single multi-axle rigid chassis dumps may increase their market share as users operating their own fleets—refuse collection or skip hiring, for example—transition to an SHV design that allows them to move a heavier load safely and legally.

Box 2. Key Limitations of Dump Truck Types 2017

1. Single Dumps. Key customer areas excluded due to competition, productivity limits, and job size.
2. Articulated Dump Trailer. Seen on almost all contracts, unprofitable on key contracts due to access, requires a CDL license.
3. SHV. Expensive but productive. Not yet adopted by bigger fleets but attractive to small operators who can compete moving a wide range of commodities.

7.3 The Economics of Dump Truck Operations

Box 2 lists the three main dump truck designs in operation today. Survey research in the stone/gravel/excavation sectors shows that many SHV users are small fleet operators. Figure 7.1 offers some insight as to why that might be the case.

[8] These ships were termed *Panamax* and allowed the container limit to increase by over 30% per transit.

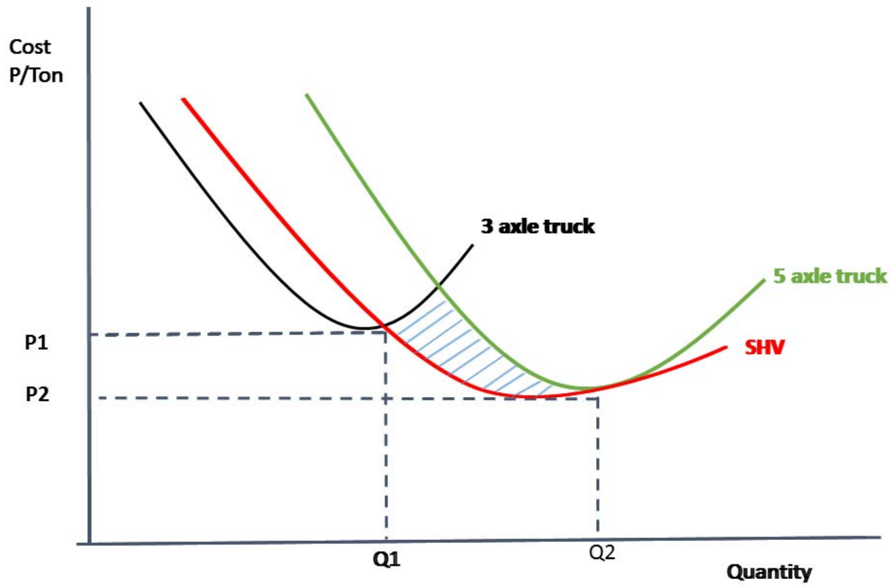

Figure 7.1: Cost per ton for different load levels: standard (three-axle), articulated (five-axle), and SU7 dump trucks (SHV)

The standard three-axle dump truck is designed to haul a payload in the 14- to 16-ton range (Q1) at a cost of P1 (a measure of cost per ton). An articulated five-axle truck is designed for the 23- to 26-ton range at a cost of P2. An SU7 SHV competes with both truck types—axles lifted vs. the smaller struck and lowered vs. the articulated dump. The shaded area shows that the SHV is the most efficient truck to haul loads ranging from Q1 to Q2, which could be critical load levels in many sectors.

The SHV has other attractive operating characteristics for the users facing a range of load types. The storage or operating base for the trucks—including parking, yard, and administrative office—is smaller than that needed for articulated vehicles. An SHV can serve any facility or worksite that can be accessed by a three-axle single dump, skip, or refuse truck. Finally, once recognized as a reliable type, an SHV can be used by owner-drivers to grow their fleet because its productivity allows a new truck to be added to fleet faster than a three-axle truck can be added, based on its utilization and productivity.

7.4 SHV Adoption Rates in Texas

Adoption rates of truck technologies may exhibit asymptotic characteristics—where a design or component is pilot tested and then introduced, demand is low at first with a slight but positive increase over time as the technologies are tested in the field in normal, competitive operations[9]. As the benefits become clearer and feedback from the field improves operational reliability, adopter numbers increase and their demand lowers production costs. The adoption rates then climb more steeply and finally flatten out as all potential beneficiaries adopt the technology. This would suggest an SHV adoption rate similar to that shown in Figure 7.2, which has been used

[9] UPS has been testing a small hybrid delivery truck fleet for over 4 years without reaching a decision to grow their numbers.

to describe product life cycles for production and pricing strategies of new products[10] for over 40 years.

Increasing dump truck productivity can involve adding axles to a basic chassis, lengthening the chassis, and adding more axles and pulling another, smaller dump trailer, known sometimes as a "pup." These latter types are being replaced by SHV designs because their low productivity excludes them from competing on most construction and material hauling jobs. SHVs can complete more efficiently on a wider range of contracts and the dump truck-pup trailer configuration is likely to be an infrequent vehicle seen on state highways.

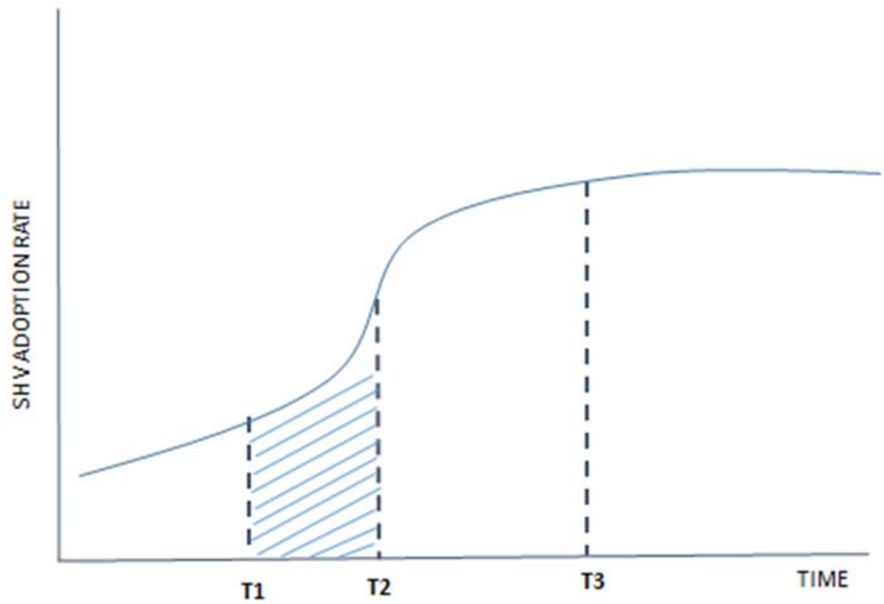

Figure 7.2: Theoretical SHV adoption rates

The strategic elements of the SHV in Figure 7.2 capture introduction, early adoption and testing, strong growth, and finally maturity[11]. Relating this asymptotic curve to SHVs, it suggests that SHVs have completed the period of pilot tests and experimentation, which characteristically exhibit low rates of adoption until thorough testing is completed and positive results measured and monetarized. The vehicle type then enters a relatively steep adoption rate as the benefits become known within the industry and operators replace depreciated trucks with the new designs. The area T1 to T2 represents a hypothetical period that could be where SHVs stand in 2017. In this phase, further refinements are introduced and standardization occurs, reducing the different configurations to a few preferred types. For example, the preferred types might be SU5 and SU7 configurations, especially if original manufacturers promote the designs and offer incentives. In product life analysis, the preferred types then comprise the major SHV trucks on the highway and enter a maturity stage where numbers only increase with fleet size or when older depreciated SHVs are replaced. Adoption maturity rates also suggest that key design features become common on most models. The variety of initial solutions evolves to those combinations that best suit the

[10] For more on this topics, see Kotler, P., & Keller, K. (2016). *Principles of Marketing* (15th ed., pp. 273-282). Upper Saddle, N.J: Pearson.

[11] In product life cycle analysis, maturity can be followed by negative adoption as users replace SHVs with some other truck type/configuration based on performance, profit, and/or restrictive legislation.

operational needs of the customers. A company with more than 50 vehicles might standardize non-SHVs to lower both maintenance and purchase costs. Excavation projects could be serviced by traditional, standardized Class 8 tractor-trailers, supplemented by three-axle Class 6 dumps for smaller jobs or working tight locations. This also suggests that SHVs may not grow into a major truck class but rather a segment of the larger dump fleets.

The dump truck class is characterized by multiple operators and industries moving a wide variety of commodities, many of which are dense and heavy. If not controlled by third parties—like companies loading the vehicles—these dense, heavy loads can create severe direct and external costs like accidents and fatalities. As noted in earlier sections of this report, dump truck manufacturers and operators have increased productivity during the last decade by adding a variety of axle types and groups to specific SU chassis lengths so that the vehicle meets or exceeds the pavement and FBF safety standards when loaded. The standards can be set in state and federal laws and reflect consumption and safety factors described in earlier chapters.

Truck designers develop critical component specifications—especially linked to chassis, suspension, and braking—that enable the vehicle to operate more safely when overloaded, which is typically when mistakes are made by the operator of the loading device. These mistakes can be costly, since both the trucker and loader can be held legally responsible for any overloading and can receive large financial penalties. However, repetitive truck overloading creates rapid component deterioration, potentially serious safety incidents, higher maintenance costs, lower productivity during higher maintenance periods (downtime), and less income—so all rational truck operators *strenuously* avoid regular overloading. In addition, U.S. laws do not stop with operators but also extend responsibility to those companies loading the trucks. This is especially important when a loaded truck is involved in a serious accident or fatality and the whole supply chain from the loading site to the accident site is examined in detail for legal culpability.

All this leads to one simple conclusion—overloading penalties impact both truck owners and those responsible for loading so that they strenuously limit the likelihood of overloaded trips when making decisions to work on contracts. It makes no economic sense to move from the optimal gross and axle loads specified by the truck manufacturer. In some cases, original or second owners have taken advantage of chassis dimensions to retrofit additional lift axle(s) to take advantage of permissible weight laws, but they realize that any truck that is overloaded creates an unacceptable financial risk.

7.5 SHVs and Permissible Weight Laws

In the construction industry, a wide range of materials is loaded with a high level of accuracy when loading is controlled by an experienced person. Loading a single, regularly used item or palletized material is easier, since the weight is derived by the known weight per object times the number on the truck[12]. In many, cases, the load is measured at the site and then recorded on the vehicle ticket prior to leaving the site, which forms the basis of productivity records, invoices, and profit for both the facility and the vehicle owner. The forms are simple and record the material in terms of weight (tons) or volume (cubic yards). Per current laws, both the company loading the vehicle and the vehicle owner share this responsibility, which can play a role in lawsuits, particularly regarding liability in the case of a serious accident when loaded. This can result in underloading of material not easily measured, such as where a thin pavement overlay is

[12] This is one of two suggestions used by the International Maritime Organization to measure containerized loads now required in international law. The other method used involves commercial scales to precisely weigh the load.

being prepared. To investigate this process, research team members observed an overlay application in the Sunset Valley area. These observations, together with discussions with both drivers and the milling machine operator, showed that the truckers were paid by trip from the site to a recycling disposal area, with the load operator deciding on when the vehicle was loaded. All SHVs lowered their liftable axles even though the load was less than the permissible weight for the vehicles. Observations at excavation sites in Austin[13] and Houston[14] confirmed that the operators of the frontend loader did not vary the number of bucket loads per vehicle type, although the SHVs had more volume per bucket if they had more axles. While this information is anecdotal, it does suggest that while excavation work is measured in cubic yards, it can be accurately estimated by a skilled operator. In both these cases, loaded vehicles were recorded by an employee when they left the site. These construction sites are temporary, even when large sites are being prepared, so no weighing is undertake. The assumption is that a loaded trip is noted, together with the average volume (cubic yards) based on vehicle type and size.

Larger production sites, like quarries and ready-mix plants, always weigh the trucks as they leave. A site visit was undertaken in July to a large central Texas quarry that uses a sequential system to serve its customers and control overloading.

1. Their operations are based on the TxDPS permissible weight table that provides max weight (lbs.) for combinations of axles and distance in feet between the first and last axle, which is used by TxDPS to enforce weight laws[15].

2. All trucks have to be registered on the company system that, when completed and checked, allows the truck to be loaded. Items include:
    a. Distance (ft./in.) from front steering axle to rear axle,
    b. Whether it is an SHV or articulated dump trailer,
    c. Total number of truck axles,
    d. Max gross weight (lbs.)
    e. Indicated max gross weight (tons)
    f. Truck tare weight (tons)
    g. Net payload (tons)

3. The document is then:
    a. Signed by the driver (signature and printed name)
    b. Truck owner (signature and printed name)
    c. Dated and signed off by a quarry employee

4. The truck is then allocated a unique number plate that is entered into the company system before any loading can take place. In addition, the truck must go through the entire registration system again if it is not used again at the site within 30 days. The number must be visible from the outside at all times when on site.

[13] Foundations for a multistory apartment building: 1711 Guadalupe Street, Austin, May 2015
[14] Foundations for a new hotel: 6900 Main Street, Houston, July 19/20, 2016
[15] A TxDPS inspection for load only includes those axles running on the vehicle. If an axle, or axle set, is lifted, it is excluded from the analysis.

5. Each time a registered truck arrives, a load invoice is generated, and it is directed to the appropriate storage area for loading. The large rubber-tired front loaders have a bucket scale with an accuracy of +/- 300 lbs. The driver knows his load limit and gives it to the front loader driver who then uses his scales to load the truck.

6. The truck them moves to the weight scales (two locations) and the vehicle enters the first of three scales that each have a guardrail painted in feet (which remote cameras use to check and record length). At the same time, an operator sited in an elevated portion of the facility enters the unique number that provides the load limits for the vehicle as it moves on to the weighing scales. The gross weight is measured; the product and tare weight are already known, so the payload can now be determined. If it is over the limit for that specific vehicle on its record form, it is rerouted to a smaller grab crane remotely operated from the weighing office where the excess product is removed. The vehicle then returns to the scales for a final invoice from a machine at cab height at the end of the scale.

7. The driver pulls the ticket and leaves the facility.

8. The five-axle articulated dump and SU7s were close to, but under, 80,000 lbs. All SHVs are weighed with their axles lowered and all data recorded at the scales are kept in company records and are not available for research purposes.

Succinctly, the company weighing operations and business model mirrors the TxDPS measurements if the vehicle is pulled over and inspected. Staff at the site confirmed that use of SHVs—the company calls them "bobtails"—has grown significantly in recent years from single figures per day a decade ago to about half of all trucks processed daily. The facility currently handles around 1300 trucks per day, five days a week, reflecting the demand generated from contracture of all types in the metropolitan and greater Austin area.

7.6 Conclusions

SHVs have established their presence in a range of trucking operations despite the high capital cost when purchased. The ability to dynamically configure the truck by the company dispatcher[16] or driver offers a competitive advantage over traditional non-liftable dump trucks. Three perspectives are summarized in this section—operator, truck manufacturer, and agencies—as they relate to highway legislation, operations, and enforcement.

1. Truck Operator

   a. An operator, irrespective of the vehicle numbers in the fleet, faces choices in several areas that, when aggregated, comprise the total costs of ownership. Capital costs play an important role, as does fuel consumption, driver salary, safety, truck reliability, and maintenance costs. Small fleets (under five units) in the truck sectors now using SHVs have sometimes entered the sector by purchasing a well-maintained basic two- or three-axle truck and adding a

[16] Dispatchers are used in larger companies; in smaller companies, the owner-operator/driver knows the work schedule at the beginning of each day.

liftable axle. This study considers the current wide variety of SHV but notes there is strong evidence derived at the dealer level that new SHVs are taking a large share of the market.

b. SHVs are expensive ($150,000 to 240,000) and annual vehicle mileage is typically lower than other truck classes, thus raising the depreciation costs per mile. Nevertheless, the productivity gains more than compensate in terms of ton-mile revenues, so if demand is strong and consistent, an SHV is a better investment because it is a greater contributor to company profitability and growth.

c. An SHV fleet moves more cargo weight (ton-miles) than a traditional rigid dump truck[17] fleet when all costs are included. This is strengthened as SHV designs are refined, tested, and introduced by the leading U.S. truck manufacturers.

d. Although a wide variety of SHV types will exist for some time, experience suggests that demand will center on two or three types. SU5 is a strong contender for booster specifications because larger tires can be accommodated on the liftable axles. As booster sets gain axles, the booster tire size gets smaller, even if the chassis length increases. SU7 meets FBF contract requirements on interstate highways and federal contracts.

2. Truck Manufacturer

a. SHVs are now recognized as an important subsector by U.S. original equipment manufacturers. All of the major brands in the heavy truck sector provide models that either are offered as original equipment under the company guarantee or can be modified by approved secondary companies. Freightliner, for example, now features an SU6 range of trucks in the severe- to medium-duty range (*Heavy Duty Trucking*, 2017a). Hendrickson—a global leader in the manufacture of medium- and heavy-duty suspension, axle, and brake systems—now offers integrated drive axle/liftable booster axles sets for SHV original equipment specifications. Kenworth, Peterbilt, and International all report strong sales for dump trucks with liftable axles.

b. Truck manufacturers are maintaining a sharp focus on SHV accidents and safety in their business models but the accident data are sparse and generally lack specificity. In 2015, the class containing SHVs—SU trucks[18], grossing over 10,000 lbs.—were involved in 620 fatal highway accidents, representing 15% of all truck fatalities. The annual rates of fatalities per unit distance for all heavy vehicles in the period 2011–2015 remained in the range of 1.40 to 1.47 fatalities per 100 million VMT. Anecdotal accident on SHV accident causes are generally centered on brake failures—which result in rollovers or property damage—and hydraulic failures/a blown tire on a stinger axle that suddenly

[17] It is claimed that this can include articulated dump trucks in certain applications. For more information, see www.superdumps.com

[18] Some companies refer to SHVs as "bobtails" and this term appears in federal accident data. In this report, a "bobtail" is defined as an articulated tractor unit moving with a trailer and is not an SHV.

shifts the load center of gravity, making the vehicle difficult to control by the driver. Technologies are being introduced—like active monitoring of tire pressures—to counter specific problems[19].

c. SHVs will inevitably benefit from many of the innovations related to autonomous trucks under test at this time. Features that mitigate system failures (like hydraulic and tire pressure issues) and incorporate innovations (like automatic braking) will clearly prevent or reduce accident severity and will be offered as they move from testing to real-time operations.

3. Agencies related to highway legislation, provision, operations and enforcement

    a. Texas has over 40 different types of permits for truck operations on state and county highways, in addition to federal size and weight laws. Heavier truck operations continue to grow in Texas. The 83rd Legislative session approved a 30-mile OW container bill from Port Houston to run on as yet unspecified routes for a single annual fee. Earlier chapters have referred to the creation of OS/OW legislation, including TxDMV permits for single trips on specified routes to annual and seasonal cargo on sets of counties. This creates a substantial challenge to TxDPS officers tasked with enforcing size and weight legislation. This responsibility also extends to drivers, operators, and companies that load the vehicle—in the case of this report, an SHV.

    b. The term *SHV* covers a wide range of specific axle configurations within the category of a three-axle, rigid chassis truck category, sometimes described as medium- to heavy-duty depending on the technical specification of the engine, transmission, and chassis dimensions. The axles are designed for one specific purpose—to redistribute load so that it meets TxDPS scrutiny and FBF limits. The axles are not connected to transmission systems but play a critical role in the truck's braking performance. Anti-lock braking is a major safety system that will be thoroughly examined by original truck manufacturers as they compete in this sector.

    c. DPS officers are trained to inspect SHVs and focus on chassis length between the first and last axle, and the number of axles actually running on the pavement, to categorize the specific SHV type. They then measure the weights on each axle and may undertake further tests on other safety issues noted during inspection. This can be an exacting process and calls for axle scales, blanks[20], and time. TxDPS officers work off a permissible weight table[21] that computes permissible loads per unit distance between the first and last axle hubs to the nearest 500 lbs.

    d. These data frame decisions on SHV chassis and axle configurations by manufacturers, companies loading the trucks, and the driver/owner of the truck. The objective in all trucking operations where cargo weight is an issue is to get as

[19] See an example at: http://www.superdumps.com/features/features_index.php

[20] These are placed under the opposite axle(s) to the side being measured to balance the load being transferred to the pavement by the paired axles.

[21] Using data carried forward from "Article 6701d-11, Section 5, Subsection (4) when it was amended on December 16, 1974 by Senate Bill 89 of the 64th Legislature."

close as possible to the permitted limits. The recent growth in Texas SHV registrations clearly shows that more operators are choosing SHV designs to increase productivity, compete over a variety of cargo densities, and raise utilization levels, which impacts both depreciation costs per mile and ultimately profit. This is critical where the average trucking rate of return in the first quarter of 2017 was 4% below 2016 levels for one key U.S. trucking sector (Heavy Duty Trucking, 2017b), although not directly transferrable to SHV operations.

e. The final, overarching conclusion is the need to integrate gross and axle load legislation, gains in economic efficiency and productivity, and the marginal costs of pavements and bridges with easier enforcement and compliance. This is, as yet, incomplete in the SHV class, although this research is a first step in the process.

7.7 References

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Heavy Duty Trucking (2017a). Vol 196. No. 8, pg.19. Bobit Business Media, Torrance, CA. August 2017.

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Chapter 8. Policy Findings and Recommendations

This five-section chapter provides policy recommendations for optimizing SHV configurations and load posting signage. The first section recaps current Texas laws and regulations for registering vehicles with TxDMV, outlines commercial motor vehicle enforcement by TxDMV and TxDPS, and reviews case law within the U.S. around SHVs. The section also briefly presents current weight and other restrictions for specific types of SHVs within Texas statues and regulations. Section 8.2 briefly summarizes the major findings of the project regarding data capture and analysis and the pavement and bridge consumption components. Section 8.3 details TxDOT's current load posting policies for bridges. Section 8.4 details current signage recommendations from the MUTCD and suggested signage that has been developed by other state(s). Section 8.5 concludes with the research team's major policy recommendations.

8.1 Overview of Texas Law and Regulation

While the federal government allows a maximum of 80,000 lb GVW on interstate highways in the U.S., Texas also typically authorizes a maximum of 80,000 lb GVW on state-maintained roads. However, parts of the state's network of bridges and highways were constructed over 60 years ago and while some of these have been upgraded, many have weight restrictions and are load posted (bridges) or load zoned (pavements). As an example, about 19% of the state-maintained system in Texas (about 16,000 centerline miles) is load zoned at a maximum of 58,420 lbs GVW, which was the maximum legal load limit in Texas from 1951 to 1959 when many of the roads were constructed. The Texas Highway Commission load zoned these roadways through a single Commission Minute Order in response to the federal government's increase in national GVW limits to 73,280 lbs in coordination with the Interstate Highway Program (Murphy 2010) (Harrison et al., 2000). In addition, there are approximately 2,089 load posted bridges in Texas (178 are along on-system and 2,077 are off-system routes) (TxDOT 2016). Bridges are load posted by maximum allowable GVW, single or tandem axle weight, or a combination of these three limits.

Texas Transportation Code, Sec. 621.101 authorizes the legal weight limit across axles. Typically, a maximum of 20,000 lb is authorized on a single axle; a maximum of 34,000 lb is authorized on a group of two closely spaced axles; and 42,000 lbs is authorized on three closely spaced axles, with larger authorized axle group loads for greater numbers of axles and axle spacing. The maximum legal weight allowed on a group of two or more axles depends on the number and spacing of the axles in the axle group, and is determined using the FBF and rounding the result to the nearest 500 lbs. The formula is:

$$W = 500 [(LN/(N - 1)) + 12N + 36]$$

where:
"W" is maximum allowed overall gross weight on the axle group;
"L" is distance in feet between the axles of the group that are the farthest apart; and
"N" is number of axles in the group

8.1.1 Permissible Weight Table

The Permissible Weight Table (Table 8.1) indicates the maximum legal weight for a group of two or more consecutive axles of a vehicle depending on the number and spacing of axles determined using the FBF. The number in the leftmost column, labeled "Distance in Feet," is the distance between the outermost axles of any group of two or more consecutive axles.

Table 8.1: Permissible Weight Table

Distance in Feet	Number of Axles					
	2	3	4	5	6	7
4	34,000					
5	34,000					
6	34,000					
7	34,000					
8	34,000	34,000				
8+ (These figures apply only to an axle spacing greater than 8 feet but less than 9 feet)	38,000	42,000				
9	39,000	42,500				
10	40,000	43,500				
11		44,500				
12		45,000	50,000			
13		45,500	50,500			
14		46,500	51,500			
15		47,500	52,000			
16		48,000	52,500	58,000		
17		48,500	53,500	58,500		
18		49,900	54,000	59,000		
19		51,400	54,500	60,000		
20		52,800	55,500	60,500	66,000	
21		54,000	56,000	61,000	66,500	
22		54,000	56,500	61,500	67,000	
23		54,000	57,500	62,500	68,000	
24		54,000	58,700*	63,000	68,500	74,000
25		54,500	59,650*	63,500	69,000	74,500
26		55,500	60,600*	64,000	69,500	75,000
27		56,000	61,550*	65,000	70,000	75,500
28		57,000	62,500*	65,500	71,000	76,500
29		57,500	63450*	66,000	71,500	77,000
30		58,500	64,000*	66,500	72,000	77,500
31		59,000	65,350*	67,500	72,500	78,000
32		60,000	66,300*	68,500	73,000	78,500
33			67,250*	68,500	74,000	79,000
34			68,200*	69,000	74,500	80,000

Distance in Feet	Number of Axles					
35			69,150*	70,000	75,000	
36			70,100*	70,500	75,500	
37			71,050*	71,050	76,000	
38			72,000*	72,000*	77,000	
39			72,000*	72,500	77,500	
40			72,000*	73,000	78,000	
41			72,000*	73,500	78,500	
42			72,000*	74,000	79,000	
43			72,000*	75,000	80,000	
44			72,000*	75,500		
45			72,000	76,000		
46			72,500	76,500		
47			73,500	77,500		
48			74,000	78,000		
49			74,500	78,500		
50			75,500	79,000		
51			76,000	80,000		

Source: TxDMV Permissible Weight Table (n.d.)

*These figures were carried forward from Article 6701d-11, Section 5(a)(4) when Senate Bill 89 of the 64th Texas Legislature amended it on December 16, 1974. The amendment provided that axle configurations and weights that were lawful as of that date would continue to be legal under the increased weight limits.

Vehicles that exceed the legal size and weight limits need to obtain an OS/OW permit and approved route from TxDMV to operate on roads in Texas. Texas Administrative Code Chapter 219, Rule 219.11, General Oversize/Overweight Permit Requirements and Procedures, details the maximum permit weight limits; see Table 8.2. For load-restricted roads, the maximum allowed permit weight for an axle or axle group is reduced by 10%.

Table 8.2: Maximum legal and permit weights

Number of axles in axle group	Maximum legal weight (lbs)	Maximum permit weight (lbs)	Maximum permit weight on load-zoned roads (lbs)
Single axle	20,000	25,000	22,500
Two-axle group	34,000	46,000	41,400
Three-axle group	42,000	60,000	54,000
Four-axle group	50,000	70,000	63,000
Five-axle group	58,000	81,400	73,260
Note: Axle groups with six or more axles are not allowed unless the group has steerable or articulating axles or an engineering study of the equipment has been completed.			

Source: Texas Administrative Code, Chapter 219, and TxDMV, 2015

An axle group must have a minimum spacing of 4 feet, measured from center to center of axles, between each axle in the group to achieve the maximum permit weight for the group. Two opposing axle groups must have a minimum spacing of 12 feet, measured from the center of the last axle of the front group to the center of the first axle of the following group. For two or more consecutive axle groups having an axle spacing of less than 12 feet, measured from the center of the last axle of the preceding group to the center of the first axle of the following group, the maximum allowed permit weight will be reduced by 2.5% for each foot less than 12 feet.

In addition, each axle in a group of axles must equally share the weight of the group at all times, with no more than a 10% weight difference between any of the axles in the group, if the axles share suspension (TxDMV, 2015).

Moreover, the maximum permit weight for an axle group with spacing of 5 or more feet between each axle will be based on an engineering study of the equipment conducted by TxDOT. An OW-permitted vehicle is not allowed to travel over a load-restricted bridge if its gross weight exceeds the posted capacity of the bridge, unless a special exception is granted by TxDOT. Furthermore, a permitted vehicle is not allowed to exceed the manufacturer's rated tire carrying capacity. An exception to this policy is allowed for land-locked bridges, which provide the only route into or out of a community. In cases of land locked bridges, load posting limits are suspended for routine deliveries that cannot be made in other way.

Following are the legal size limits for vehicles operating on Texas highways without a permit:

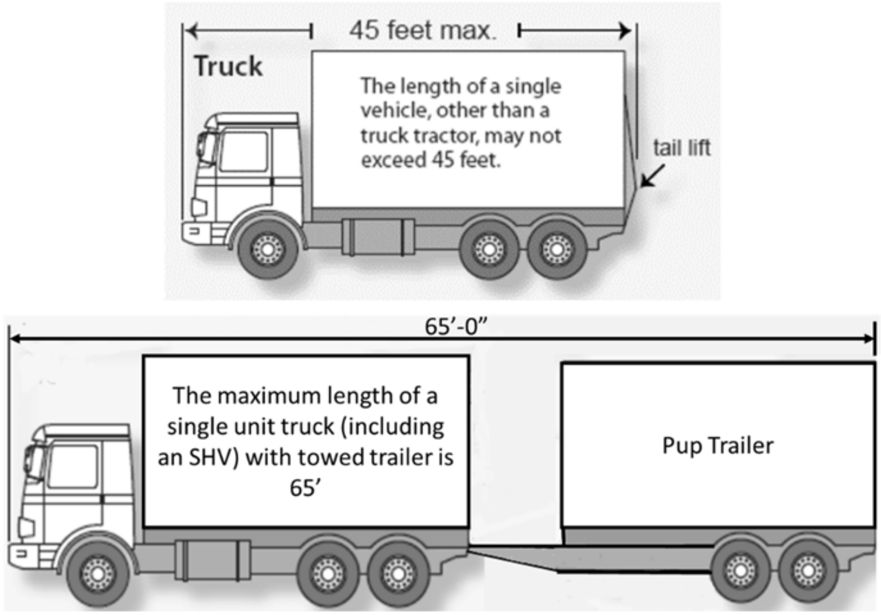
- Maximum width – 8'6"
- Maximum height – 14'
- Maximum length is shown in Table 8.3.

Table 8.3: Maximum truck lengths in Texas

Vehicle Type	Length Limit
Applicable to SHVs	
Truck or single vehicle	45 feet
Truck-tractor	Unlimited
Truck-tractor combination	Overall length unlimited but the trailer is limited to 59 feet
Front overhang	3 feet
Rear overhang	4 feet
Applicable to other trucks	
Truck and trailer combination	65 feet
Semi-trailer single unit	59 feet
Semi double trailer	28.5 feet

Length Diagrams

Figure 8.1 shows the legal length limits for trucks that are applicable to SHVs.



Source: TxDMV, 2015 (SHV with pup trailer drawing modified by authors)

Figure 8.1: Legal length limits for an SHV and an SHV with pup trailer

8.1.2 Exceptions Based on the Type of Commodity

The state of Texas allows exemptions of the legal size and/or weight limitations for trucks carrying certain types of goods on roads within the state (except for on the interstate highways).

Garbage Collection Vehicles

Texas Transportation Code, Sec.621.206(b), allows a vehicle that collects garbage or recyclable materials and is equipped with front-end loading attachments and containers to carry a load that extends more than three feet beyond its front or more than four feet beyond its rear, which other vehicles are typically not allowed to exceed. No permit or bond or fee is required for this exception.

Recyclable Materials or Solid Waste Trucks

Texas Transportation Code, Sec.622.131-136 (for recyclable materials truck) and Transportation Code, Sec.623.161-165 (for solid waste truck) allows a truck (single vehicle) used exclusively to transport recyclable materials or solid waste to operate without an OS/OW permit on state highways, excluding interstate and defense highways, with a single axle weight up to a maximum of 21,000 lbs, a tandem axle group weight up to a maximum of 44,000 lbs, and gross weight up to a maximum of 64,000 lbs. In addition, the statutes also state that owners of recyclable materials or solid waste trucks with a tandem axle weight exceeding 34,000 lbs are required to file a surety bond with TxDOT not to exceed $15,000 per vehicle as security against any road damages caused by operation of the truck.

Ready-mix Concrete Trucks

Texas Transportation Code, Sec.622.011, allows a vehicle transporting ready-mix concrete or a concrete pump truck to operate on state highways (without a permit) with a single-axle weight up to a maximum of 23,000 lbs, a tandem axle group weight up to a maximum of 46,000 lbs, and gross weight up to a maximum of 69,000 lbs. Ready-mix concrete trucks that do not operate under the provisions of a permit may be subject to additional county and municipality weight restrictions for operations on county and municipal roads, and are also subject to local bond requirements. Texas statute (Transportation Code, Sec. 622.015) states that a county or municipality government may require a ready-mix concrete truck owner to file a surety bond not exceeding $15,000 as security against any damages caused to a highway by the operation of a truck with a tandem axle weight of more than 34,000 lbs.

As per Texas Transportation Code, Sec.623.0171, a permit can be issued to ready-mix concrete trucks with three axles by the TxDMV that would allow these trucks to exceed the allowable single and tandem axle weights stated above by a tolerance of 10% provided the maximum GVW does not exceed 69,000 lbs. The annual permit fee is $1000. The permit does not allow the ready-mix concrete trucks to exceed legal size limits. The permit allows operations of permitted vehicles on municipal roads, county roads (including load-zoned county roads), FM roads, Texas state highways, and U.S. highways in the counties listed on the permit for an unlimited number of moves during the time specified on the permit. However, this permit does not allow the vehicles to operate on interstate and defense highways (Texas Transportation Code; TxDMV, 2015; Prozzi et al., 2012).

8.1.3 Other Permit Types That Could Be Used by SHVs

TxDMV issues an annual Over Axle/Over Gross Weight Tolerance Permit that allows a vehicle carrying divisible loads, such as crude oil and gravel, to operate above the legal weight limits on state-maintained roadways and county roads (in the counties selected on the permit application) but not the interstate highways (TxDMV, 2016). This permit is also referred to as the "2060" or "1547" permit (named after the House Bills that authorized these permits). TxDMV's website also notes that the "2060" permit does not allow the permitted vehicle to exceed load-posted bridge weight restrictions unless the bridge is the only way to publicly access the origin or destination.

The "2060" permit allows an additional 10% axle weight tolerance for non-agricultural commodities, or additional 12% axle weight tolerance for agricultural commodities above the maximum allowable axle weight, and additional 5% GVW above the maximum allowable GVW applicable to the vehicle. However, the axle weight tolerances, when combined, cannot exceed the 5% GVW tolerance. Certain types of trucks are not eligible for the 2060 permit, based on the type of commodity they transport—such as solid waste trucks, trucks transporting recyclable materials, and processed milk, among others—as other special statutes apply to them (TxDMV, 2015).

8.1.4 Case Law Analysis

A review of case law within the U.S. and Texas was undertaken to determine if, or where, a DOT or local jurisdiction may have been held liable for incidents/crashes occurring on load posted bridges. A search of Westlaw and LexisNexis was conducted during the first week of August 2017 (to ensure this was as up to date as possible). These databases allow a Boolean search, whereby the search parameters used keywords no more than three words apart. The keywords were *load posted bridge*, *load posting*, *load posted*, *bridge*, *specialized hauling vehicle*, *specialized hauling trucks*, *single unit vehicle*, *single unit truck*, *dump truck*, *concrete truck*, and *ready-mix truck*. A large number of cases arose with concrete or dump truck, but these were mostly focused on either contract or tort litigation regarding quality of the truck or its parts, or the negligence in operating the vehicle. The search was then further refined to include DOT or Local Jurisdiction as a party (defendant or appellant). Refining the parameters further narrowed the search results from over 750 cases to 13 cases. Out of these cases, the five cases that date from 1970 are summated below.

Hansmann v. County of Gosper, 207 Neb, 659, 300 N.W.2d 807, 1981 Neb. LEXIS 709.

The defendant county appealed a judgement of District Court for Gosper County (NE) that found in favor of the plaintiff in an action to recover injuries sustained when a bridge collapsed while he drove on it. The bridge load limit was 10 tons, and had been posted, but for six months prior to the accident, the posted sign had not been in place. The plaintiff drove a truck weighing between 11–12 tons, loaded with hog feed. The district court held the county liable for failure to replace tonnage sign as an insufficient or want of repair of the bridge, and rendered the county liable. The Appeal Court affirmed the judgement of the District Court.

DeSoto Parish Police Jury v. Bell, 463 So. 2d 887, 1985 La. App. LEXIS 8051

Appellants (DeSoto Parish Policy Jury, hereinafter "DeSoto") at a regular meeting received an engineer's report on the condition of parish bridges. The report found three bridges to be in critical condition, and that the bridge in this action should be posted for light loads and scheduled for immediate rehabilitation in February 1980. No warnings were posted, nor repair actions taken by the time of the accident in March 1983. A driver of defendant appellant's (Don N. Bell) company, attempted to cross the bridge with a large bulldozer that weight approximately 32,000 pounds. When the full weight of the bulldozer was on the bridge, it collapsed. The driver noted that he had not experienced problems when crossing similar bridges in similar machines, and noted he had crossed other bridges that were load posted. Defendant-Appellant was held liable by the trial court for damages of $3,000 to the bridge that collapsed to DeSoto.

The issue reviewed on appeal was whether DeSoto was contributorily negligent, and if this contributory negligence would defeat a claim for damages. On August 1, 1980, Louisiana had changed prior law, to add comparative negligence law, by providing that a person's contributory negligence would not defeat a claim for damages. However, as this case arose prior to the Act's effective date, any negligence on the part of DeSoto would act as a bar to it recovering damages from the defendant-appellant. Therefore, the judgement of the trial court was reversed. The court in its discussion noted that the appellant was negligent in attempting to drive a bulldozer across the bridge and that the appellant owed a duty to use reasonable care in crossing the bridge. The court also noted that DeSoto also has a duty to warn persons using highways and bridges under its control of the presence of dangerous conditions and that this was 'actual' or 'constructive' notice of a danger that gave sufficient opportunity to either eliminate the condition or warn of its presence. DeSoto had actual notice of this dangerous condition of the bridge at least three weeks before collapse. Although the court noted that this may have been insufficient to eliminate the dangerous condition, the time period was sufficient to load post. DeSoto was found to break this duty by failing to warn of the danger.

Corbet, Inc. v. County of Pawnee, 219 Neb. 622, 365 N.W.2d 437, 1985 Neb. LEXIS 983,

This was a cross appeal from a District Court decision that had found the defendant was not liable for damages due to the collapse of a bridge that the plaintiff's truck was crossing.

Plaintiffs sought damages for collapse of a bridge. While the court did find the county negligent in failing to load post (the bridge had been inspected in 1980 and was rated at four tons), this negligence was not the proximate cause of the accident. The proximate cause was an intervening cause by the negligence of the truck driver in driving over the bridge with a load of grain that weighted approximately 22 tons and a truck weighing approximately 12.5 tons. The court found that after reviewing pictures of the bridge that a reasonable and prudent person would not expect another attempt to drive a loaded vehicle weighting almost 34 tons across the structure. In this instance, the judgement was affirmed on the grounds that the negligence in failing to post a sign was not the contributing factor, and that the interceding event of driving the truck over the bridge was the proximate cause of the accident.

Duffy v. County of Chautauqua, 225 A.D. 2d 261, 649 N.Y.S.2d 297, 1996 N.Y. App. Div. LEXIS 13310

This was a cross-appealed case, and on appeal held the County 25% and employer 75% liable for a bridge collapse that killed an employee driver and injured another employee passenger. The employees were driving a pickup truck that followed their boss driving a crane weighing 16 tons across a bridge that was load posted and signed to eight tons. The employer made it safely across bridge, but the bridge collapsed when the pickup crossed. The employee driving the pickup died. The appeals court found that the trial court had properly denied the request to charge the jury regarding contributory negligence of the employees who were passengers, because they did not have a duty to read the load limit sign. The court found that the trial court should have charged the jury regarding the contributory negligence of the employee who was the driver and further held that the trial court properly denied requests of the employer and the county to consider the negligence of the employee who was driving the pickup in apportioning liability under New York statute.

Fudge v. Cottle County, 467 S.S.W.2d 570, 1971 Tex. App. LEXIS 2712

The appellate court brought suit against appellant driver and trucking company to recover for damages to a county bridge allegedly caused by the appellant driver's negligent actions.

The judgment denying appellant driver and trucking company's plea of privilege in appellee county's suit to recover for alleged bridge damage was reversed and remanded for another hearing on grounds that the record was devoid of any probative evidence that the alleged negligent act was the proximate cause of the damages.

The appellants filed 'pleas of privilege' to be sued in their respective counties of residence and a controverting plea was filed by appellee. The trial court overruled appellants' pleas of privilege and the appellants appealed.

The bridge was close to a road construction project. No testimony was presented whether these trucks crossed the bridge, and no witness testified to seeing the driver cross the bridge, but one witness testified that he was told by the driver that he had driven across the bridge with a truck at a gross weight of 74,500 pounds. The bridge was not load posted, and testimony was not given regarding the type or structure of the bridge. The time that Fudge drove across the bridge was not fixed in relative time when the damage to the bridge occurred, and testimony was not given regarding the bridge's condition either prior or subsequent to the time when driver crossed the bridge. The appeals court noted "*at best the evidence is speculative that the truck driven by Fudge caused the damage complained of, and fails to constitute a primate facie cause of action against appellants.*" It was apparent from the trial court record that facts were not fully developed at the hearing and the cause should be reversed and remanded for another hearing.

8.1.5 Case Law Conclusions

The analysis of case law shows that in most instances TxDOT (or the local jurisdiction) will not be liable for damages because of load posting, often because of contributory negligence on part of the truck/driver, or other interceding events.

In addition, for many states sovereign liability is restricted under Torts Liability laws. The Federal Tort Claims Act (28 U.S.C. §2674) was passed in 1946, which waived immunity to suit for some actions. Most states fall into one of two types of regimes, those that follow the Federal Tort Claims Act, and have a general waiver of immunity with certain exceptions, or those that have reenacted immunity and have limited waivers that only apply to certain types of claims. According to the National Conference on State Legislators, currently 33 states have Acts that 'cap' or limit monetary damages that can be recovered from judgments against the states, and at least 29 states (usually in combination with the cap) prohibit judgment against a state to include punitive or exemplary damages (NCSL, 2010).

Texas sovereign immunity (the Texas Tort Claims Act) is detailed within Texas Civil Practice and Remedies Code (TCPRC) at §101.001 et. seq,. Section 101.021 defines that:

"A governmental unit in the state is liable for:

(1) property damage, personal injury, and death proximately caused by the wrongful act or omission or the negligence of an employee acting within his scope of employment if:

(A) the property damage, personal injury, or death arises from the operation or use of a motor-driven vehicle or motor-driven equipment; and

(B) the employee would be personally liable to the claimant according to Texas law; and

(2) personal injury and death so caused by a condition or use of tangible personal or real property if the governmental unit would, were it a private person, be liable to the claimant according to Texas law."

"The Duty owes, by a state entity is detailed in TCPRC Section 101.022:

a) Except as provided in Subsection (c), if a claim arises from a premise defect, the governmental unit owes to the claimant only the duty that a private person owes to a licensee on private property, unless the claimant pays for the use of the premises.
b) The limitation of duty in this section does not apply to the duty to warn of special defects such as excavations or obstructions on highways, roads, or streets or to the duty to warn of the absence, condition, or malfunction of traffic signs, signals, or warning devices as is required by Section 101.060.
c) If a claim arises from a premise defect on a toll highway, road, or street, the governmental unit owes to the claimant only the duty that a private person owes to a licensee on private property."

TCPRC Section 101.060 details traffic and road control devices. As can be seen in section (a)(2), the chapter *does not apply* to failure to place a traffic or road sign as a result of a 'discretionary' action by the governmental unit (in this specific case TxDOT or local jurisdiction).

"(a) This chapter does not apply to a claim arising from:

1) the failure of a governmental unit initially to place a traffic or road sign, signal, or warning device if the failure is a result of discretionary action of the governmental unit;
2) the absence, condition, or malfunction of a traffic or road sign, signal, or warning device unless the absence, condition, or malfunction is not corrected by the responsible governmental unit within a reasonable time after notice; or
3) the removal or destruction of a traffic or road sign, signal, or warning device by a third person unless the governmental unit fails to correct the removal or destruction within a reasonable time after actual notice.

(b) The signs, signals, and warning devices referred to in this section are those used in connection with hazards normally connected with the use of the roadway.

(c) This section does not apply to the duty to warn of special defects such as excavations or roadway obstructions."

8.2 Major Project Findings

A major objective of this project was to determine the types and configurations (including GVW, number of axles, axle loads, axle types [fixed or liftable], and axle spacing) of SHVs operating in Texas and where they operate. The project reviewed and collected multiple sources of literature and data, including the following:

- TxDMV registration data
- TxDPS enforcement data, a subsection of data that is based upon roadside inspections, which required law enforcement to have probable cause that the vehicle is either overweight/height/length or has some other illegal physical element that is observed.
- VIUS by U.S. Census (terminated in 2002 so not considered up-to-date).
- SHV truck counts. The research team performed visual identification and counting of truck types, truck configuration, axle configuration, route, and, in many cases, whether the truck was loaded or empty. SHV truck counts included truck type, the axle configuration including the number of liftable pusher, tag, or booster axles and notations regarding whether the axles were lifted or on the pavement.

  The identification counts of trucks were performed at several locations within four major metropolitan areas (Austin, Houston, Dallas/Ft. Worth, and San Antonio); additional physical truck counts in Wichita Falls, Waco, Temple; and route counts of trucks traveling along routes between metro, urban, and rural areas in Texas. In addition, the researchers viewed several 24-hour videos provided by the TP&P Division; these videos are used by TP&P in conjunction with vehicle classification and count data.
- Fixed weigh station data

The literature review and data collection process yielded these key findings.

1) There are clear limitations and gaps in national and state data sources regarding the composition of the SHV fleets.
2) TxDMV cannot identify vehicle type based on registration data. Axle numbers are not included in the registration data, as this is not required by current statutory provisions. TxDMV does not require a commercial vehicle registrant to specify the number of axles, including any liftable or boost axles.
3) The registration category "Dump Trucks" does not separate out the two types of dump trucks. In addition, TxDMV does not use subcategories for oil field equipment when registering the vehicle (such as vacuum truck, hot oil unit, winch truck, etc.).
4) For agricultural trucks, TxDMV noted that they do not have data on where the trucks run, as these are mostly on a 1547 permit, which is non-routed.
5) TxDMV conducts investigations of companies operating SHVs that have OW citations. They do not, however, have data on the 'extra' axles.
6) TxDMV vehicle registration data provides the total number of vehicles of different truck types and their distribution over the state. However, four major limitations are associated with this data resource:
    i. No axle information is recorded. When a vehicle is registered with TxDMV, they are not required to specify how many axles the vehicle has, let alone how many of those axles are liftable or boost axles.
    ii. It is unclear from the data if a vehicle is an SU or not. For example, even though the TxDMV data has a specific body type labeled "Dump Trucks," it is unclear if a vehicle registered in this category is an SU truck or a dump trailer. The focus of this project is those SU trucks.
    iii. Accurate definitions of different body types are not made clear to either the vehicle registrant or registration officers. The vehicle registrant reports their vehicle as the body type they think it should be. No one checks the vehicle to see if the reported body type is correct and matches with the definition.
    iv. Some registration categories are too broad. For example, the vehicle category "Oil Field Equipment" has no subcategories to define more specifically what type of equipment it is. Thus, it may be a vacuum truck, a hot oil unit, a nitrogen pump truck, oil well service vehicle, or a winch truck—which are all very different in terms of function, truck and axle configuration, weight, and size. As an example, a vacuum truck may be an SU three-axle, an SU4 SHV, or a tractor/tank trailer unit, while an oil well service vehicle might be a three- to eight-axle SU vehicle with or without lift axles, with weights varying from 65,000 lbs to over 180,000 lbs.
7) TxDPS also has a series of weigh stations across the state. Data from fixed weigh stations is a limited subset based upon the weighing of trucks that are required to pull in. So the sample may be skewed by multiple factors. In addition, TxDPS weight enforcement data includes portable scale data collected on the roadside; this data set

encompasses both legally loaded trucks that were suspected to be OW, but were not, and trucks that were OW on a single axle, multiple axles, and potentially GVW.

8) If an SHV is stopped by TxDPS for weighing and one or more liftable axles are in the 'up' position, the truck is weighed without lowering these lift axles, which might result in OW fixed or liftable axles that were in the lowered position. The researchers have observed SHVs with variations in lift axles either up or down. An example is an SU6 with three pusher axles—the first of which is lifted, the second down, and the third lifted. Booster axles might be lifted while the pusher or tag axles have been deployed.

9) SHVs are not a major topic for law enforcement, and they do not focus on SHVs specifically.

10) SHV drivers typically obtain a CDL Type B. There is no special training required for SHV operators by the state. However, based on discussions with trucking companies, in most cases some basic training is provided to drivers regarding lift axles and, less frequently, drivers are fully trained on lift axle operations and safety considerations of SHV operations, including accounting for the high center of gravity and making safe turning movements.

11) TxDPS has only 500 weight enforcement officers for the 254 counties.

12) Allowances for variations in equipment readings or other factors are at the enforcement officer's discretion. TxDPS uses a 1,000 lb weight tolerance. There are different laws or rules that are taken into consideration. If a truck has a tire load that exceeds the manufacturer's rating, the truck is taken out of service. If the axle is above the legal limit, the 1,000 lb tolerance will be applied—as it will for GVW.

13) DPS enforcement data containing axle and total weight information that presents two major issues when estimating the population characteristics of SHVs:

    i. The sampling process is uncontrolled. Many trucks are pulled over and weighed by the roadside because the enforcement officer observed a potential weight violation. So, the percentage of trucks violating the weight law among all the trucks weighed by the TxDPS is expected to be higher than the percentage of violators among all trucks.

    ii. It may unclear from the data if an axle is liftable or not. The database contains the number of axles, spacing between axles, and tire types (single/dual) of the weighed truck. However, there is no direct information indicating whether an axle is liftable. The researchers used engineering judgment when reviewing TxDPS data specifically in relation to the number of tires on an axle(s) in relation to axles on either side. Thus, the TxDPS notation: X-X-O-O indicates a steer axle with single tires, the 2nd axle with single tires followed by two axles with dual tires. This arrangement is consistent with an SU4. Similar logic was applied to other configurations to filter out the weight enforcement records associated with SHVs.

As a consequence of the TxDPS data limitations, the results obtained by analyzing the weight enforcement data was further checked against other data sources, and validated against field data collected by the research team. Field data collection took place between January and August 2016.

8.2.1 Evaluation of Lift Axle Load Limits

Lift axles allow SHVs to carry greater cargo weights while remaining in compliance with the FBF. In addition, booster axles that extend behind an SHV to extend the outer bridge length also carry part of the total vehicle weight and may help reduce bridge stresses. However, lift axles should not be overloaded or under-loaded due to faulty load/pressure settings, mechanical malfunctions, lack of proper maintenance, or overloading of the vehicle.

Overloaded lift axles are defined by state laws as axle weights that exceed the allowable tire design load, printed on the side of the tire by the tire manufacturer. Under-loaded lift axles are defined as axles that have been improperly deployed or adjusted such that other liftable or fixed axles are overloaded above allowable weight limits.

Currently, Texas State laws do not specifically state the maximum allowable lift axle load whether in the pusher, tag, or booster position. The AASHTO Manual on Bridge Evaluation SHV load diagrams show pusher or tag axle loads at eight kips (8,000 lbs) and a booster axle load at 12 kips or 12,000 lbs. Figure 8.2 provides the SHV notional rating load and Figure 8.3 illustrates an SU4 with booster axle.

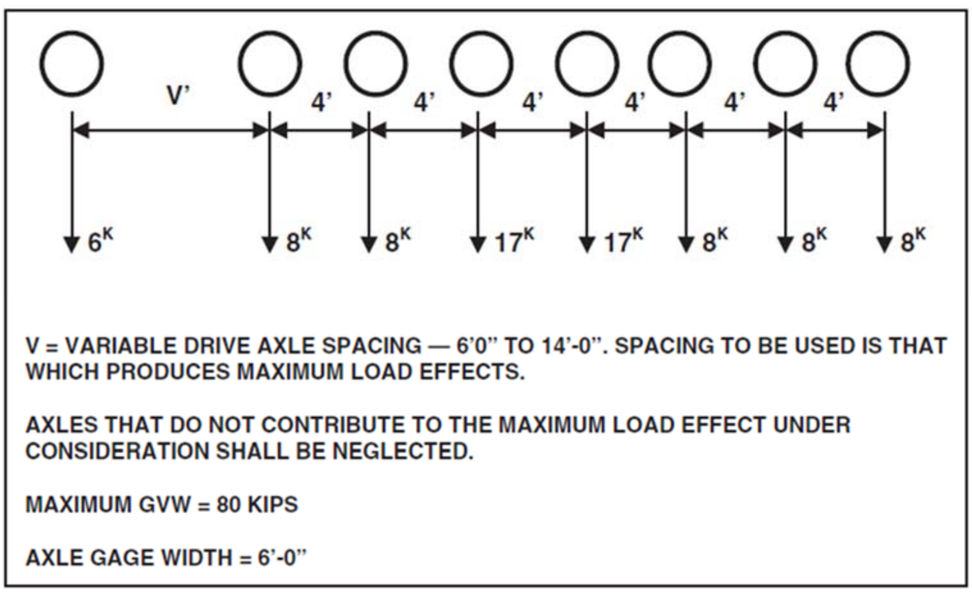


Figure 8.2: AASHTO notional rating load

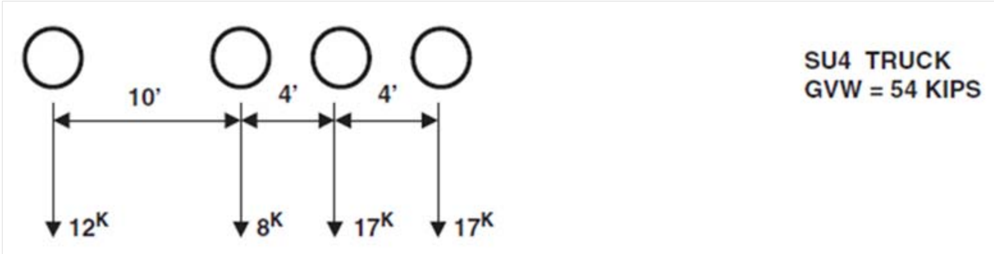


Figure 8.3: AASHTO SU4 rating for SHV with booster axle (12 kips, spaced 10 ft from the last axle)

The logic of an eight-kip pusher or tag axle load relates to axle group loads included in the AASHTO Bridge Formula, as shown in Figure 8.4.

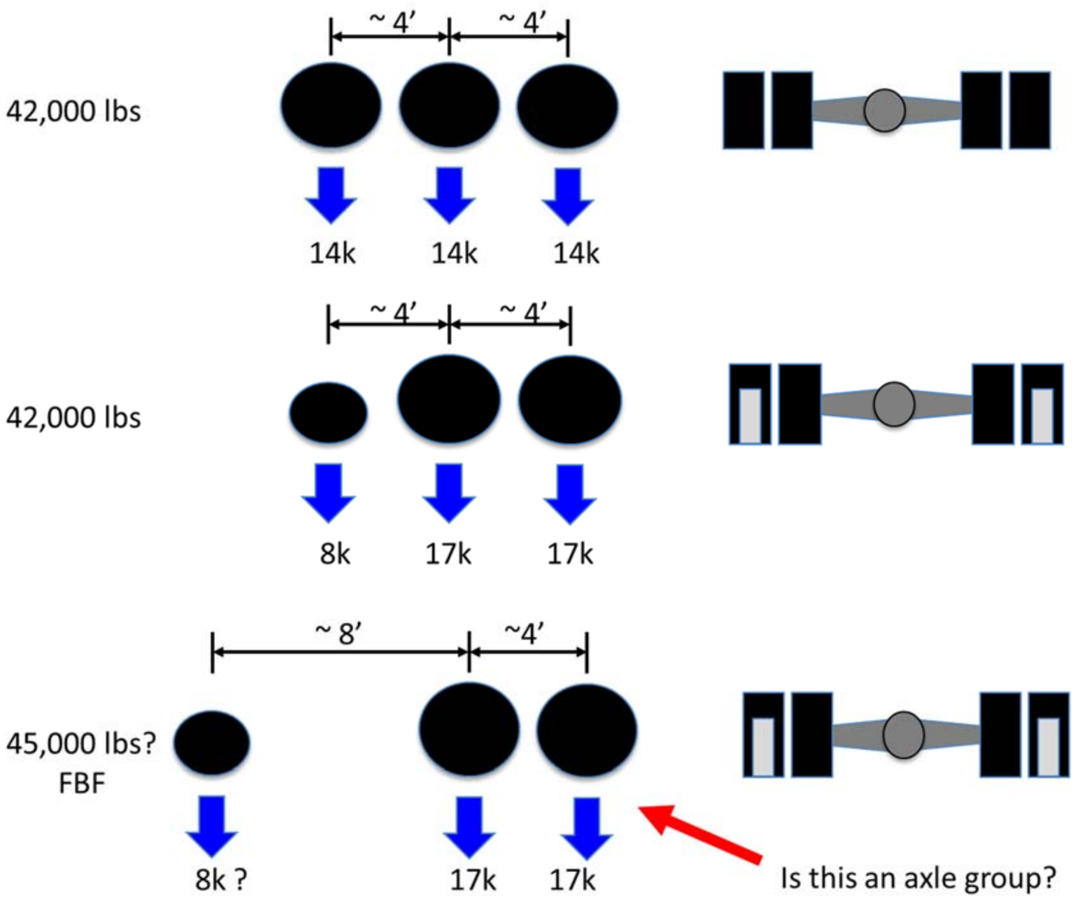


Figure 8.4: SHV tridem axle load of 42,000 lbs with two fixed axles and one liftable axle

As can be seen, adding a lift axle in either the pusher or tag position in relation to a drive tandem axle results in a closely spaced set of three axles. This configuration, according to the FBF, has a maximum allowable weight of 42,000 lbs with an outer bridge spacing of 8 feet. Thus, when adding the lift axle to a 34,000 lb tandem drive axle, the maximum allowable lift axle weight will be 8,000 lbs.

However, it might be argued by the SHV operator that the load distribution among these three axles cannot be this closely controlled, thus specifying a maximum allowable 8,000 lb liftable axle load limit may not be achievable. In addition, the bottom figure shows that the FBF chart allows higher tridem axle group loads if the outer bridge of the group exceeds 8 ft. In the case the allowable load is 45,000 lbs, which would either require the tandem axles to carry 18,500 lbs each and the lift axle 8,000 lbs; or the tandem axles 17,000 lbs each and the lift axle 11,000 lbs; or some variation of these amounts within the tire load capacities.

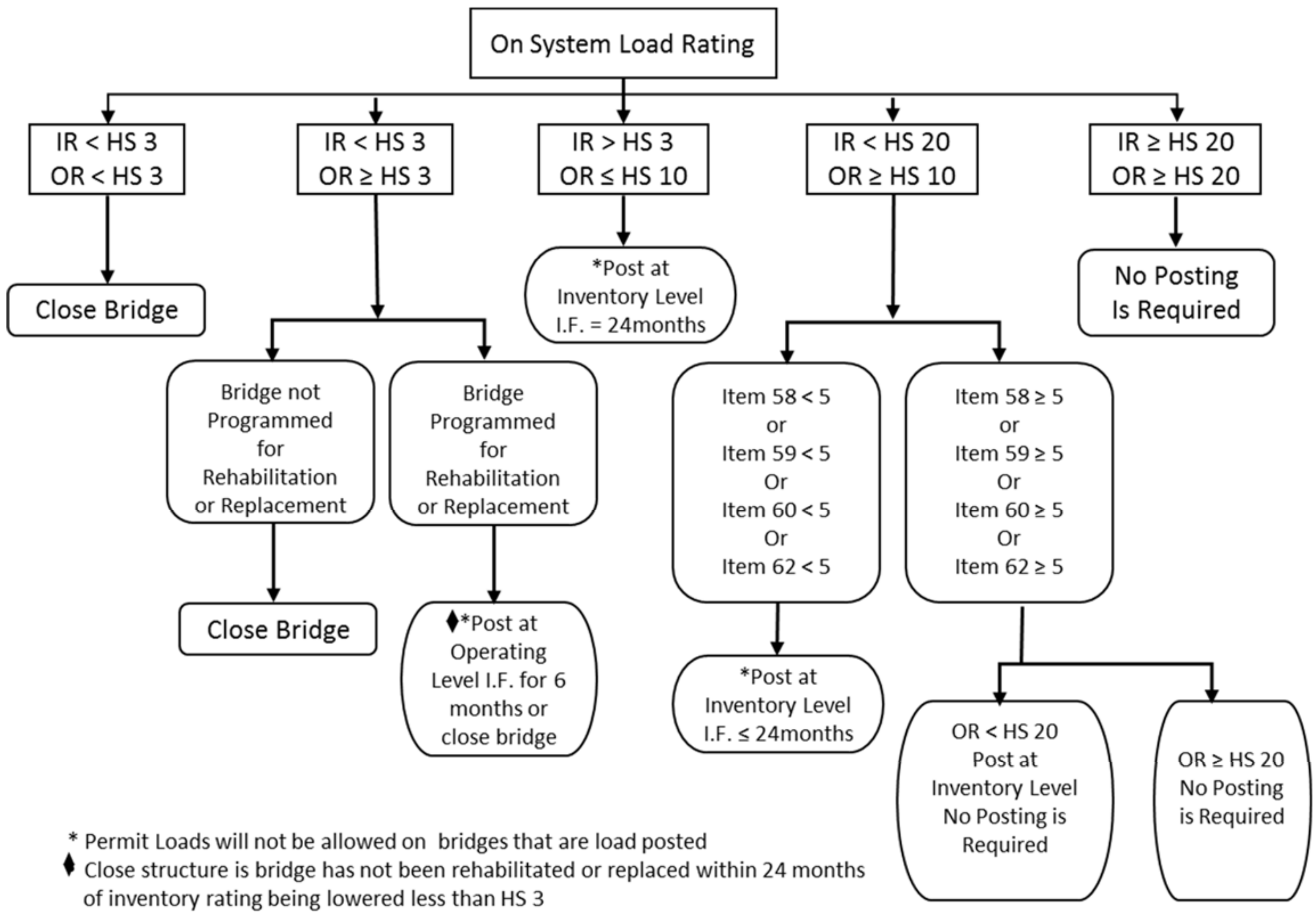
An additional consideration is that the tire designs for pusher lift axles vary substantially, as our field data indicates. The tire width, tire pressure, and allowable tire load varied significantly among SHV dump trucks, which could result in different allowable load limits and pavement consumption rates depending on individual SHV equipment. It was found that owner-operator SHVs tended to have the widest variation in tire size, pressure, load limit, and axle placement compared to fleet-operated trucks. Fleet-operated SU5, SU6, and SU7 dump trucks and SU5 ready-mix trucks tend to have low-profile trailer tires fitted in the pusher position, which have a smaller tire foot print than the drive axles.

The information collected during this study is sufficient to meet the FHWA requirements discussed in their November 2013 memo regarding bridge load ratings. However, more research is needed to evaluate the effects on pavement and/or bridge consumption of different liftable axle loads; different lift axle spacing in relation to the drive axles; and different tire sizes, pressures, and tire foot print areas.

8.3 TxDOT Bridge Posting Procedures

Load posting may be required for structures that because of original design or condition do not have structural capacity to safely carry state authorized legal loads. According to TxDOT's Bridge Inspection Manual:

> Posting is usually necessary for bridges designed at a time when the design truck for the particular stretch of roadway was only H-10 or H-15, meaning gross truck loads of 20,000 or 30,000 lbs. Structures may be posted at Operating Rating levels provided that the condition ratings exceed those defined in the On-system load posting rating process [Figure 8.5] and the process for off-system load posting guidelines [Figure 8.6] and other requirements are met (TxDOT, 2013-1).



* Permit Loads will not be allowed on bridges that are load posted

⧫ Close structure is bridge has not been rehabilitated or replaced within 24 months of inventory rating being lowered less than HS 3

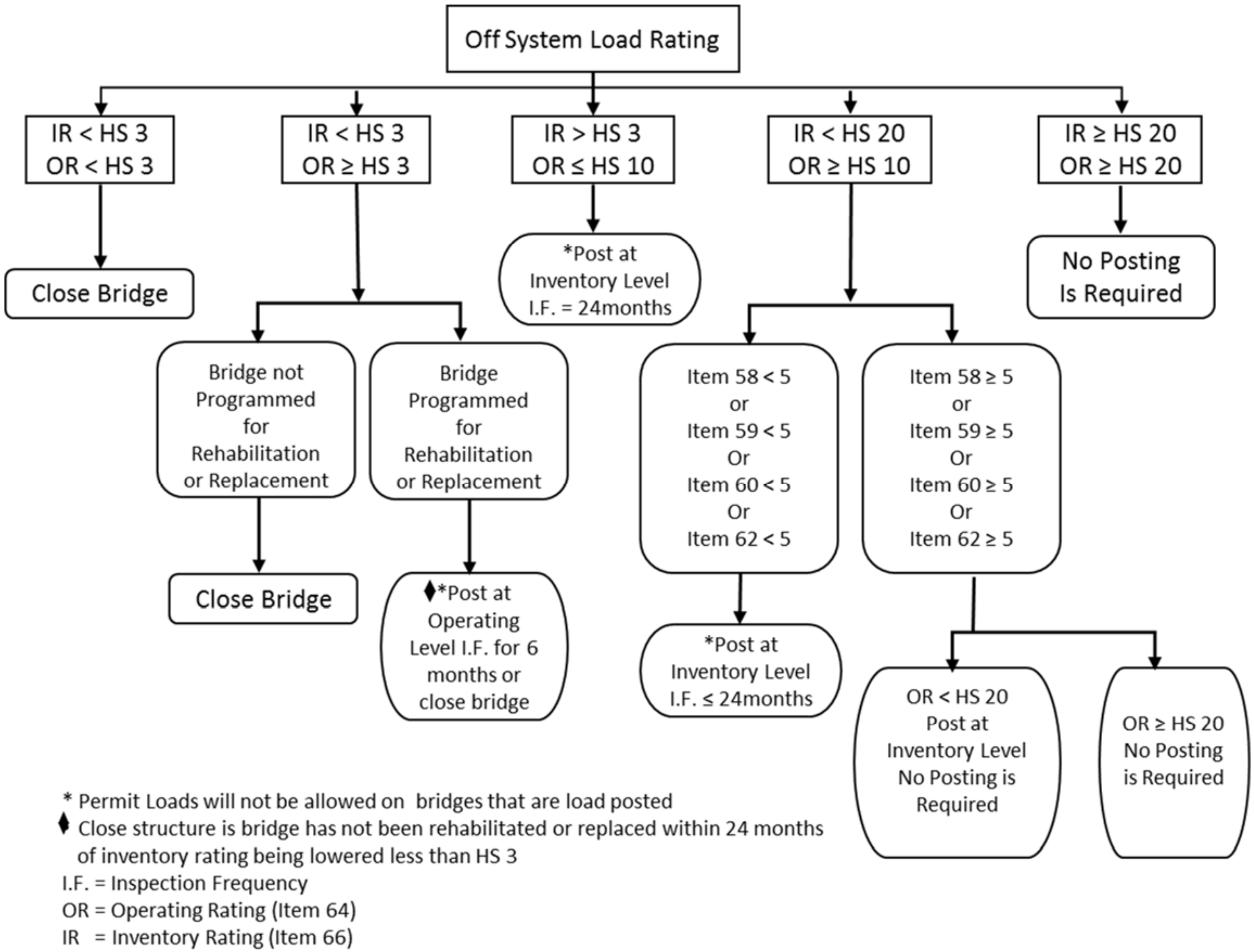
I.F. = Inspection Frequency

OR = Operating Rating (Item 64)

IR = Inventory Rating (Item 66)

Source: TxDOT Bridge Inspection Manual (2013)

Figure 8.5: On-system load posting procedure



Source: TxDOT Bridge Inspection Manual (2013)

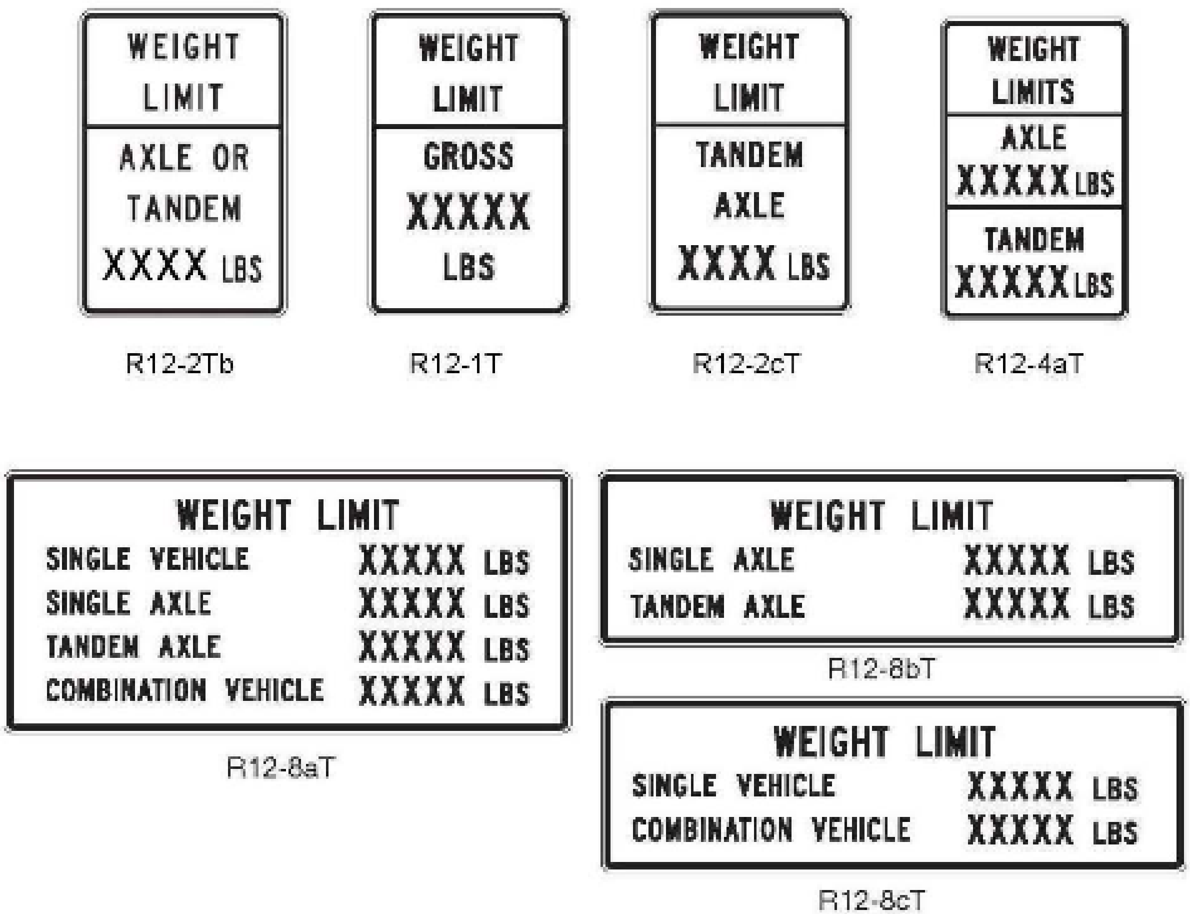
Figure 8.6: Off-system load posting procedure

A load posting of a given truck size allows two trucks of the posted capacity to safely pass on a bridge. The manual notes, however, that some bridges (particularly off-system ones) may be load posted assuming only one truck. This usually occurs due to either the volume of traffic, the structure or approach width, striping, or runners, which make the bridge functionally a one-lane bridge for trucks.

A revised posting after bridge inspection is due 90 days after the change in system for on-system bridges and 180 days for off-system bridges.

8.3.2 Current Load Posting Signage

Figure 8.7 provides current load posting signage found in the Bridge Inspection Manual.



Source: TxDOT Bridge Inspection Manual (2013)

Figure 8.7: Load posting: typical signs

8.3.3 County Bridge Posting Rules

Counties can establish load limits for a country road or bridge with the concurrence of TxDOT, under statutory authority given by Senate Bill 220 of the 77th Legislature in 2001 that amended Transportation Code at Section 621.301.

If a county determines a load limit that differs from the load determined by TxDOT inspection, then it can submit a new proposed limit to the district engineer. The request must be accompanied by supporting documentation that includes at a minimum calculations supporting the proposed limit and a structural evaluation report documenting the condition of the bridge. An engineer must seal the documentation. The district engineer will give a concurrence to a county's proposal in writing. If TxDOT does not denote concurrence or non-concurrence in writing within 30 calendar days of receipt by TxDOT of a request (with all required documentation), the proposed load limit must be deemed to be concurred by TxDOT. TxDOT may review load limits and withdraw its concurrence at any time through written notice to the county. A county may appeal the decision of the district engineer by submitting a written request along with the required documentation to the executive director. The executive director will review the request and determine if department concurrence will be granted. The executive director's decision is final.

TxDOT will then supply the recommended load posting information to affected municipalities and counties along with posting signs and placement hardware. TxDOT will also send a list of off-system bridges recommended by certified mail to owners of bridges, and after installation, the letter of compliance must be sent back to TxDOT by the local jurisdiction.

8.4 Bridge Posting Signage

8.4.1 MUTCD

The MUTCD defines standards to be used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and public roads that are open to public travel. The MUTCD is published by the FHWA under 23 Code of Federal Regulations Part 655 SubPart F. The most current edition of MUTCD is dated May 2012 (FHWA, MUTCD webpage).

Signage for SU trucks is found at Part 6, Temporary Traffic Control, at Section 6F.10, Weight Limit Signs. As Figure 8.8 shows, there are three signs (R12-1, R12-2, and R12-5) for weight limits that show the gross weight or axle weight permitted. These are to be consistent with state or local regulations and shall not be installed without the approval of the authority having jurisdiction. When weight restrictions are imposed, a marked detour shall be provided for vehicles weighing more than the posted limit (MUTCD, 2012).

Source: MUTCD, 2009 Edition

Figure 8.8: MUTCD weight limit signs

8.4.2 Other States

While all states are required to comply with the FHWA's 2013 memorandum entitled "Load Rating of Specialized Hauling Vehicles," a literature search has revealed only one publically available report on load posting for SHVs, published by the Oregon DOT (ODOT). This section also discusses a report commissioned for the Ohio DOT.

Oregon

ODOT has developed new bridge posting requirements for SHVs. In a PowerPoint briefing, it was noted that Group 1 bridges (defined in the FHWA memo as bridges with the shortest span not greater than 200 feet) are to be re-rated for SHV loadings by December 2017. Oregon has 986 bridges that have been evaluated, comprising 178 bridges on the state highway system and 808 on the city and county system (ODOT, 2014).

ODOT (2016) provided an example of a regular weight sign (Figure 8.9) and an additional axle limit sign (Figure 8.10).

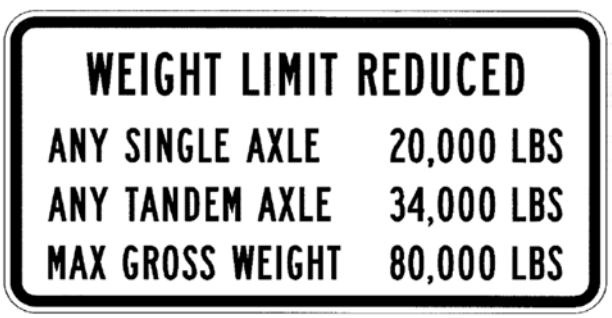


Figure 8.9: Regular weight sign

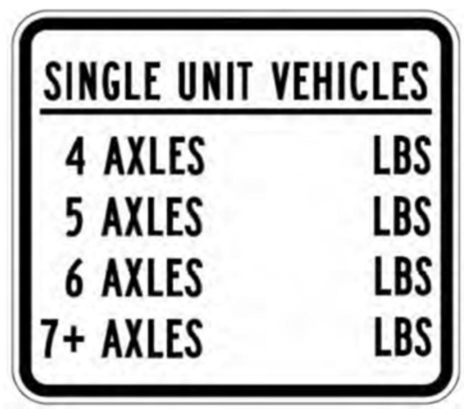
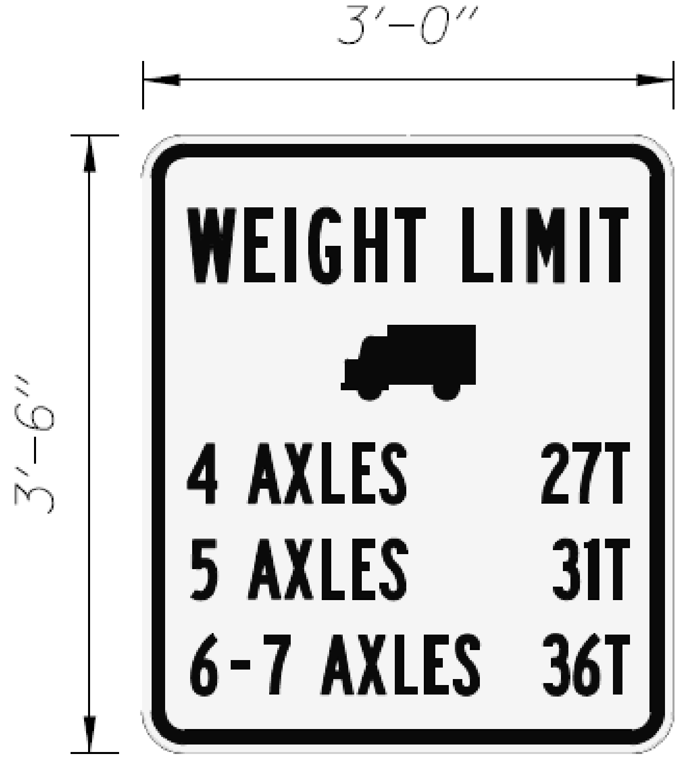


Figure 8.10: Additional axle limit sign

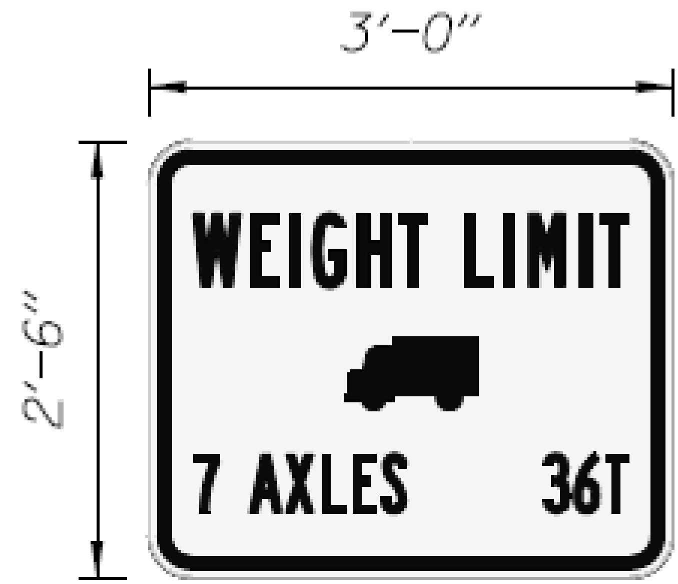
In another PowerPoint that was developed in 2016 (ODOT, 2016), ODOT noted that they had created a map of bridges to be evaluated by December 2017, available through ODOT's GIS website at https://gis.odot.state.or.us/transgis.

Here a new set of signs was showcased (Figure 8.11 and 8.12), with details on height of signs.



Source: ODOT, 2016

Figure 8.11: ODOT signage for weight limit reduced for SHVs only

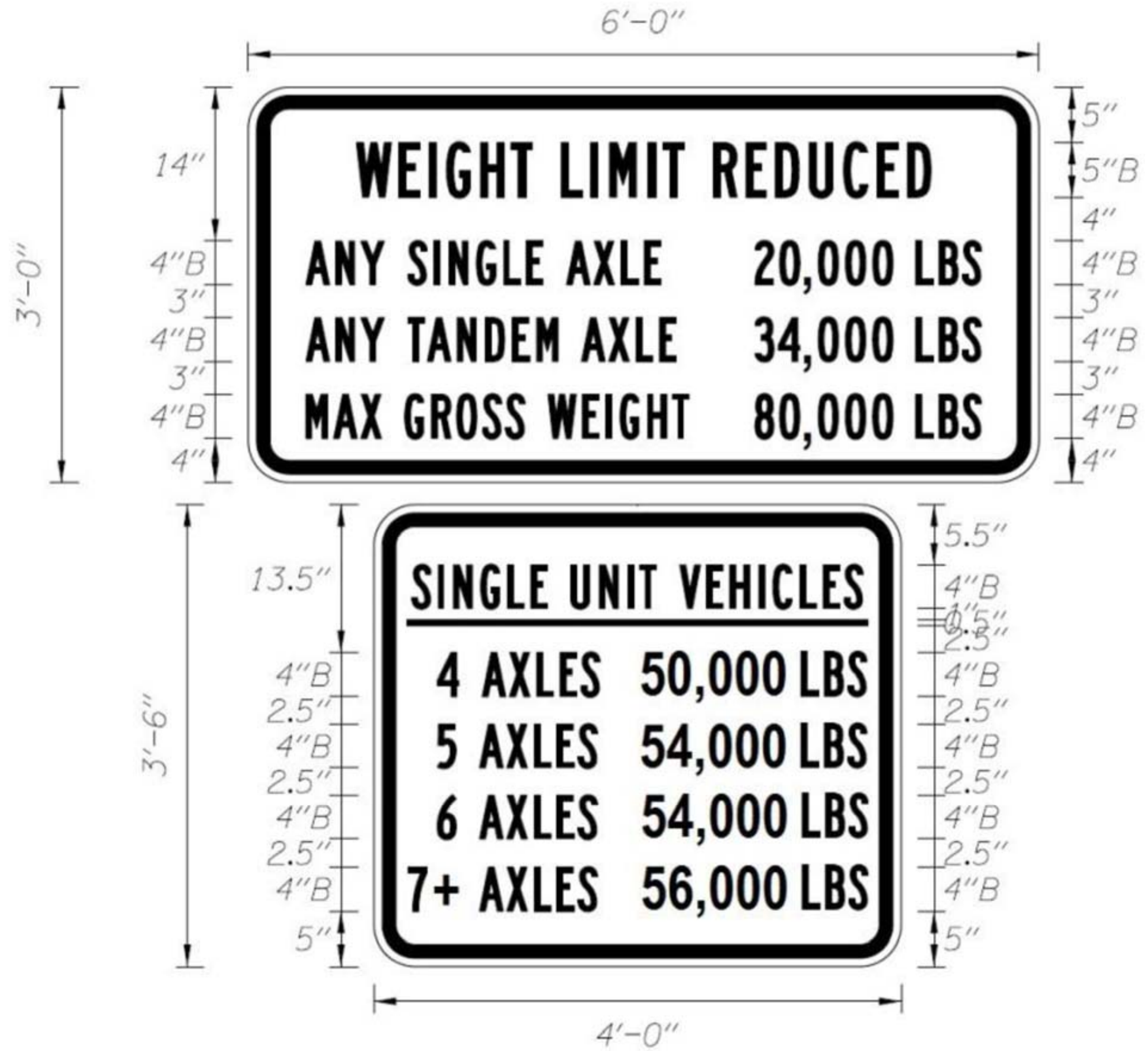


Source: ODOT, 2016

Figure 8.12: ODOT signage for weight limit reduced for SHVs only

Another, undated PDF was found on the topic of new posting requirements for SHVs (ODOT, n.d.); the file depicts three different types of new signage details.

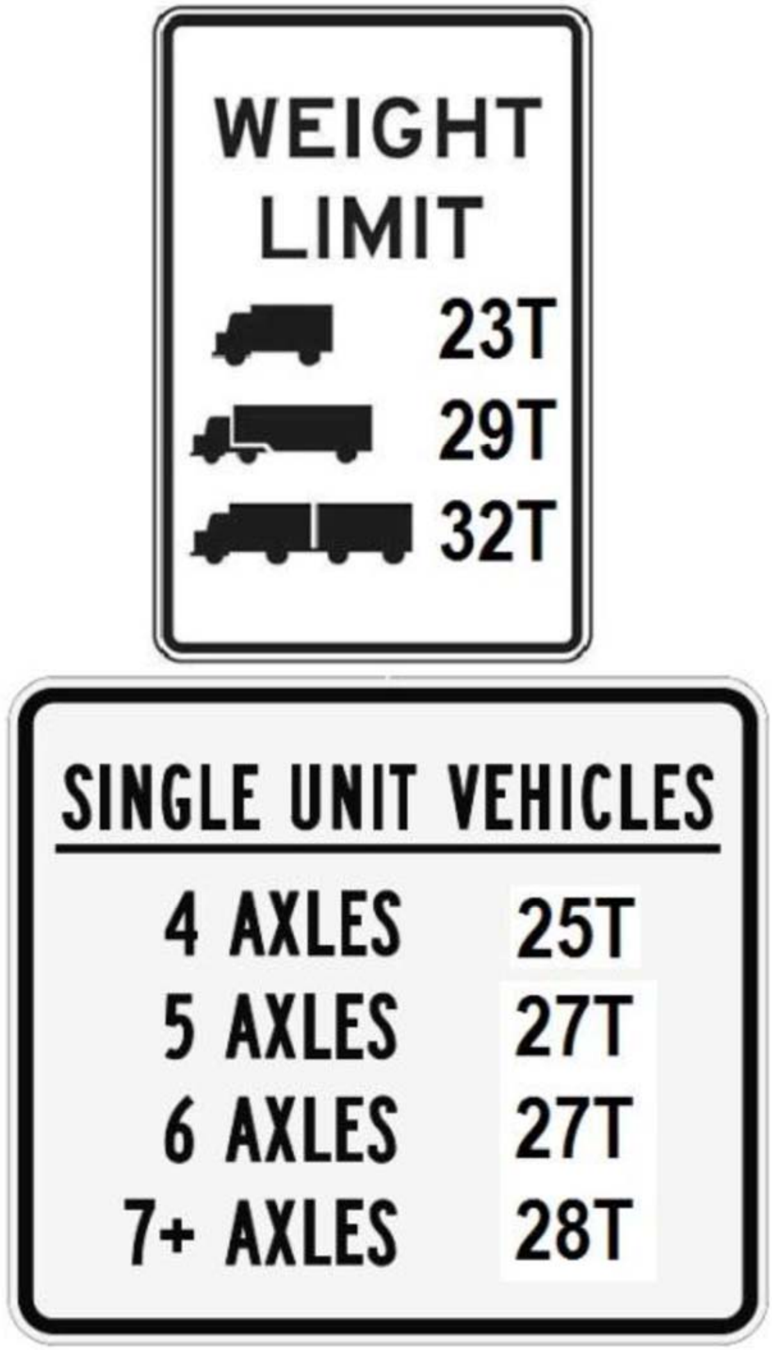
The first posting sign (Figure 8.13) is to be used as a rider (a supplemental sign) below posting sign for legal limits, where there is a possibility that a bridge has sufficient capacity for legal axle weights and for routine commercial traffic (80,000 lbs GVW), but does not have sufficient capacity for different SHV configurations. ODOT notes that "instead of penalizing all trucks from using the bridge, the following posting sign was developed to restrict SU vehicles to a lower GVW. The posted weight for each SU vehicle will be determined on a case-by-case basis for the safe load capacity of the bridge" (ODOT, n.d.).



Source: ODOT, not dated

Figure 8.13: ODOT signage for rider for bridges with capacity for legal weights at 80,000 lbs

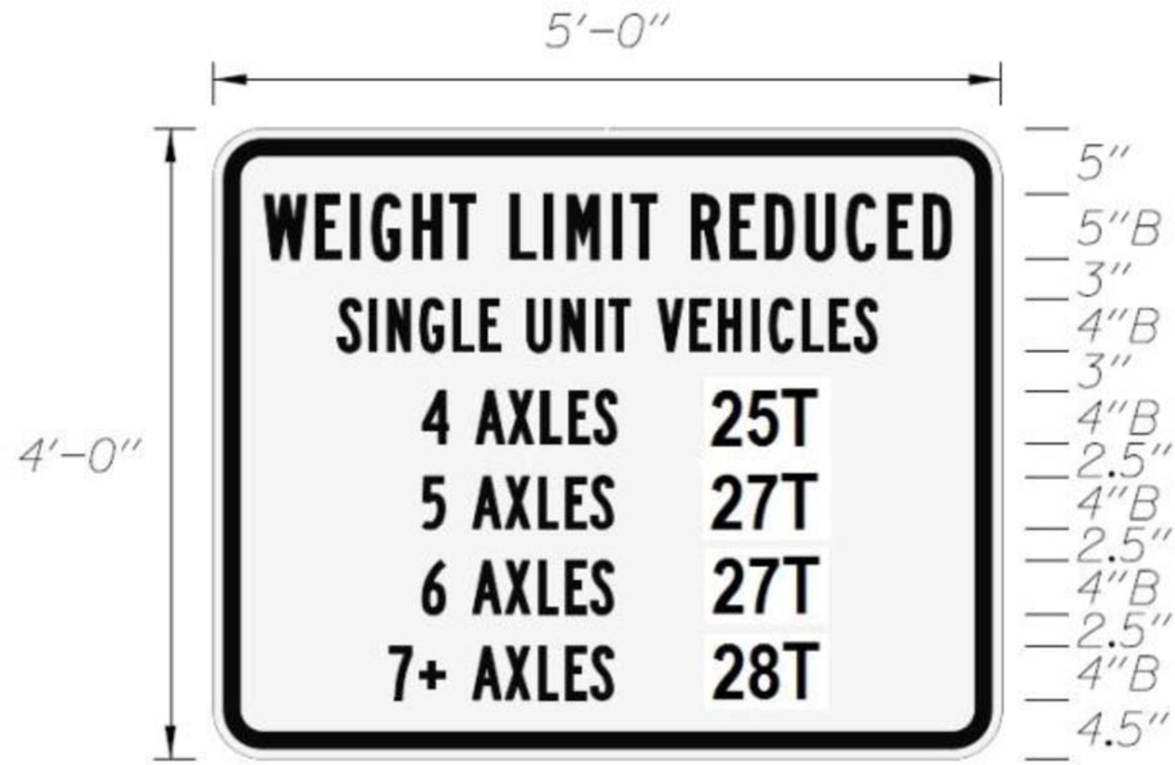
The second posting sign (Figure 8.14) is to be used as a rider below a three-vehicle combination sign where routine and SHV vehicles require posting.



Source: ODOT, not dated

Figure 8.14: ODOT signage for rider below three-vehicle combination sign for routine and SHV traffic

The third posting sign (Figure 8.15) is for SHVs and is intended to be used without any other posting signs when a bridge has sufficient capacity for routine traffic but doesn't have capacity for various SHV configurations.

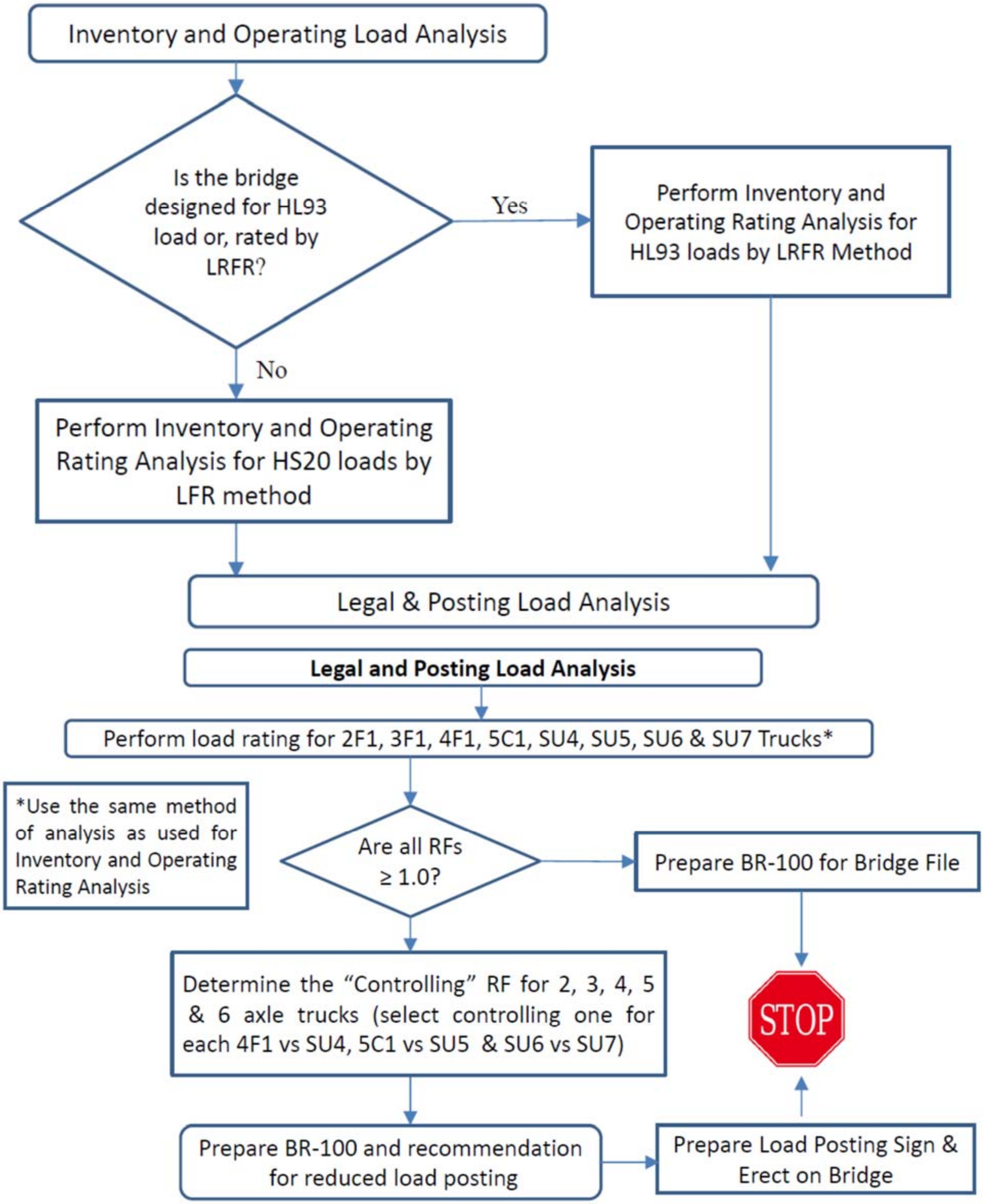


Source: ODOT, not dated

Figure 8.15: ODOT signage for SHV traffic

Ohio

A report developed for the Ohio DOT in October 2016 (Ahmad, et al., 2016) proposed assessing bridges with an Ohio legal rating factor (RF) greater than 1.35 to meet SHV requirements. That research team postulated that any bridge with a current RF ≥ 1.35 based on Ohio's legal loads will not need posting. To arrive at this calculation, they reviewed a statistically valid sample of the Group 'A' bridges for SHV loads, to show the RF ≥ 1.0 at a reasonable confidence level. This approach, they noted, would save the Ohio DOT money compared to performing an analysis of the complete inventory. That research project's load rating flowchart is provided in Figure 8.16.



Source: Ahmad, et al., 2016

Figure 8.16: Load rating flowchart

As of the time of this report, the Ohio DOT had analyzed 200 bridges with a variety of bridge types, spans, and skews. They did not include less common bridge types, e.g., cable stayed, suspension, and arch bridges. Ohio DOT provided their existing Bridge Analysis and Rating System and bridge rating software files to the Ahmad research team. Bridges were load rated using AASHTOWare bridge rating software version 6.8. Table 8.4 shows the status of their analysis as of October 2016.

Table 8.4: Status of bridge analyzed

Bridge Type	Structural Type Code	No. Obtained	Analyzed	Checked	Passing	Pass Percentage (%)
Concrete Slab Bridge- Simple	111	24	14	14	14	100
Concrete Slab Bridge- Continuous	112	39	1	1	1	100
Concrete Beam- Simple	121	1	0	N/A	N/A	N/A
Prestressed Concrete Beam- Simple	221	1	1	1	1	100
Prestressed Concrete Beam- Continuous	222	2	1	1	1	100
Prestressed Concrete Box Beam- Simple	231	1	1	1	1	100
Prestressed Concrete Box Beam- Continuous	232	1	0	N/A	N/A	N/A
Steel Beam- Continuous	322	46	2	2	2	100
Total		117	20	20	20	100

Source: Ahmad, et al., 2016

8.5 Policy Recommendations for SHVs, including Signage for Load Posting

Based upon the research team's analysis and findings, this section outlines our key recommendations broken out by subject matter. The research team is cognizant that not all of these recommendations are directly pertinent to TxDOT's operations, and the responses to the FHWA regarding load posting analysis must be delivered by December 2017. However, the research team considers that the following recommendations are instructive in providing TxDOT with a state of current activities and potential challenges.

8.5.1 Recommendations regarding SHV Vehicle Registration Data

1. Require the total number of axles and whether an axle is liftable to be noted in vehicle memorialization (TxDMV registration data).

a. This will assist TxDOT and TxDMV in determining the numbers and types of SHVs operating in the Texas truck fleet for analysis purposes. For example, it will be much easier to respond to FHWA requirements regarding future analysis of SHVs and bridge load ratings.

b. If truck axle number and types are not included in registration data, TxDOT may need to periodically update field data collection of these vehicles including vehicle type, configuration, number of axles, axle spacing, and weights to ensure bridge load postings address deployment of these vehicles.

8.5.2 Recommendations regarding Placement of Lift Axle Controls

We have two recommendations, one for each component of the control system. (The first system controls the pressure of the air bag suspension that is attached to the axle; this control is calibrated by shop personnel to result in a given amount of load. The second system is operated by the driver and simply lowers or lifts the axle by deflating or pressurizing the air bag suspension.)

a. Establish policies that require the controls used to adjust the axle load (through air bag suspension pressure levels or mechanical means) to be placed outside the truck cab and/or out of the driver's reach.

b. Establish policies that allow the controls that lift or lower axles to be placed in the cab within the driver's reach, so that axles can be lifted when entering a construction zone or unloading area and lowered when leaving the loading area and driving onto the public road system.

8.5.3 Recommendations regarding Mechanical Functionality and Condition of Lift Axles

The following recommendations are presented as draft legislation; many of these recommendations were identified from legislation or policy that has been implemented by other states to address proper use and maintenance of lift axles.

a. Lift axles with single tires in the pusher, tag or booster position shall be caster steered in order to track the turning movement of the SHV

b. Lift axles with dual tires are not required to be caster steered, though drivers are required to exercise precautions during turning movements to ensure the pavement surface is not damaged

c. Lift axles shall be maintained in good working condition to ensure the caster steering mechanism performs as designed to track the turning movement of the vehicle

d. Lift axles that are retrofitted to a long-haul truck tractor that has been modified to operate as a vocational (work) type truck such as a dump or ready-mix truck, shall be installed to minimize mounting bracket cracking or breaking due to improper load distribution and vehicle torsional effects

e. Lift axle pressure mechanisms shall be properly adjusted to ensure that the lift axle load amount is in compliance with the FBF and the tire ratings of the tires mounted to the lift axle

f. Lift axle lifting mechanisms shall be properly maintained to ensure that the axle is fully retracted or extended to the pressure setting required to comply with the FBF

g. Lift axle tie rods, joints, brakes, king pin and other components that make up the lift axle mechanism shall be properly maintained

h. If, during a law enforcement officer inspection, a lift axle is found to have broken components, is improperly adjusted, is not fully retracted or is found to be over loaded, the officer shall direct the driver to have the SHV towed to a maintenance facility where the SHV shall be out of service until proper repairs are made

8.5.4 Recommendations regarding Signage

a. As of the time of drafting, the only signage developed for SHVs that was publically available is signage developed by ODOT (as described in Section 8.4). Therefore, the research team makes no specific recommendations on signage. Given the sheer volume of bridges that may need posting within Texas, TxDOT should review Oregon's proposed signage along with any internal working data from AASHTO on bridge signage that may be underway, and determine the types of signage that will be feasible for the Texas network.

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Chapter 9. Report Summary and Findings

9.1 Background

Project 0-6897 was initiated in response to the FHWA Memo entitled "Load Rating of Specialized Hauling Vehicles" dated November 13, 2015. The FHWA required the state DOTs to respond that either:

1. Their state does not permit the operation of SHVs, or
2. Their state has conducted a bridge load rating analysis using the AASHTO Manual for Bridge Evaluation (MBE). This manual contains SHV design vehicles representing an SHV notional rating load as well as the SU4 through SU7 vehicle configurations.

If the AASHTO MBE bridge load-rating vehicles do not represent the SHV configurations permitted to operate in a state, the state must conduct bridge load-rating analyses using a design vehicle configuration that represents these SHVs. The memo further requires that two groups of bridges are evaluated by specified deadlines:

(a) Group A: bridges on which the longest span is less than 200 ft. These bridges must be analyzed for load ratings using SHV load rating configurations and the results provided to the FHWA no later than December 31, 2017.

(b) Group B: bridges not included in Group A. These must be evaluated by December 21, 2022.

In order to comply with these requirements, the research team developed the following goals and objectives for project 0-6897:

- Task 1. Conduct a literature review of SHV regulations, configurations, and operations in other states, Canada, and Mexico.
- Task 2. Prepare an estimate of the number of SHVs operating in Texas, including rural and urban locations and roadway route types.
- Task 3. Identify SHV configurations used in Texas including GVW, number of axles, axle loads, axle types (fixed or liftable), and axle spacing.
- Task 4. Conduct an SHV consumption impact analysis for pavements in Texas compared to a baseline three-axle truck configuration.
- Task 5. Conduct an SHV consumption and load posting impact analysis for bridges in Texas for both on- and off-system.
- Task 6. Conduct a safety analysis of SHV operations to determine factors that can increase crash risk.
- Task 7. Conduct an economic analysis of SHV operations to determine why SHVs are operated by certain companies, but not by others.
- Task 8. Evaluate data obtained in Tasks 1 through 7, and develop policy recommendations regarding SHV operations in Texas.

9.2 Major Findings

The following summary discusses the major project findings. Recommendations are provided if appropriate and additional information is presented to clarify certain points.

9.2.1 Chapter 1: Literature Review

A review of state laws and various surveys found that 25 states have enacted legislation or policies specifically addressing SHVs or lift axles, while 25 states, including Texas, have no laws regarding SHVs or liftable axles. Table 9.1 summarizes the laws that have been enacted.

As can be seen, eleven states have enacted laws that regulate placement of the lift axle or the axle pressure setting controls such that the driver cannot change the pressure settings while the truck is in motion. Seven states require that the lift axles are down at all times; this would of course apply when the truck is loaded such that not lowering the axle would result in overloading of the fixed axles. Six states require that the lift axle loads must provide for 'reasonable' load distribution; three states—including Alaska, Nebraska, and Wyoming—specify the minimum lift axle load (AL 6,000 lbs.; NE 8% of GVW or 8,000 lbs whichever is the least; WY 8% of GVW). Four states allow lift axles to be lifted during turning movements and three states require lift axles to be steerable, though it is understood that lift axles with dual tires are generally not steerable. Table 9.1 also identifies rules or code unique to a particular state and related to lift axle inspection procedures or the requirement that a lift axle group must have a pressure equalization valve. This information will be used in conjunction with the research team's findings when making recommendations about possible policy or legislation regarding SHVs and lift axles in Texas.

Regarding lift axle minimum load limits based on percentage of the GVW or specified lift axle weights, actual TxDPS truck weight data for all operational types indicates that SU4 lift axle loads vary from 9.4% to 14% of the GVW. SU5 lift axle loads for all operational types vary from approximately 8.5% to 12.8% of GVW; SU6 dump truck lift axle loads vary from 8% to 10.2% of GVW and SU7 pusher lift axles are variable depending on axle position based on TxDPS weight and range from 6% to 8% with the booster axle consistent at approximately 15% of GVW. SU7 WIM data pusher lift axle weight is approximately 8% of GVW and booster axle weight approximately 12.6% of GVW. Thus, specifying a single percentage of GVW or a minimum axle weight as the minimum lift axle load limit would not reflect SHV operations in Texas.

Mexico has no laws governing the use of lift axles. Canadian provinces have laws governing use of lift axles that are directed primarily to their use on tractor-trailer units. Most provinces have similar laws to US states that govern placement of the lift axle pressure control and the lift axle lift controls. Table 2.15 in Chapter 2 provides detailed information about Canadian practices regarding lift axles.

The most comprehensive single study regarding SHV operations and lift axles to date is the NCHRP 575 report *Legal Truck Loads and AASHTO Legal Loads for Posting*. The report was published in 2007 and resulted in recommendations about SHV truck load configurations that were adopted in the AASHTO Manual on Bridge Evaluation. The research team thinks that as State DOTs address the FHWA requirement to evaluate SHVs and bridge load postings, several new publications will be made available that will update and augment the NCHRP 575 study.

Table 9.1: State laws that address SHVs and/or lift axles

State	Specific Truck Types Named regarding lift axles	Pressure Controls outside cab	Lift Controls inside Cab	Lift axles must be steerable (*unless axle has 4 tires)	Specifies which Axles may be liftable	All liftable axles down at all times when truck is over legal weight limit	Lift axles must provide resonable load distribution	Lift axles in a group must have a shared, pressure equalization valve	Minimum Lift axle load	Axles may be lifted when turning	Inspection Procedures for Lift Axles	Trucks with Lift axles banned from traveling over certain bridges	Lift axle may be lifted if deployment results in illegal inner bridge
Alaska	Ready Mix	Yes	Yes			Yes			6,000 lbs				
Idaho						Yes							
Illinois											Yes		
Iowa										Yes			
Kentucky													
Louisiana		Yes	Yes				Yes						
Maine					Yes	Yes							
Maryland		Yes	Yes, all axles either up or down						Yes, rules determine load in relation to GVW	Yes			
Minnesota	All axles either up or down' rule does not apply to Garbage trucks or farm trucks	Yes	Yes, all axles either up or down										
Montana							Yes, if GVW exceeds legal limits						
Nebraska									8% of GVW or 8,000 lbs whichever is least				
New Hampshire					Yes, references SU4 only								
New York		Yes		Yes									
North Dakota		Yes, if there is more than 1 lift axle	Yes										
Ohio						Yes		Yes					
Oregon		Yes	Yes			Yes	Yes						
Pennsylvania						Yes				Yes			
Rhode Island												Yes	
South Carolina							Yes						
South Dakota		Yes	Yes			Yes				Yes, by Permit			
Utah		Yes	Yes	Yes			Yes, all axles must be within legal limits						
Vermont											Yes		
Washington		Yes	Yes	*Yes									
Wisconsin		Yes	Yes										
Wyoming							Yes		8% of GVW				Yes

9.2.2 Chapters 2 and 3: Field Data Collection and Analysis

Data for 53,519 trucks was collected in the field statewide to document truck type, configuration, numbers and types of axles, route, and other information necessary to determine the number of SHVs for each truck type observed. The field data collection effort included point counts at urban and rural locations, route counts during trips along routes connecting metropolitan areas, and analysis of 24-hour classification videos provided by the TP&P Division.

Based on this data, the researchers found that dump, ready-mix, and waste management vehicles comprise the greatest numbers of SHVs operating in Texas. Using the field data (which included a statistically valid sample of truck types to allow an estimation of the number of SHVs operating in Texas for these three truck types), we generated the following estimates.

Dump Trucks

- Total number of registered dump trucks in Texas, per TxDMV registration data = 71,172
- In all, 6,193 dump trucks were counted during route and video data collection, representing approximately 12.2% of all trucks observed. This sample included 4,327 tractor-semi trailer dumps and 1,866 SU dumps, including SHVs. Based on this sample, the researchers estimate that the 71,172 dump trucks in Texas, of all configurations, are distributed as shown in Table 9.2 (95% confidence with 2% error):

Table 9.2: Estimated number of dump trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Five-axle tractor trailer dumps	49,727	69.8%
Three-axle SU dumps	14,871	20.9%
SU4	3,218	4.5%
SU5	1,460	2.1%
SU6	655	0.9%
SU7	1,241	1.7%
Total	71,172	100%

Ready-Mix Trucks

- Total number of registered ready-mix trucks in Texas, per TxDMV registration data = 9,275
- In all, 848 ready-mix trucks were counted, representing approximately 1.6% of all trucks observed. Based on this sample, the researchers estimate that the 9,275 ready-mix trucks in Texas are distributed as shown in Table 9.3 (95% confidence with 4% error):

Table 9.3: Estimated number of ready-mix trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Three-axle SU trucks	8,236	88.8%
SU4	459	4.9%
SU5	558	6.0%
SU6	22	0.02%
SU7	0	0.00%
Total	9,275	100.0%

Waste Management Trucks

- Total number of registered waste management trucks in Texas, per TxDMV registration data = 9,155
- In all, 1,032 waste management trucks were counted, representing approximately 1.9% of all trucks observed. Based on this sample, the researchers estimate that the 9,155 waste management trucks in Texas are distributed as shown in Table 9.4 (95% confidence with 3% error):

Table 9.4: Estimated number of waste management trucks of each configuration (route – network level)

Truck Configuration	Estimated Number of Trucks (Network)	% Total
Three-axle SU trucks	6,301	68.8%
SU3	27	0.03%
SU4	547	5.9%
SU5	7	0.07%
SU6	0	0.0%
SU7	0	0.0%
Five-axle tractor trailer	2,274	24.8%
	9,155	100.0%

* Includes five-axle garbage transfer tractor-trailers, scrap dumps, and heavy roll-off units

Of the 53,519 trucks observed, 971 SHVs were documented, as summarized in Table 9.5.

Table 9.5: Number of SHVs observed by operation type and configuration*

	SHV Operational Type									
SHV Configuration	Dump	Ready Mix	Waste Management	Tank Trucks	Flat Beds	Heavy Wreckers	Box Vans	Truck Cranes	Other Types	Totals
SU-3	0	0	3	0	0	0	5	0	0	8
SU-4	280	104	82	54	51	19	6	5	7	608
SU-5	127	51	1	1	6	0	0	6	0	192
SU-6	57	1	0	0	0	0	0	0	0	58
SU-7	108	0	0	0	0	0	0	0	0	108
Subtotal	572	156	83	55	57	19	11	11	7	971
Percent of Grand Total	58.9%	16.1%	8.5%	5.7%	5.9%	2.0%	1.1%	1.1%	0.7%	100.0%

* Based only on route data collection and 24 hour videos

Note that a very small number of SU3 SHVs were observed—these were not identified as an SHV type in the NCHRP 575 study or the AASHTO MBE SHV configurations. These are essentially three-axle trucks with one liftable axle in the pusher position relative to the drive axle.

9.2.3 Chapters 4 and 5: Pavement and Bridge Consumption Analysis

Pavement and bridge consumption analyses were performed using the most commonly occurring SHV configurations for dump, ready-mix, and waste management trucks. Based on observations during field data collection and evaluations of TxDPS weight enforcement data, the research team notes that many different SHV configurations operate in Texas, although several configurations may be uncommon. CTR investigated many information sources to determine the different SHV configurations operating in Texas and other states, and found that not every SHV configuration known to operate in other state(s) was necessarily observed operating in Texas during field data collection (though this configuration might in fact exist in Texas).

As an example, Figures 9.1 through 9.4 provide examples of common and uncommon SHV SU7 dump truck configurations:

Figure 9.1: SU7 dump with three pusher lift axles with single tires and one booster lift axle (a common configuration; seen in Texas)

Figure 9.2: SU7 dump with four liftable pusher axles (single tires) but no booster axle (an uncommon configuration; seen in Texas)

Figure 9.3: SU7 dump with four liftable pusher axles (single tires), no booster axle, with long outer bridge length (uncommon; seen in Texas)

Figure 9.4: SU7 dump with three liftable pusher axles with single tires and one liftable tag axle with dual tires (operates in Kentucky and possibly other states; not observed in Texas during this study)

The following SHV dump truck configuration (Figure 9.5), named the "Super Niner," was designed by Strong Industries, a major 'super dump' manufacturer located in Houston. Strong Industries also developed the 'strong arm' booster axle commonly seen in Texas. Another booster axle manufacturer is Maxle; their products are less commonly seen in Texas. The Super Niner has four liftable pusher axles with single tires, though the first liftable axle is located directly under the cab and has a different tire size than the remaining three pushers. In addition, a tandem drive axle and a tandem booster axle is fitted to the truck. The booster axle is unusual in that the tandem axle bogie slides out, revealing a cargo compartment. Strong Industries describes this booster axle arrangement as a 'trailer' and compares the Super Niner to an SHV towing a pup trailer. Strong Industries has also designed new configurations for waste management trucks that incorporate a booster axle and advertised higher load limits.

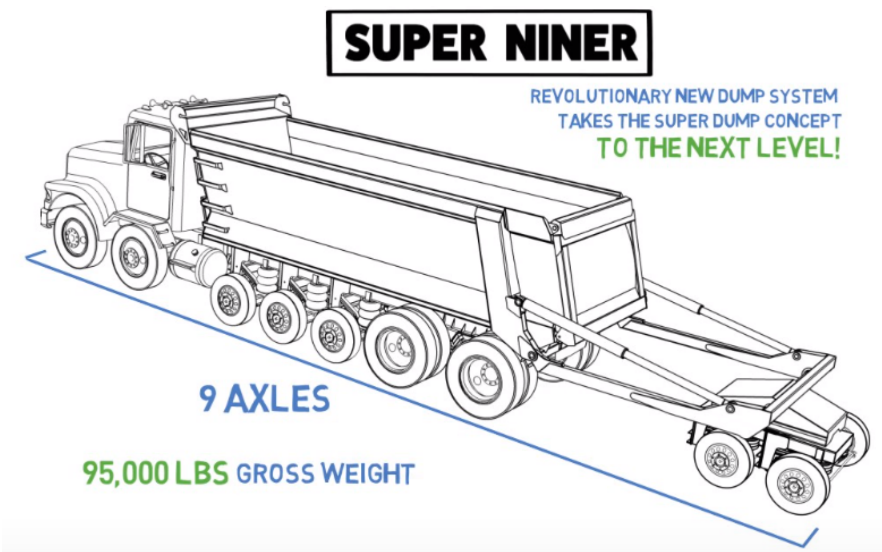


Figure 9.5: "Super Niner" SU9 dump truck designed by Strong Industries (not yet observed in Texas)

Discussions with the Bridge Division revealed that although a county might not have any registered SHVs, bridges requiring load posting based on a project-level analysis may require posting in any case for certain SHV configurations. This raises the question whether a bridge that requires load posting for a configuration not known to operate in Texas would require posting for that configuration, given the possibility that it may operate on Texas roads in the future.

Developing a sign that could possibly address all <u>potential</u> (controlling) configurations for any given truck type could be impractical; thus in Chapter 5, the controlling design vehicle configuration was identified for further consideration by TxDOT's Bridge Division based on SHVs observed during this study. In many (but not all) cases, one of the AASHTO MBE SHV design vehicle configuration controls the bridge stress analysis though further, project-level analysis of a particular bridge is necessary to establish actual load limits.

TxDOT's Bridge Division is in consultation with other DOTs regarding format and uniformity of SHV bridge load posting signs. At the time of this report, the only signage developed for SHVs that was publically available is signage developed by the Oregon DOT (shown in Chapters 5 and 8).

Pavement and Bridge Consumption Analysis and Use of Load Xpert Analysis Software

Based on discussions with various industry representatives and analyses performed using the Load Xpert Analysis software, we've determined that it may not be possible to achieve the allowable legal load limit on every truck axle or to achieve the legal maximum GVW.

For example, consider the case of a ready-mix truck that through state exemption can legally operate with a 23,000 lb steer axle and a 46,000 lb tandem drive axle load for a total GVW of 69,000 lbs. However, given the input from discussions with ready-mix industry representatives and analyses of various ready-mix truck configurations, Load Xpert results indicate that it is not possible to achieve a 23,000 lb steer axle load without exceeding the 46,000 lb allowable tandem drive axle load limit. This means that in actual operations, a three-axle ready-mix truck cannot legally carry 69,000 lbs GVW even though this weight is legal by state exemption. Thus, a permit was developed for ready-mix trucks that allows a 10% tolerance on axle loads as long as the 69,000 lb GVW limit is not exceeded. Based on the permit tolerance, the tandem drive axle can be loaded up to 50,600 lbs, which allows a higher steer axle load and the ability to achieve 69,000 lbs GVW.

Other examples regarding three-axle straight trucks can be shown in which it is not possible to achieve the legal 20,000 lb steer axle load if the 34,000 lb legal drive tandem axle load is maintained. Both TxDPS enforcement data and TxDOT WIM data also show that only in rare cases do truck steer axles approach 20,000 lbs. The 'legal' GVW weight limit can be achieved only if the tandem axles are overloaded in the case of a three-axle truck.

Thus, the consumption analyses considered consumption rates for a base case truck loaded at the legal allowable maximum axle load limits—but the research team noted that this base case truck could not actually (legally) operate on Texas roads. For this reason, different base case trucks for dump, ready-mix, and waste management vehicles were determined considering the legal (but unachievable) loads, and base case vehicles considering the loads that can be actually be carried legally as well as a base case vehicle that operates with a permit (if a permit is available, as is the case for the ready-mix truck). Thus, there are actually four base case vehicles that were analyzed for pavements and can be compared to the various SHV configurations. In addition, the SHV configurations were analyzed based on the observed loads measured by TxDPS weight enforcement officers during roadside stops. In some cases, the vehicle was operating legally, though the weights were recorded in any case and were of use in this study. In addition, the TxDPS data was examined for SHVs with overloaded axles that were nevertheless legal in terms of GVW and SHVs that were overloaded for axles and GVW. Using this method, CTR was able to create a table of weights based on percentiles for each SHV configuration (SU4 through SU7) when applicable. The consumption calculations for these different configurations are given in Chapter 4 (Tables 4.3–4.14) and will not be repeated here.

Due to the additional analyses that would have been required to replicate these same configurations for bridge consumption calculations, the decision was made to use only the base case with achievable (real axle loads) rather than a base case truck with legal, but unachievable, axle loads. This was considered to provide a more realistic comparison of the consumption ratios between the legal three-axle truck and the SHVs based on TxDPS weight data.

The configurations selected for the bridge analysis do correspond to configurations provided in the pavement analysis so that a pavement + bridge = total consumption analysis could be performed for the base case and each SHV configuration based on a statewide analysis. For bridges, additional analyses were performed for selected counties with high bridge density to show the variations in consumption rates between statewide and these, predominately, metropolitan counties. This same approach was employed for the TxDOT State Legislative Affairs Truck

Configuration Library analysis considering that sealed ocean containers primarily operate in Houston, at the Barbours Cut Terminal and in other metro areas such as Dallas, SH 114 near DFW Airport. As discussed in Chapter 3, SHVs typically operate within metro areas or on links between metro areas in cases where material sources or landfills are outside city limits.

Load Posting Configuration or Tonnage for Bridges

Chapter 5, Tables 5.31–5.39, provide the AASHTO MBE SHV load rating vehicle configuration, a TxDPS SHV configuration and load, or a PonTex load configuration that controls for a specified number and percentage of off-system or on-system bridges and will not be repeated here.

An Access database and an ArcGIS map were provided as deliverables, which document the locations of 6,081 off-system and 1,956 on-system bridges that experienced bending moments above operating rating for the configuration types shown in Tables 5.32 through 5.39. Additional information is provided in Chapter 5 regarding possible bridge load posting sign formats as previously discussed.

Table 9.6 presents the results of the pavement consumption analysis presented in Chapter 4 and the bridge consumption analysis presented in Chapter 5. The consumption analysis focused on the three operational types—dump trucks, ready-mix trucks, and garbage trucks—that comprise the majority of SHVs in Texas. The research team recognizes that there are other types of SHVs that operate in Texas, such as SU4 and SU5 flatbed bed construction material transports; fuel, oil, and liquid waste tankers; and other operational types. However, the research team thinks that the three operational types that were analyzed are representative of consumption values for other types of SHVs that operate in smaller numbers.

The research team would like to again point out that an extensive field data collection effort was undertaken to identify the different types and configurations of SHVs operating in Texas. However, this does not mean that every operational type or SHV configuration was in fact observed. In particular, though oil field equipment trucks were observed, including a small number of SHVs, it is expected that the significant reduction in oil field activities over the past 2 years influenced the sample size and configurations observed. When oil field activities resume, in particular fracking operations, TxDOT may want to consider a future study update on SHV operations.

Table 9.6: Pavement & bridge consumption rates for dump, ready-mix, and garbage trucks

Analysis	Configuration	GVW	Pavement $ / VMT	Bridge $ / VMT	Total $ / VMT
Base Case	3-axle	49,390	$0.120	$0.0341	$0.154
Dump 1	SU-4	59,000	$0.160	$0.0565	$0.217
Dump 2	SU-5	67,604	$0.180	$0.0741	$0.254
Dump 3	SU-6	74,580	$0.230	$0.0968	$0.327
Dump 4	SU-7	80,350	$0.310	$0.0922	$0.402
Base Case	3-axle	63,760	$0.300	$0.0795	$0.380
Ready Mix 1	SU-4	69,734	$0.280	$0.0855	$0.366
Ready Mix 2	SU-5	75,066	$0.280	$0.0991	$0.379
Base Case	3-axle	52,770	$0.140	$0.0413	$0.181
Garbage 1	SU-4	63,855	$0.270	$0.0763	$0.346
Garbage 2	SU-4	61,526	$0.180	$0.0634	$0.243
Garbage 3	SU-5	65,599	$0.160	$0.0691	$0.229

This information shows that consumption rates increase for dump trucks as the number of lift axles and GVW increases. Ready-mix and garbage trucks consumption rates vary with increased numbers of axles and decrease in consumption rates for certain configurations relative to the three-axle base case vehicle.
Note: Garbage 1 is an SU4 with pusher axle; Garbage 2 is an SU4 with tag axle.

9.2.4 Chapter 6: Safety Analysis

The research team reviewed literature, federal code, crash records, and news reports to obtain information about SHV operational safety. The following summary lists the key points that were learned.

Federal Code and Truck Braking Requirements

NHTSA conducted a series of truck braking tests that were used to set the maximum allowable braking distances for a loaded or unloaded straight truck, for truck tractors with no trailer and truck tractors with an unloaded flatbed semi-trailer. The NHTSA study results are listed in the Code of Federal Regulations (CFR Title 49 Volume 6 Section 571.121). There is no distinction in the Code regarding an SHV or a non-SHV SU truck with respect to maximum allowable braking distance at different speeds. In fact, the two conditions listed are a loaded or unloaded SU truck with no indication of truck weight (GVW or GVWR), number of axles or types of axles. The maximum allowable braking distance for either loaded or unloaded SU trucks at different speeds is given in Table 6.1 and will not be repeated here. It is noted that the maximum allowable stopping distance is greater for an unloaded truck than for a loaded truck.

The research team notes that the methods used to determine braking distances in both NHTSA and the Society of Automotive Engineers (SAE) testing are fundamentally different than skid testing performed by DOTs to measure pavement texture, pavement friction and skid number. NHTSA and SAE typically conduct testing with either loaded or unloaded trucks on dry pavements at different speeds to determine truck braking distances. Pavement coefficient of friction is measured using a section of tire tread, weighted with concrete which is dragged over the pavement surface. The amount of friction resistance is measured using a mechanical or digital scale attached to the weighted tire tread segment. The factors used by NHTSA, SAE, and many law enforcement officials or professional accident investigators, are not directly comparable to methods or factors used by DOT pavement engineers to evaluate pavement skid resistance. An example is vehicle drag factor, which is a function of braking distance and vehicle speed for an actual, loaded, or unloaded truck.

Factors That Can Affect SHV Operational Safety

a. When in the down position, lift axles reduce the turning ability of SHVs compared to three-axle trucks. To compensate for tires scrubbing on the pavement during a turn, a driver may lift the axles. However, lifting the axles increases the truck center of gravity and may increase the potential for a truck roll-over.

b. The many different lift axle designs and axle load limits are based on manufacturers' ratings, which range from 6,000 lbs per lift axle to over 20,000 lbs per lift axle. Accordingly, the manufacturer established the lift axle maximum allowable load in relation to the design of the axle structural components, the brakes, and other factors. However, though SU trucks are sometimes retrofitted with lift axle(s) years after they were first manufactured, there is no current process in place to check the braking capacity of a lift axle or the entire loaded truck once additional axles have been fitted. This brings into question the overall braking efficiency of an SHV if the lift axle capacity and brakes have not been properly selected.

c. It is reasonable to assume that adding one or more lift axles to an existing three-axle SU truck implies that the owner plans to operate at a higher GVW. However, it is unclear if TxDMV requires that the original truck manufacturer's GVWR) or the registered gross weight is changed in the truck registration data when a SU truck is modified by fitting one or more liftable axles. If additional axles are added, the allowable GVW of the truck can increase based on the FBF. However, based on TxDMV registration rules, the GVW cannot exceed the manufacturer's GVWR (TxDMV, 2017). As previously mentioned, current registration requirements do not include data about the truck configuration (SU or tractor-trailer) or the number and types of axles. It is also unclear how the GVWR would be determined beyond merely considering the number of axles, axle spacing, axle load capacity, and tire rating. Other factors that could affect the weight a truck could safely transport include braking capacity, load distribution among all truck axles and the relationship between routine or permitted GVW and the modified GVWR of the SHV. The research team thinks that modification of a SU truck by adding lift or booster axles should require inspection by a truck specialist trained to make judgments about the GVWR of a truck that has been modified by adding one or more lift axles.

d. The allowable GVW is established by state laws based on truck configuration, number of axles and the FBF. The TxDMV's "Motor Vehicle Registration Manual" indicates that the truck should not be registered for more than the manufacturer's GVWR and the vehicle GVW should not exceed the GVWR. In addition, the gross registered weight of a commercial vehicle is equal to the empty weight of the truck including permanently mounted equipment plus the weight of the heaviest load carried.

e. Truck manufacturers develop different truck designs in the medium, long-haul, and heavy or severe duty categories that typically relate to the operational use and amount of weight the truck will carry. The truck manufacturer indicates the truck load capacity based on the GVWR, which is typically found on the truck door frame or on a stamped metal plate fixed inside the cab. The GVWR rating is directly related to truck components designed to transport heavy loads under severe duty conditions, such as off-road use for dump, ready-mix, and garbage trucks. Increased GVWR may result in heavy-duty chassis rails, heavier axles, different braking systems, and tire ratings, different engine designs, and other features. Since each truck is custom tailored for the buyer, individual trucks of a given GVWR may vary in design component configuration.

f. OW permits may be purchased from the TxDMV may to increase the truck GVW. In addition, state exemptions allow increased truck GVW for certain types of trucks or commodities. Based on a review of permitting practices and crash reports, the researchers have not found that the vehicle GVWR is required to be either entered on a permit application or documented by the investigating law enforcement officer during a crash investigation.

   It is noted that certain permits indicate that purchase of the permit does not authorize the permit holder to exceed tire load capacities based on the tire rating. In addition, most permits fix the maximum allowable GVW that can be operated with the permit. Thus, it appears that it is the truck driver or trucking company responsibility's not to exceed the GVWR if purchasing a permit. It is not clear how often a permitted vehicle GVW does in fact exceed the GVWR. As an example, though a permit may allow a truck to operate at 84,000 GVW, the actual GVWR for that truck might be 70,000 lbs—suggesting that brakes, axles, and other components are under-designed for the permitted load.

g. SHV operators might or might not receive training to operate an SHV. There are currently no requirements for a CDL driver who operates an SHV to have special training or to demonstrate the ability to safely operate an SHV.

h. One case study conducted indicated that a tire blowout on a booster axle resulted in a crash due to truck instability and a rollover.

9.2.5 Chapter 7: Economic Factors related to SHV Operations

Though SHVs are expensive to purchase and maintain, the SHV numbers are increasing due to higher profit margins for certain market sectors. Though more SU4s are operating in Texas now as compared to any other SHV configuration, the market suggests that SU5 and SU7 configurations may increase market share.

Though many SHVs are retrofitted vehicles to which one or more lift axles have been added, major truck companies such as Freightliner, Kenworth, and Peterbilt offer trucks with lift axles installed during the manufacture of the new truck. In addition, new truck dealerships can equip either new or used trucks with lift axles.

Three perspectives are summarized in this section—operator, truck manufacturer, and agencies—as they relate to highway legislation, operations, and enforcement.

Truck Operator

a. An operator, irrespective of the vehicle numbers in the fleet, faces choices in several areas that, when aggregated, comprise the total costs of ownership. Capital costs play an important role, as does fuel consumption, driver salary, safety, truck reliability, and maintenance costs. Small fleets (under five units) in the truck sectors now using SHVs have sometimes entered the sector by purchasing a well-maintained basic two- or three-axle truck and adding a liftable axle. This study considers the current wide variety of SHV but notes there is strong evidence derived at the dealer level that new SHVs are taking a large share of the market.
b. SHVs are expensive ($150,000 to $240,000) and annual vehicle mileage is typically lower than other truck classes, thus raising the depreciation costs per mile. Nevertheless, the productivity gains more than compensate in terms of ton-mile revenues, so if demand is strong and consistent, an SHV is a better investment because it is a greater contributor to company profitability and growth.
c. An SHV fleet moves more cargo weight (ton-miles) than a traditional rigid dump truck fleet when all costs are included. This is strengthened as SHV designs are refined, tested, and introduced by the leading U.S. truck manufacturers.
d. Although a wide variety of SHV types will exist for some time, experience suggests that demand will center on two or three types. SU5 is a strong contender for booster specifications because larger tires can be accommodated on the liftable axles. As booster sets gain axles, the booster tire size gets smaller, even if the chassis length increases. SU7 meets FBF contract requirements on interstate highways and federal contracts.

Truck Manufacturer

a. SHVs are now recognized as an important subsector by U.S. original equipment manufacturers. All of the major brands in the heavy truck sector provide models that either are offered as original equipment under the company guarantee or can be modified by approved secondary companies. Freightliner, for example, now features an SU6 range of trucks in the severe- to medium-duty range. Hendrickson—a global leader in the manufacture of medium- and heavy-duty suspension, axle, and brake systems—now offers integrated drive axle/liftable booster axles sets for SHV original equipment specifications. Kenworth, Peterbilt, and International all report strong sales for dump trucks with liftable axles.
b. Truck manufacturers are maintaining a sharp focus on SHV accidents and safety in their business models but the accident data are sparse and generally lack specificity. In 2015, the class containing SHVs—SU trucks, grossing over 10,000 lbs.—were involved in 620

fatal highway accidents, representing 15% of all truck fatalities. The annual rates of fatalities per unit distance for all heavy vehicles in the period 2011–2015 remained in the range of 1.40 to 1.47 fatalities per 100 million VMT. Anecdotal accident data on SHV accident causes are generally centered on brake failures—which result in rollovers or property damage—and hydraulic failures/a blown tire on a stinger axle that suddenly shifts the load center of gravity, making the vehicle difficult to control by the driver. Technologies are being introduced—like active monitoring of tire pressures—to counter specific problems.

c. SHVs will inevitably benefit from many of the innovations related to autonomous trucks under test at this time. Features that mitigate system failures (like hydraulic and tire pressure issues) and incorporate innovations (like automatic braking) will clearly prevent or reduce accident severity and will be offered as they move from testing to real-time operations.

Agencies related to Highway Legislation, Provision, Operations, and Enforcement

a. Texas has over 40 different types of permits for truck operations on state and county highways, in addition to federal size and weight laws. Heavier truck operations continue to grow in Texas. This creates a substantial challenge to TxDPS officers tasked with enforcing size and weight legislation. This responsibility also extends to drivers, operators, and companies that load the vehicle—in the case of this report, an SHV.

b. The term SHV covers a wide range of specific axle configurations within the category of a three-axle, rigid chassis truck category, sometimes described as medium- to heavy-duty depending on the technical specification of the engine, transmission, and chassis dimensions. The axles are designed for one specific purpose—to redistribute load so that it meets TxDPS scrutiny and FBF limits. The axles are not connected to transmission systems but play a critical role in the truck's braking performance. Anti-lock braking is a major safety system that will be thoroughly examined by original truck manufacturers as they compete in this sector.

c. TxDPS officers are trained to inspect SHVs and focus on chassis length between the first and last axle, and the number of axles actually running on the pavement, to categorize the specific SHV type. They then measure the weights on each axle and may undertake further tests on other safety issues noted during inspection. This can be an exacting process and calls for axle scales, blanks, and time. TxDPS officers work off a permissible weight table that computes permissible loads per unit distance between the first and last axle hubs to the nearest 500 lbs.

d. These data frame decisions on SHV chassis and axle configurations by manufacturers, companies loading the trucks, and the driver/owner of the truck. The objective in all trucking operations where cargo weight is an issue is to get as close as possible to the permitted limits. The recent growth in Texas SHV registrations clearly shows that more operators are choosing SHV designs to increase productivity, compete over a variety of cargo densities, and raise utilization levels, which impacts both depreciation costs per mile and ultimately profit. This is critical where the average trucking rate of return in the first quarter of 2017 was 4% below 2016 levels for one key U.S. trucking sector, although not directly transferrable to SHV operations.

e. The final, overarching conclusion is the need to integrate gross and axle load legislation, gains in economic efficiency and productivity, and the marginal costs of pavements and bridges with easier enforcement and compliance. This is, as yet, incomplete in the SHV class, although this research is a first step in the process.

9.2.6 Chapter 8: Policy Findings

The following policy recommendations are presented regarding vehicle registration data for SHVs. However, the research team suggests that requiring additional registration, titling, and state inspection data for all commercial vehicles would be beneficial for understanding the truck fleet makeup in Texas. Additional data should include a) truck configuration, including SU or tractor-trailer; b) number of axles; c) axle configuration; and d) GVWR.

SHV Vehicle Registration Data

a. Require the total number of axles and whether an axle is liftable to be noted in vehicle memorialization (TxDMV registration data and TxDPS truck inspection data).

   This step will assist TxDOT and TxDMV in determining the numbers and types of SHVs operating in the Texas truck fleet for analysis purposes. For example, including this information in registration/state inspection data would make it much easier to respond to FHWA requirements regarding future analysis of SHVs and bridge load ratings. In addition, evaluations regarding the growth in SHV operations within counties, regions, or statewide would be much easier to accomplish. This information would also make it much easier for TxDOT and other agencies to track SHV numbers and configuration trends over time for different counties, regions, and the state as a whole.

   If truck axle number and types are not included in registration/state inspection data, TxDOT may need to periodically update field data collection of these vehicles, including vehicle type, configuration, number of axles, axle spacing, and weights, to ensure bridge load postings address deployment of these vehicles.

b. Document retrofitting lift axles to a truck in the truck registration data, to be consistent with a) recommendations regarding memorialization of the truck, including numbers of fixed and liftable axles and axle configuration.

   This information could potentially be added to the items that are evaluated during a truck safety inspection and incorporated in the vehicle registration data. CTR realizes that creating a requirement for TxDMV and TxDPS to collect and document this information would necessitate action by the state legislature.

Placement of Lift Axle Controls

a. Establish policies that require the lift axle controls (used to adjust axle load through air bag suspension pressure levels or mechanical means) to be placed outside the truck cab and/or out of the driver's reach.

b. Establish policies that allow the lift axle controls to be placed in the cab within the driver's reach so that axles can be lifted when entering a construction zone or unloading area and lowered when leaving the loading area and driving onto the public road system.

Mechanical Functionality and Maintenance of Lift Axles

The following recommendations are presented as draft legislation; many of these recommendations were identified from legislation or policy that has been implemented by other states to address proper use and maintenance of lift axles.

a. Lift axles with single tires in the pusher, tag, or booster position shall be caster steered in order to track the turning movement of the SHV.
b. Lift axles with dual tires are not required to be caster steered, though drivers are required to exercise precautions during turning movements to ensure the pavement surface is not damaged.
c. Lift axles shall be maintained in good working condition to ensure the caster steering mechanism performs as designed to track the turning movement of the vehicle.
d. Lift axles that are retrofitted to a long-haul truck tractor that has been modified to operate as a vocational (work) type truck, such as a dump or ready-mix truck, shall be installed to minimize mounting bracket cracking or breaking due to improper load distribution and vehicle torsional effects.
e. Lift axle pressure/load setting mechanisms shall be properly adjusted to ensure that the load amount of the axle is in compliance with the FBF and the tire ratings of the tires mounted to the lift axle.
f. Lift axle lifting mechanisms shall be properly maintained to ensure that the axle is fully retracted or extended to the pressure setting required to comply with the FBF.
g. Lift axle tie rods, joints, brakes, king pin, and other components that make up the lift axle mechanism shall be properly maintained.
h. If, during a law enforcement officer inspection, a lift axle is found to have broken components, is improperly adjusted, is not fully retracted, or is found to be over loaded, the officer shall direct the driver to have the SHV towed to a maintenance facility where the SHV shall be out of service until proper repairs are made.

SHV Safety and Enforcement Aspects

a. TxDOT should consider modifying the CR-3 reports and the CRIS database to include the following information collected by a law enforcement officer during a crash investigation:
    i. the number of fixed and liftable axles and axle configuration of a SU truck
    ii. the GVWR of the truck based on the manufacturer's information (often stenciled on the door frame or on a plate in the cab)
    iii. whether or not the truck operator or driver was in possession of an OS/OW permit at the time of the crash, the type of permit, and the allowable GVW and/or axle weights permitted

iv. the truck and cargo weight at the time of the crash as documented by a truck scale weight ticket required for purchase of a permit; or

v. the truck and cargo weight at the time of the crash as documented by a truck scale weight ticket obtained from a landfill, material supplier, or similar operation during loading of the truck; or

vi. the truck and cargo weight at the time of the crash based on a statement from the driver. If the driver does not know the weight of the truck and cargo at the time of the crash, this should be noted on the CR-3 report.

Additional Findings

a. CTR found that TxDPS or other law enforcement officers rarely indicate the number of axles for a SU truck involved in a crash. There are currently no requirements to note the number of fixed or liftable axles in CR-3 crash reports, the axle arrangement, or whether axles were lifted or deployed during the crash event.

b. It would be difficult or infeasible to obtain the actual weight of the truck and its cargo during the crash unless the weight is documented in a permit accompanied by a weigh-station ticket.

c. Certain businesses in Texas specialize in converting late model or older trucks into reconfigured and refurbished SHVs. These trucks are carefully designed, and fitted with lift axles to provide a safe, operational SHV. However, based on discussions with TxDPS officers that conduct roadside weight and safety inspections, in some cases over-the-road long haul tractors are converted to SHV dumps or other operational types. These trucks were not originally designed to operate with the full cargo weight carried on the truck chassis, which can result in cracked frames, cracked suspension brackets, and other damage. These conversions might be performed by local truck garages or by the truck owner/operator.

9.3 Suggested Topics for Further Research

The research team suggests the following research topics for further study of SHV operations in Texas.

9.3.1 Evaluation of Pavement Friction Characterization

The researchers recommend that a study is undertaken to evaluate and compare the factors used by NHTSA, SAE, law enforcement, and professional crash investigators in relation to skid numbers obtained using an ASTM locked wheel trailer with water spray. The study should consider the methods used to measure and calculate pavement friction and other factors to determine if different methods and/or equipment should be employed by DOTs to measure available pavement friction for autos and for heavy trucks.

9.3.2 Continued Evaluation of Texas SHV Types, Configurations, Safety, and Economics

The 0-6897 study provides a wealth of information, not previously available, on Texas SHV types, configurations, operations, pavement and bridge consumption rates, safety, economics, and policy recommendations. However, the time constraints of a 2-year study limits the amount of field observations that can be collected, which might lead to gaps in knowledge about SHV operations in Texas.

9.3.3 Evaluation of Relationships between Truck GVWR, Legal or Permitted Truck GVW, and Safety

TxDMV registration rules require that the truck GVW should not exceed the truck GVWR. However, it is unclear if SU trucks that a modified by adding lift axles are registered at a higher GVWR and, if so, how this value is determined. If the GVWR is not increased, though the truck might be able to legally carry a higher GVW based on the FBF, the truck would be illegal since the higher GVW exceeds the GVWR (unless updated). It is recommended that further evaluation of the relationship between GVWR and actual GVW is undertaken to determine how this process is managed during titling and registration and how GVWR is determined actual braking distances, crash rates, and crash severity for trucks that operate at GVWs that are higher than the GVWR for that vehicle.

9.3.4 Development of Improved Methods for Characterizing SHVs for Pavement and Bridge Consumption Analyses

The 0-6897 study included a discussion of a method to characterize SHV pavement consumption using equivalent strain measurements calculated using the CIRCLY linear elastic layered theory program. This method was employed because AASHTO Pavement ME automatically distributes axle loads equally among an axle group. However, a ‘tridem axle’ or other axle group that consists of one or more lift axles and a fixed tandem drive axle typically does not have equal load distribution. Rather, the lift axle(s) loads range from approximately 5,000 to 9,000 lbs. For a tridem axle that incorporates a lift axle, the lift axle will be loaded to approximately 8,000 lbs and the drive tandem to 34,000 lbs to arrive at the legal 42,000 lb tridem axle load. It is recommended that a study is undertaken to develop a methodology that automates the process of arriving at equivalent strains for a given SHV configuration for use in the AASHTO Pavement ME program. In addition, the current pavement consumption analysis methodology determines ECFs for rutting, fatigue, and roughness (IRI). The average ECF is calculated to represent a given axle group and load since a detailed study has not been undertaken to determine how these distresses should be weighted. It is recommended that this study includes an analysis of the appropriate ECF weighting factors for each distress type.

9.3.5 Development of a System for Prioritizing On- and Off-system Bridges for Load Posting or Structural Improvements

As discussed in Chapter 7, which addresses economic considerations regarding SHVs, the number of permitted OW vehicles is increasing due to strong economic development in Texas. The 0-6897 bridge consumption and load posting evaluation has shown that thousands of on- and off-system bridges may require posting based on a more detailed project-level evaluation. Thus, the research team proposes that a study is conducted to develop a system that will prioritize both on- and off-system bridges for load posting and/or improvement so that they are compatible with SHV operations.

The system will consist of several attributes that will determine the priority of the bridge and the possible interventions in a decision-tree or similar approach. The system will be supported by the data analysis that we completed in this project.

Appendices

Appendix A: Review of Reports

1. AASHTO. Guide for Maximum Dimensions and Weights of Motor Vehicles and for the Operation of Non-Divisible Load Oversize and Overweight Vehicles. Washington, DC (1987).

Criteria for Liftable Axle Design (not adopted by all states)

Retractable or Variable Load Suspension (VLS) Axles

In computation of gross vehicle or axle weight limits for highway legal vehicles not requiring OS/OW permits, no allowance will be made for any retractable or variable load suspension meeting the following criteria:

- All controls must be located outside of and be inaccessible from the driver's compartment.
- The gross axle rating of the VLS devices must conform to the expected loading of the suspension and shall in no case be less than 9000 lbs.
- Axles of all retractable or VLS devices manufactured or mounted on a vehicle after January 1, 1990, shall be engineered to be self-steering in a manner that will guide or direct the VLS mounted wheels through a turning movement without the tire scrubbing or pavement scuffing.
- Tires in use on all such axles shall conform in load capacity with relevant state regulations or with Federal Motor Vehicle Safety standards or with both as is deemed appropriate.

Weight Distribution within Axle Groups

All axle group suspension systems shall at all times distribute the loads equally among all axles of the group in order to be allowed the upper weight limits specified in Section 2.07, without the necessity for downward adjustment due to imbalance. "Equally" for the purposes of this report means no more than +/− 10% variation from the theoretical maximum average axle load of the group.

2. AASHTO. Manual for Condition Evaluation of Bridges (MCE). Washington, DC (1994).

The HS20 truck or lane load was specified as the rating live load to be used in the basic load-rating equation.

Bridges that do not pass the HS20 ratings with a rating factor of 1.0 or higher are subjected to a posting analysis to determine the need for weight-limit posting.

3. Washington State Transportation Center. An Evaluation of the Lift Axle Regulation in Washington. University of Washington, Seattle (1994).

Common Drawbacks of Liftable Axle Trucks

Lift axles, when deployed, reduce the turning capabilities of the truck and may cause the truck to jackknife on slippery roads. If the axles are raised through the turn, the truck's stability is compromised and the chance of rollover is increased.

The proportion of the load carried by the lift axle is often controlled by the driver. If the axle is deployed too far, it may carry too much of the load. If the axle is not deployed far enough, the other axles may be overloaded.

Enforcing compliance with lift axle regulations is very difficult. Lowering retractable axles when approaching a weigh facility and then raising the lift axles after clearing the weigh facility is not uncommon. Regulatory agencies sometimes require the controls for raising and lowering the lift axles to be located outside the cab to inhibit this practice. Some states have banned the use of lift (or retractable) axles for the reasons cited above.

Safety Issues of Liftable Axles

Payload center of gravity is the single, most powerful determinant of stability and control behavior. In terms of handling and stability, an empty vehicle is much more sensitive to lift axle deployment than a fully loaded vehicle.

Vehicle maneuverability and performance suffer in these scenarios: as the spacing between the fixed and lift axle increases; if the lift axle is installed behind a fixed axle; if the liftable axle is installed on the lead vehicle of a combination vehicle and as the load on the liftable axle increases; if a liftable axle was added to a vehicle, and if a single liftable axle was replaced by a tandem axle group.

Self-steering axles improve vehicle maneuverability, but decrease levels of vehicle control and safety. Based on limit pavement analysis, it was estimated that raising a liftable axe improperly results in 3 to 10 times more pavement damage per truck pass.

4. Nowak, A.S. NCHRP Report 368: Calibration of LRFD Bridge Design Code. Transportation Research Board, National Research Council, Washington, DC (1999).

Assumptions about side-by-side vehicle crossing possibilities (no field data):

- One out of every five trucks is a heavy truck, which describe the Ontario statistical parameters (based on a site's average daily truck traffic [ADTT] of 5,000).
- One out of every 15 heavy truck crossings occurs with two trucks side-by-side.
- Of these multiple-truck events on the span, 1 out of 30 occurrences has completely correlated weights.
- Using the product of 1/15 and 1/30 means that approximately 1/450 crossings of a heavy truck occurs with two identical heavy vehicles alongside each other.

The maximum live load moments and shears are governed by the combination with two fully correlated vehicles, each weighing about 0.85 of the maximum 75-year truck.

5. Federal Highway Administration (FHWA). Truck Characteristics Analysis. Washington, DC (1999).

This project categorized truck characteristics. The truck types that are most likely to have lift axles are basic platforms, dump trucks, and concrete mixers. The body types that most frequently have lift axles, according to TIUS, are basic platforms (27%), dump trucks (21%), and concrete mixers (13%).

Dump trucks were most common for GVWs of between 40,000 and 50,000 lbs, between 80,000 and 100,000 lbs, and over 130,000 lbs. For trucks with four or more axles, dump trucks comprise 42%, with concrete mixers at 20%.

6. USDOT. Comprehensive Truck Size and Weight Study, Volumes I-III. Washington, DC (2000).

The study reported the following:

- States that allow tandem axle loads greater than the federal limit on Interstate highways are Alaska, Colorado, Connecticut, Georgia, Hawaii, Maryland, Massachusetts, New Hampshire, New Mexico, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, and Wyoming;
- States such as Pennsylvania, South Carolina, and Florida do not apply the Federal Bridge Formula (FBF) to trucks weighing 73.28K or less on interstate highways;
- A modified bridge formula is used by California, Maine, New Mexico, North Carolina, New York, Oregon, Texas, and Wisconsin on interstate highways; and
- Many more states either do not apply FBF or use a modified bridge formula to non-interstate highways.

The national distribution of the trucking fleet by configuration was estimated at:

- Single-unit trucks: 68%;
- Truck-trailer combinations: 4%;
- Tractor-semi trailer combinations: 26%;
- Double-trailer combinations: 2%; and
- Triple-trailer combinations: 1%.

SHVs represent approximately 46% of the single-unit trucks operating with three or more axles. Lift axles are used on more than 70% of all four-axle single-unit trucks.

7. NCHRP Report 454: Moses, F. Calibration of Load Factors for LRFR Bridge evaluation. Transportation Research Board, National Research Council, Washington, DC (2001).

For purposes of calibration of the LRFR manual, the following procedures and assumptions were used:

- The Ontario truck weight data (upper 20% moments of different spans) were reasonably matched (fit to a normal distribution) by a 3S2 truck with a mean of 68 Kips and a standard deviation of 18 Kips.
- The 3S2 truck has a legal weight of 72 Kips; thus, the upper fifth of the truck weight distribution can be described with a normal distribution with a mean = 0.95 × legal load limit and a coefficient of variation (COV) = 0.25. This suggests that about 8% of trucks are overloaded.
- For ADTT equal to 5,000, a 1/15 side-by-side probability was used to maintain consistency with the Load and Resistance Factor Design (LRFD) calibrations.
- For ADTT equal to 1,000, a multiple-presence probability value was set equal to 1%. This value was also verified using a simple traffic model to estimate side-by- side presence.
- For ADTT equal to 100, the multiple-presence probability was set equal to 0.001, consistent with field observations and traffic model predictions.

8. AASHTO. Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges. Washington, DC (2003).

The HL-93 design load, a combination of the HS20 truck and lane loads, was specified as the screening and reporting load. Three AASHTO trucks—Type3, Type 3S2, and Type 3-3 were used as AASHTO posting loads.

Only state legal loads that have minor variations from the AASHTO legal loads may be included in the posting analysis. Grandfathered state legal loads that induce load effects significantly greater than the AASHTO trucks have not been included in the reliability-based LRFR calibrations of live-load factors.

In response to the changing truck configurations, several states have adopted a variety of short multi-axle vehicles as state legal loads for rating and posting purposes (SHVs). The current AASHTO legal loads selected at the time to match closely the FBF do not represent these newer axle configurations.

9. NCHRP Report 495: Fu, G. Effect of Truck Weight on Bridge Network Costs. Transportation Research Board, Washington, DC (2003).

This project developed the recommended methodology for estimating bridge network costs. A truck's gross weight, axle weights, and axle configuration (collectively referred to as "truck weight" in this study) directly affect the useful life of highway bridge superstructures.

The cost impact category for deficient existing bridges is likely the dominant contributor to the total cost impact of a change in truck weight limits. This is mainly because there are no general effective methods to strengthen existing bridges for increasing the load ratings.

The current AASHTO fatigue truck model is found valid based on the current WIM data used.

The models for assessing structural material fatigue (for both steel components and reinforced concrete decks) have more uncertainty than the strength assessing models. Essentially it is because fatigue accumulation largely depends on microscopic original discontinuities and acquired damages, which are randomly distributed in location and severity.

Wheel loads have a very significant effect on RC deck fatigue accumulation, according to the fatigue model introduced herein. This result has important implications to wheel load limit development and enforcement.

10. NCHRP 575: Bala Sivakumar. Legal truck loads and AASHTO legal loads for posting. Vol. 575. Transportation Research Board, 2007.

Information and data from truck production companies was found to not be useful in determining precise axle configurations and weights because these are often customized. But an increase in the use of lift axles was observed since the FBF was enacted.

The study investigated state legal loads and weight limits and found that many states allow loads that exceed the federal weight limits. Although the federal weight limits generally apply both on and off the Interstate system, only seven states apply the federal limits statewide without modification or “grandfather right” adjustment.

Most trucks and combinations operate at or below the GVW limits; Tank trucks and hauling trucks that operate at average load levels reach their maximum weight limit and “weigh out” over 80% of the time. This occurs less than 20% of the time for enclosed van trailers used to transport commodities that have low density.

Lift axles were found to be routinely used on single-unit trucks such as dump trucks and cement mixers as well as on semi-trailers. In most states, the load and spacing of lift axles are governed by the same bridge formula that governs fixed axles.

Lift axles are used on heavy vehicles that are more prone to OW violations, the dump truck is the most likely truck type among vehicles with one lift axle, most commonly with a liftable-axle preceding a tandem axle group. In concrete mixers, two lift axles are common: one following the steering axle and one at the extreme rear of the truck. Lift axles may be self- steering, controlled steering, or non-steering: Non-steerable axles suffer the greatest resistance as the vehicle turns. They may encourage the practice of lifting the retractable axles around corners; Self-steering axles, recommended by AASHTO guidelines, have wheels that articulate under forces developed between the tire and the road surface; Steerable axles are controlled by a hydraulic steering mechanism coupled to the front axle steering mechanism.

Posting regulations were found to vary widely among agencies including the criteria for initiating a posting action, methodology for setting the allowable truck weight limit, and techniques for how the limits should be represented on highway signage. A large number of state legal loads (33/45) had unusual axle configurations different from the AASHTO loads. A large number of state legal loads (19/45) that deviate from the AASHTO loads exceeded federal weight limits.

Several state posting loads satisfied FBF gross weight limits but violated the FBF limit for axle groups or the federal 20-kip limit for a single axle (FBF Trucks). Many states either do not apply FBF or use a modified bridge formula to non-Interstate highways; several states have adopted a non-Formula B version of the four-axle dump truck and other common truck configurations as rating and posting vehicles (non-FBF Trucks).

WIM data analysis was undertaken. Axle configurations for trucks with three to eight axles were obtained from the screening of the WIM data. Criteria reviewed were:

- Total wheelbase ≤35 ft.
- Meets the FBF and federal weight limits.

The team investigated whether the truck induced a load effect that exceeded the maximum of the three AASHTO legal rating vehicles. (Moment effect at the mid-span section and the shear at a support of bridges with different simple spans)

WIM data from U.S. sites indicated multiple-presence factors of only 1% to 2%, even for Interstate sites with ADTT of above 2,000, indicating the probability (1/15) assumed in LRFD calibration report is conservative. The multiple-presence probabilities for this site are quite low compared with past assumptions (LRFD: 1/15). Multiple-presence probabilities are a function of the number of lanes of traffic. Trucks are more likely to travel in the center lane than in the left lane, leading to higher multiple-presence likelihood on three-lane highways.

The expected maximum live-load effect in 2 years due to side-by-side random trucks is 3.3 times the load effect of a single legal 3S2 truck or 3.2 times the load effect of a legal Type 3 truck.

It was also shown that the maximum moment and shears due to two side-by-side legally loaded SHV trucks satisfying Formula B would not exceed 3.0 times the load effect of a legal Type 3 AASHTO truck. This means that legal SHV trucks satisfying Formula B would produce a lower maximum live-load effect than the effect of the random commercial truck traffic modeled by Nowak and used in the LRFR calibration.

In the LRFD and LRFR calibrations, it was shown that the maximum live-load effect is governed by OW or illegal vehicles.

Maximum load is usually based on the occurrence of several heavy trucks simultaneously on the bridge, their headway probabilities, and the probabilities for the gross weights for the trucks. For two-lane bridges, the maximum load effect was obtained with two trucks side-by- side with perfectly correlated weights.

Extreme loading on the structure is affected by the side-by-side probabilities and the sequence of trucks in each lane.

It was observed that for spans under 100 ft, truck separation over 40 ft was less significant on span moments. For longer spans, vehicles with up to 60-ft headway separation should be considered as the second truck's load effects could be significant. For longer spans and continuous spans, the headway separation in the same lane could also be important.

The project began development of candidate legal loads. They found that the studies show the need to revise the present family of three AASHTO legal loads to better provide uniform safety for the new generation of Formula B truck configurations.

Three FBF trucks (T7A, T7B, and T8) seemed to envelop all other candidate Formula B trucks developed in this project as well as the Formula B state rating and posting loads. Analysis Results for Generic Spans showed that:

- T7A, T7B, and T8 (with seven and eight axles) are generally the governing (envelope) vehicles in most spans and impose the highest load effects. For very short spans under 20 ft, T5A or T6A could govern over these three trucks by a small margin.
- The eight-axle T8 truck often governed shear and negative moments in continuous spans. Positive moment was governed by one of the seven-axle trucks (T7A or T7B).
- The spans most vulnerable to overstress from the candidate FBF trucks were the shorter spans in the 10-ft to 75-ft span range for simple as well as to continuous spans.
- Truck T7A also governed live-load reactions on transverse floor-beams. T7A live-load reactions were from 29% to 50% higher than the reactions from the governing AASHTO truck.

- The shear and moment effects of these new SHVs and show load effect increases up to 50% over the current AASHTO trucks.

Candidate Notional Rating Load Model

The notional truck BFT (Bridge Formula Truck, 80 Kips) was identified to envelop the load effects of all reasonable Formula B truck configurations on simple and continuous spans ranging from 10 ft to 200 ft.

- Certain axles in the BFT load model that do not contribute to the maximum positive moments need to be neglected (bridges with spans under 25 ft).
- A rating factor (RF) <1.0 indicates that further analysis is required to determine the need for posting.

Comparison of force effects induced by the Notional Rating Truck with HS20 and AASHTO Legal Loads indicated that HS20 is not a suitable screening load model for all Formula B trucks:

- The proposed rating truck BFT consistently produces higher force effects than the current AASHTO legal loads for the test suite of simple- and continuous-span bridges.
- Simple-span BFT moments are about 10% to 20% higher than HS20 for spans governed by the HS20 truck loading. For longer spans governed by HS20 lane loading (over 170 ft), HS20 moments exceed BFT moments. BFT moments are significantly higher than AASHTO legal loads for most simple spans.
- Simple-span shears for BFT and HS20 truck are within 8% for most spans.
- HS20 negative moments are significantly higher than the BFT negative moments for most continuous-span configurations. The difference increases with increasing span.
- BFT positive moments for most continuous spans are higher than the HS20 moments by up to 20% (truck governs). For the same force effect, BFT exceeds the AASHTO legal loads by over 50% in certain cases.
- Continuous-span shears for BFT and HS20 generally do not vary by more than 8%, except when the lane load governs HS20 shear.

Options for Selecting the Proposed Legal Loads for Posting

- Option 1: Includes the worst four-axle (T4A), worst five-axle (T5A), worst six-axle (T6A), and worst seven-axle (T7A) trucks.
- Option 2: Includes the worst four-axle truck (T4A) and uses truck T5A as a single representative truck for Formula B truck configurations with five to eight axles.

Analytical studies show that the truck that produces the highest moment or shear per unit weight will govern the posting value (will result in the lowest weight limit). For very short spans (spans <30 ft), the shorter trucks will always govern posting. T4A consistently generates the highest moment per unit weight for all span lengths. For trucks with five to eight axles, T5A would be the most critical for posting.

The Delaware DE3 (EX 3) and Connecticut T4 (EX 4) trucks were the most severe of the family of three- and four-axle grandfathered loads. They can, however, be used as representative of grandfather trucks for LRFR calibration and rating.

The live-load factors were determined by reducing the target beta level from the design level of 3.5 to the corresponding operating level of 2.5. The live-load factors for SHVs are smaller than the corresponding factors for routine commercial traffic represented by the three AASHTO legal loads (Table 1.13).

- **LRFR live-load factors for Formula B SHVs**

Traffic Volume (one direction)	Load Factor for AASHTO Legal Loads	Recommended Load Factors for Formula B SHV
ADDT > 5,000	1.80	1.60
ADDT = 1,000	1.65	1.40
ADDT < 100	1.40	1.15

Source NCHRP 575

Suggested further research recommended included gathering additional WIM data to resolve assumptions on the SHV truck weight distribution. Further research is needed to investigate the likelihood of an SHV alongside an SHV and the likelihood of a heavy SHV alongside a heavy routine truck. In addition, the target reliability index for SHVs is needed to research because safety and operational needs may necessitate deviations from this set target for the class of SHV trucks.

11. Fu, Chung C., and Ti Awna Moffatt. Examine Impact to Highways/Structures–Vehicles Equipped with Lift Axles. No. MD-11-SP009B4K. 2011.

This research studied the impacts to highway structures from vehicles equipped with lift axles. Most lift axle systems are operated by the usage of a hydraulic or air pressure bag technology in the axle configuration, which regulates the lowering of the lift axle. Lift axles are used on more than 70% of all four-axle single-unit trucks.

New lift axle technology developments are moving toward self-steering air suspension configurations. The new series will provide a 20,000-lb capacity for new lift axles. This is significant because other versions of lift axles only allow capacities of up to 10,000 and 13,500 lbs.

The effects of lift-axle equipped dump trucks on pavement performance depend on traffic volumes, the structural design of the pavement, pavement construction, materials and maintenance, and truck gross weights.

The approaches used for analysis of highway bridges and pavement include punching shear approach (bridge), yield line approach (transversal behavior of the bridge deck under heavy vehicle loads), and analysis of bridge girders. The researchers used the equivalent single-axle load (ESAL) approach to measure damage and to connect damage costs to axle load damage to the pavement on both rural roads and highways.

Nominal truck configuration was assumed at:

- Nominal Gross Truck Weight: 67,669.2 lb

- Average Axle Weights:
- Axle 1: 13,881 lb
- Axle 2: 12,559.3 lb (Lift Axle)
- Axle 3: 20,696.2 lb
- Axle 4: 20,532.7 lb
- Average Spacing:
- Spacing 1: 12.48 ft
- Spacing 2: 4.26 ft
- Spacing 3: 4.39 ft

The mean lift axle weight is 12,559 lbs with a standard deviation of 2,371 lbs, making the nominal lift axle weight 14,930 lbs.

Surveys were undertaken, and the lift axle survey showed that there are no uniform regulations for lift axles and each state has their own truck regulations—some states do not even have laws regulating their usage.

State regulations regarding the position of control system were reviewed. For control systems located inside the truck and controlled by the driver, 36% of states had regulations, while 28% had regulations pertaining to exterior systems controlled by the driver. Finally, 36% of states had no current specifications in regulations.

The team undertook a virtual weigh station statistical data analysis and found that there is no relationship between OW trucks and lift axle weights since there are OW trucks with lift axle weights both above and below the mandated lift axle weight.

The research investigated weight of SHVs on road:

- Four-axle trucks (504 checked; 65 non-compliant), five-axle vehicles (2 checked; 0 non-compliant), six-axle vehicles (3 checked; 1 non-compliant), seven-axle vehicles (2 checked; 0 non-compliant)
- The number one violation is not having the proper air-pressure on the lift axle (33 violations or about 6% of all checked vehicles). The next highest is the lift axle certification not meeting the conditions (19 violations or about 4% of all checked vehicles). The third one has to do with vehicle operation—e.g., not activating the lift axle. The research team also added items 5 and 6, plus five-axle vehicle violations to this (8 violations or about 2% of all checked vehicles). The last one has to do with equipment (6 violations or about 1% of all checked vehicles).

Bridge deck shear analysis found that the punching shear of the tandem-axle case is 1.32 times larger than the tridem-axle case with the same total axle weights, which means 32% higher potential failure in punching shear for tandem-axle trucks as compared to tridem-axle cases.

The bridge deck moment check noted that the yield line theory indicates that the tandem-axle configuration (four-axle truck with lift axle raised) has a bending moment approximately two times greater than that of the tridem-axle configuration, which means—based on yield line theory—that the tandem-axle truck has 100% higher potential failure in deck moment compared to tridem-axle cases.

The bridge girder analysis found that for short span bridges, the bending moments were higher. But for longer spans over 20 feet, the bending moments for the tandem- and tridem-axle cases were almost identical.

The pavement analysis found that a truck that has its lift axle lifted when it is supposed to be deployed causes about three times the damage of a tridem-axle truck.

12. NCHRP 683: Sivakumar, B., M. Ghosn, and F. Moses. TranSystems Corporation. Protocols for collecting and using traffic data in bridge design, Lichtenstein Consulting Engineers. Inc., Washington, DC. (2011)

This report documents and presents the results of a study to develop a set of protocols and methodologies for using available recent truck traffic data to develop and calibrate live-load models for LRFD bridge design.

The HL93, a combination of the HS20 truck and lane loads, was developed using 1975 truck data from the Ontario Ministry of Transportation to project a 75-year live-load occurrence. Because truck traffic volume and weight have increased and truck configurations have become more complex, the 1975 Ontario data do not represent present U.S. traffic loadings.

The WIM data collected as part of this study shows that the actual percentage of side-by-side multiple truck event cases is significantly lower than assumed by the AASHTO LRFD code writers, who had to develop their models based on a limited set of multiple presence data.

In many spans, the maximum lifetime truck-loading event is the result of more than one vehicle on the bridge at a time. Studies done using New York WIM data during this project show that there is a strong correlation between multiple presence and ADTT. The multiple presence statistics are mostly transportable from site to site with similar truck traffic volumes and traffic flow and need not be repeated for each site. The site ADTT could serve as a key variable for establishing a site multiple-presence value. The multiple-presence probabilities for permit trucks are significantly different from those used for normal traffic. Side-by-side heavy truck probability was taken as 1/15 for an ADTT of 5000 (1/30 for the modified rating loads used by MDOT); as 1/100 for an ADTT of 1000; and as 1/1000 for an ADTT of 100.

13. NCHRP 700: Mlynarski, Mark, Wagdy G. Wassef, and Andrzej S. Nowak. A comparison of AASHTO bridge load rating methods. Vol. 700. Transportation Research Board, 2011.

The vehicle loadings obtained by the NCHRP Project 12-78 survey were used to investigate the resulting shears and moments in comparison to the HL-93 live load. The survey results indicated that the actions caused by the AASHTO legal loads (Type 3, Type 3S2, and Type 3-3) are significantly lower than those caused by the HL-93 loading.

14. Bowman, Mark D., and Raymond N. Chou. “Review of Load Rating and Posting Procedures and Requirements.” (2014).

This project reviewed other states’ rating and posting practice and found:

- The majority of states are using the AASHTO Manual for Bridge Evaluation, 2nd Edition, which is the current specification for load rating and posting bridges.

- Many states are not using the ASR method for load rating and posting of bridges. Most states that are using the ASR method are only using the method for select applications.
- Almost all states prefer or accept both the LFR method and the LRFR method for load rating and posting of bridges.
- It appears that the few states that are currently not using the LRFR method plan to use the method in the future.
- The majority of states are using the AASHTO prescribed legal loads, or similar state variations of these loads, for load rating and posting of bridges.
- The SHVs were recently developed to model common, short wheelbase, multi-axle vehicles. These vehicles can produce extreme loading effects, and they were previously not considered in load rating and posting

15. Eamon, Christopher D., Vahid Kamjoo, and Kazuhiko Shinki. Side by Side Probability for Bridge Design and Analysis. No. RC-1601. 2014.

This study found that there is significant variation in the required LF from one bridge case to another. Due to the very wide variation among the different truck cases and bridge spans, the ideal case to maintain consistency in reliability as well as to avoid unnecessary traffic restrictions would be to apply individual LFs for each truck for each bridge case. However, this is impractical.

The single lane load effect is generally found to govern LF overall, but this does not mean that single lane traffic produced a higher load effect than the side-by-side effect in every bridge case considered; in fact, in many cases side-by-side produced a greater result.

Appendix B: Review of Journal Articles

1. Sebaaly, Peter E., and Nader Tabatabaee. "Effect of tire parameters on pavement damage and load-equivalency factors." Journal of Transportation Engineering 118.6 (1992): 805-819.

The scope of this paper is to investigate the effects of tire pressure, tire type, axle load, and axle configuration on the response and load-equivalency factors of flexible pavements, and to compare these with those developed from the AASHO road test. Tire types are tested against the 11R22.5 tire to evaluate their relative damage to pavements.

The effect of truck tire types cannot be ignored in the pavement design process. Tire pressure had no significant effect on strains or deflections for the range of pavement thickness tested in this study. Wide-base single tires consistently had significantly higher strains and deflections than dual tires. The damaging effect was higher for single tires than for dual tires for both cracking and rutting predictions. Smaller-size dual tires had slightly higher strains and deflections than conventional duals, but not as high as single tires.

The tandem-axle configuration had higher rutting LEF than the single axle, but lower fatigue LEF. The use of multiple axles (tandem, tridem or more) can reduce cracking. By comparison, it is found that tandem axles with single axles on the basis of similar per-axle load level, the passage of one tandem axle produces less fatigue damage than the passage of two single axles.

2. Nowak, Andrzej S. "Live load model for highway bridges." Structural safety13.1 (1993): 53-66.

The major load components of highway bridges are dead load, live load (static and dynamic), environmental loads (temperature, wind, earthquake) and other loads (collision, emergency braking). The basic load combination for highway bridges is a simultaneous occurrence of dead load, live load and dynamic load.

- Dead load: Gravity load due to the self-weight of the structural and non-structural elements permanently connected to the bridge.
- Live load: Forces produced by vehicles moving on the bridge. (Depends on span length, truck weight, axle loads, axle configuration, position of the vehicle, number of vehicles [multiple presence], girder spacing, and stiffness of structural members.)
- Dynamic load: A function of three major parameters: road surface roughness, bridge dynamics (frequency of vibration) and vehicle dynamics (suspension system). Dynamic deflection is almost constant and does not depend on truck weight.

The project found that the development of live load model is essential for a rational bridge design and/or evaluation code. It was recommended to specify DLF as a constant percentage of live load decreases for heavier trucks. For the maximum 75-year values, the corresponding dynamic load does not exceed 0.15 of live load for a single truck and 0.10 of live load for two trucks side-by-side.

It was found that the lane live load moment is governed by a single truck up to about 40 m span, shear up to about 35 m, and negative moment (continuous spans) up to about 15 m. For two-lane bridges, the maximum 75-year effect is caused by two side-by-side maximum two month trucks, with fully correlated weights.

3. Gillespie, Thomas D. Effects of heavy-vehicle characteristics on pavement response and performance. No. 353. Transportation Research Board, 1993.

The study assessed the significance of truck, tire, pavement, and environmental factors as determinants of pavement damage.

Maximum axle load and pavement thickness have the primary influences on fatigue damage. Truck properties, such as number and location of axles, suspension type, and tire type, are important but less significant.

Axle weight is a more significant determinant in pavement damage than GVW. An increase in axle weight generally causes an exponential increase in pavement damage, increase in static axle weight has the greatest effect on fatigue damage, because the fatigue damage is exponentially related to static load on an individual axle.

The maximum axle load is the strongest determinant of fatigue damage on both rigid and flexible pavements. The damage from closely-spaced tandem axles (48 to 52 inches of spread) is reduced by load interactions on rigid pavements, however, flexible pavements do not have significant load interaction.

The primary determinant of flexible pavement rutting is GVW. However, there would be no benefit from limiting GVW in light of the fact that it would only force more trucks on the road to meet commercial transport needs (assuming there is no modal shift of commercial transport). No evidence was found to suggest that specific truck characteristics (which are practical to control) could reduce rutting damage.

The dynamic loads arising from the interaction of road roughness with truck dynamics increase fatigue damage of rigid and flexible pavements. Among relevant truck properties, the dynamic behavior of suspensions is the most important and amenable to control.

The primary tire variable affecting road stress and fatigue damage, particularly on flexible pavements, is the contact area.

4. Nowak, Andrzej S. "Load model for bridge design code." Canadian Journal of Civil Engineering 21.1 (1994): 36-49.

The paper deals with the development of dead load, live load and dynamic load models for the Ontario Highway Bridge Design Code.

Based on the analysis of truck survey data for one lane bridges with spans up to about 40 m, a single truck governs the largest live load effect for spans up to 30-40 m; for longer spans, two trucks following behind the other provide the largest live load effect. For two lanes, two fully correlated trucks govern.

Based on simulations, the dynamic load is modeled. The results of calculations indicate that dynamic load depends not only on the span but also on road surface roughness and vehicle dynamics. Therefore, dynamic load as a fraction of live load decreases for heavier trucks. It is further reduced for two trucks side-by-side. The recommended design value of dynamic load is 0.25, for all spans larger than 6 m.

5. **Hewitt, Julie, et al. "Infrastructure and economic impacts of changes in truck weight regulations in Montana." Transportation Research Record: Journal of the Transportation Research Board 1653 (1999): 42-51.**

The objectives of this project were to determine infrastructure and economic impacts in the state of Montana of changing truck weight limits. The project investigated the impacts result from imposing maximum allowable GVWs (80,000 lb; 88,000 lb; 105,500 lb; and 128,000 lb).

Higher GVWs reduce truck traffic, while lower GVWs increase truck traffic, based on same cargo hauled. An increase in maximum GVW was noted to has a positive impact on the state's economy.

Infrastructure costs were higher in two of the reduced-GVW and the increased- GVW scenarios, with the former caused by greater road wear due to more trips on lighter trucks with fewer axles. However, infrastructure costs and system performance changes were small in magnitude, especially so in comparison with the economic impacts.

An I-O model of Montana's economy, with changes in infrastructure and productivity costs entered to reflect the 80,000 lb GVW limit, showed a long-run decline in gross state product (GSP, output net of inputs) of 0.4%, and employment and income declined 0.2%. The change in GSP is between 2 and 20 times as large as the infrastructure costs in the first year and grows with time.

6. **Laman, Jeffrey, and John Ashbaugh. "Highway network bridge fatigue damage potential of special truck configurations." Transportation Research Record: Journal of the Transportation Research Board 1696 (2000): 81-92.**

The primary objective was to evaluate 78 existing common and FHWA-proposed truck configurations for relative fatigue damage potential, develop a methodology and algorithm to accurately quantify relative fatigue damage to bridges resulting from all types of vehicles, and evaluate the influence of impact (IM) values and endurance limits specified in bridge codes for fatigue analysis.

It was found that fatigue damage potential is primarily a function of axle weight, spacing, and vehicle length instead of GVW.

Certain vehicle axle configurations that will induce significantly lower fatigue damage to bridges for a given GVW. Longer vehicles, typically combination vehicles, with lower axle weights tend to induce an average of 15% of the damage induced by shorter vehicles for a given GVW.

Short rigid-body vehicles or tractor semitrailer vehicles induce an average of 6.5 times more damage than the longer combination vehicles.

Larger fatigue IM values reduce the difference in fatigue damage potential between the least-damaging and the most-damaging vehicles. As the assumed IM increases, low-damage potential vehicles will induce greater normalized fatigue damage and the high-damage potential vehicles will induce less normalized fatigue damage.

7. **Hajek, Jerry, and John Billing. "Trucking trends and changes that affect pavements." Transportation Research Record: Journal of the Transportation Research Board 1816 (2002): 96-103.**

An overview of ongoing and anticipated changes in trucking that affect highway infrastructure, particularly the structural design and performance of pavements is provided. Trends studied included truck volumes, weights, and dimensions and changes in trucking that arise from economic and political changes, regulatory changes in vehicle weights and dimensions, and engineering changes in truck technology.

Weights and dimensions of trucks and truck volumes determine the size and structural design of highway infrastructure and govern its rate of deterioration. Truck loads in North America are now predominantly applied through air suspensions and wheels equipped with radial tires.

Truck Volumes were reviewed. Truck traffic has been increasing for more than 50 years. Growth in truck traffic varies considerably by type of highway and highway location, depending on regional and local factors. Recent studies projected a 34% increase in truck traffic during an 8-year period, or 3.7% per year. More recent U.S. data suggest an actual increase of 22% for the past 5 years, or about 4.0% per annum. However, the past rapid growth in truck traffic may not guarantee future growth.

Liftable axles are increasingly being used on straight trucks, truck trailers, and tractor-semitrailers in states that regulate only by the Bridge Formula. It is often difficult to turn a loaded vehicle when these axles are deployed, so the driver will raise them to allow the vehicle to turn.

Liftable axles make compliance with and enforcement of axle weight limits difficult. The load on the lift axle can be adjusted by the driver, often from inside the cab. Improperly adjusted liftable axles, and especially those that are raised when the vehicle is loaded, result in axles that are loaded beyond allowable weight limits. If a liftable axle load is too high, the axle is overloaded. If it is too low, other axles may be overloaded.

Liftable axles greatly accelerate pavement damage, particularly on ramps, intersections, and local roads. Because of liftable axles, consumption of the highway resource is no longer just a function of traffic volume and allowable weights; it depends on driver behavior as well.

8. Chatti, Karim, Hassan Salama, and Chadi El Mohtar. "Effect of heavy trucks with large axle groups on asphalt pavement damage." Proc., 8th Int. Symp. on Heavy Vehicle Weights and Dimensions. 2004.

The main objective of this paper is to investigate the relative damage (fatigue and rutting) of asphalt pavements using laboratory and field data by considering various axle and truck configurations.

Traffic loads play a key role in consumption of pavement life. Conclusions drawn from the laboratory test results were:

- The dissipated energy method is very useful in determining the fatigue damage caused by multiple axle groups because it directly accounts for the interaction between axles without the need for simplifying assumptions.
- Fatigue damage caused by multiple axles, when normalized by the load they carry, decreases with increasing number of axles per axle group. Therefore, multiple axles are more economically efficient from the point of view of damage caused by the amount of goods transported.
- Rutting damage caused by multiple axles increases with increasing number of axles per axle group. When normalized to the load each axle carries, the results were inconclusive.

There were no conclusive results on the effect of axle/truck configuration on fatigue and rut damage when using performance data from in-service pavements (field data).

9. Chatti, Karim, and Chadi El Mohtar. "Effect of different axle configurations on fatigue life of asphalt concrete mixture." Transportation Research Record: Journal of the Transportation Research Board 1891 (2004): 121-130.

This paper described the effect of different axle configurations and truck types on the fatigue response of an asphalt mixture by laboratory testing and the dissipated energy approach.

Multiple-axle groups were found to be less damaging per tonnage than single axles. Increasing the number of axles carrying the same load resulted in less damage. This decrease in damage was found to be more significant for single, tandem, and tridem axles, while it started to level off at higher axle numbers.

Trucks with more axles and axle groups had lower TFs (damage axle configuration/ damage 18-kip standard axle) per tonnage than those with single axles.

10. Al-Qadi, Imad L., et al. "Effects of tire configurations on pavement damage. Journal of the Association of Asphalt Paving Technologists 74.1 (2005): 921-961.

The main objective of this paper was, therefore, to quantify pavement damage caused by dual and wide-base tires using instrumentation and three-dimensional FE analysis. Results indicated that the new generations of single wide-base tires, 445/50R22.5 and 455/55R22.5, would cause the same or relatively greater pavement damage than conventional dual tires.

11. Salama, Hassan K., Karim Chatti, and Richard W. Lyles. "Effect of heavy multiple axle trucks on flexible pavement damage using in-service pavement performance data." Journal of Transportation Engineering 132.10 (2006): 763-770.

In this paper, actual in-service traffic and pavement performance data for flexible pavements in the state of Michigan are considered. Monitored truck traffic data for different truck configurations are used to identify their relative damaging effects on flexible pavements in terms of cracking, rutting, and roughness.

- Effect of heavy multiple axle trucks on flexible pavement damage:
- The results indicated that trucks with multiple axles-tridem or more-appear to produce more rutting damage than those with only single and tandem axles.
- Trucks with single and tandem axles tend to cause more cracking.

There was not enough evidence to draw a firm conclusion on whether trucks with different axle configurations affected pavement roughness differently.

12. Fortowsky, J., and Jennifer Humphreys. "Estimating traffic changes and pavement impacts from freight truck diversion following changes in interstate truck weight limits." Transportation Research Record: Journal of the Transportation Research Board 1966 (2006): 71-79.

This paper reports on two methodologies that were used to model how changes in weight policy would affect travel patterns of five- and six-axle freight trucks at GVWs above the federal weight limit.

1. Method 1 models freight truck VMT gained and lost on specific routes and the expected truck weight, configuration, and associated ESAL effects of this VMT.
2. Method 2 estimates road cost per ESAL by road type, which allows the derivation of net road costs (or saving) from the ESAL effects estimated with the first methodology.

Higher weight limits would attract to the Interstate route high-weight (between 80,000 and 100,000 lb GVW) combination trucks that currently use alternative routes on Maine state roads (which already allow these higher weight limits).

13. Salama, Hassan, and Karim Chatti. "Evaluating flexible pavement rut damage caused by multiple axle and truck configurations." Proceedings 9th International Symposium on Heavy Vehicle Weights and Dimensions. Pennsylvania. Estados Unidos. 2006.

The effect of trucks with multiple axle configurations on flexible pavement rutting is investigated using a mechanistic-empirical rut model that takes into account the rutting contributions from the various layers comprising the pavement structure and in the laboratory.

The results from mechanistic analyses showed that there is little to no interaction between axles in terms of vertical strains within the asphalt concrete layer.

The five-axle trucks with two tandem axles produced less damage than the truck with only single axles.

The rutting damage in asphalt concrete due to different axle configurations is proportional to the number of axles within an axle group or truck, although the damage caused by larger axle groups appears to be slightly lower per load carried.

14. Guzda, Mark, Baidurya Bhattacharya, and Dennis R. Mertz. "Probabilistic characterization of live load using visual counts and in-service strain monitoring." Journal of Bridge Engineering 12.1 (2007): 130-134.

The AASHTO LRFD design code for maximum live loads on highway bridges is overly conservative, this paper developed a methodology incorporating real-time visual data collection (low-cost and easy to-implement) from traffic cameras coupled with structural strain response of girder bridges. The project identified multiple presences based on the standard truck length of an HS20, 44 feet to find the maximum headway separation distances via moment influence lines, as a function of bridge span and axle configuration. For short span girder bridges, trucks exceeding headway separation distances of two truck lengths do not contribute to maximum loading conditions, thus two truck lengths was the limiting distance used in observations.

Same Lane Multiple Presences (the rear bumper of the lead truck to the front bumper):

This article reported that 6.4% of all trucks travel within two truck lengths of each other, which is not consistent with the figure assumed by Nowak and Szerszen (1998), who noted that on average 2% of trucks are followed by another truck with a headway distance of less than 30 m or roughly two truck lengths.

Adjacent Lane Multiple Presences (gauged from the front bumper of the lead truck to the front bumper of the trailing trucks):

The article stated that 7.6% of occurrences two trucks are traveling within adjacent lanes separated by a distance of less than two truck lengths; and in 0.6% of occurrences, three trucks are in adjacent lanes within two truck lengths.

When the headway distance is limited to 1.5 truck lengths, 6.0% of trucks were observed to travel side by side. When the headway distance is one truck length, 4.4% of all trucks travel side-by-side within a headway distance of one truck length. Different with Moses and Ghosn's (1983) observations (2.4 and 1.6% trucks travel within 1.5 and 1.0 truck lengths) and Nowak and Szerszen's (1998) assumption (6.7% of the heavy trucks travel cross a bridge simultaneously side-by-side)

It appears that significant conservativeness may be embedded in the definition of distribution factors and nominal truck loads in AASHTO LRFD specifications.

Consider the side-by-side presence of two trucks on two adjacent lanes of a highway bridge can be modeled using Poisson Process-Based Occurrence Model.

15. Oh, Jeongho, E. G. Fernando, and R. L. Lytton. "Evaluation of damage potential for pavements due to overweight truck traffic." Journal of transportation engineering 133.5 (2007): 308-317.

This research investigated the effect of OW truck traffic on pavement performance using field pavement response measured by multi-depth deflectometer and characterization of materials based on the nonlinear, cross-anisotropic model.

The finite-element program NCPA, which was used to model the pavement response by considering the stress dependent, cross-anisotropic characteristics for unbound granular material and subgrade soil, was found to be effective to predict the pavement response.

Equations were established to predict service life consumption due to the passage of each truck, based on the equations, it indicates greater potential for accelerated pavement deterioration on the route due to OW truck use.

16. Haider, Syed Waqar, and Ronald S. Harichandran. "Relating axle load spectra to truck gross vehicle weights and volumes." Journal of transportation engineering 133.12 (2007): 696-705.

This paper explores the possibility of extracting axle loads from truck weight and volume data and presents a practical method of modeling axle load spectra.

The axle loads and frequencies for a particular axle configuration depend on the truck types traveling on a particular highway section.

It shows that single and tandem axle types combined together represent more than 95% of the total axle counts for all sites in both data sets.

It is possible to develop reasonable relationships between truck weights and axle loads.

17. Chatti, Karim, Anshu Manik, and Nicholas Brake. "Effect of axle configurations on fatigue and faulting of concrete pavements." 10th International Symposium on Heavy Vehicle Transport Technology. Paris, France. 2008.

In this paper, the fatigue life of concrete beams was determined in the laboratory for different axle configurations to identify the relative pavement fatigue damage resulting from these multiple axle trucks.

Fatigue life is generally related to the longitudinal stress at the mid-slab in the wheel path under the moving load.

The normalized fatigue damage per axle for larger axle groups is less than the single axle under identical stress ratios. The damage is even lower when considering the reduction of stress under multiple axles.

18. Tirado, Cesar, et al. "Process to estimate permit costs for movement of heavy trucks on flexible pavements." Transportation Research Record: Journal of the Transportation Research Board 2154 (2010): 187-196.

Using Integrated Pavement Damage Analyzer (IntPave), a process based on a mechanistic–empirical (ME) analysis was developed to estimate permit fees on the basis of truck-axle loading and configuration as well as the predicted pavement deterioration that they cause.

In Texas, a GVW that exceeds 250 kips (1.1 MN) is considered a "super-heavy load" and requires a permit before the vehicle can travel on a state-maintained roadway system.

Factors Influencing Permit Fee

The more substantial the pavement structure is, the lower the incremental damage and, as a result, the permit fee will be.

The most critical layer in the pavement for reasonably stiff subgrades is the base layer. The higher the quality of the base is, the lower the permit fee will be. Thicker, lower-quality bases promote more incremental damage and, as a result, higher permit fees.

The damage to the pavements when the subgrade is extremely soft is significant, and as such, the hauling of heavy loads on such roads should not be permitted.

The policies of a local highway agency related to the damage threshold to rehabilitation have a significant impact on the permit fee. The more relaxed this threshold is, the lower the cost of a permit will be.

In contrast to actual pavement design, with the parametric study, the uncertainty in traffic volume has a small impact on the cost of the permit for passage of a heavy load.

The existing pavement damage at the time of the passage of the heavy load also affects the permit fee and may be considered.

19. Zhao, Jian, and Habib Tabatabai. "Evaluation of a permit vehicle model using weigh-in-motion truck records." Journal of Bridge Engineering 17.2 (2011): 389-392.

The standard permit vehicle in Wisconsin was evaluated by using WIM truck records on the basis of statistical analyses of the maximum moments and shear in simply supported, 2-span, and 3-span continuous girders in the selected heaviest 5% of trucks in each vehicle class/group.

The comparisons showed that five-axle, short, single-unit trucks may cause larger moment/shear in bridge girders than the standard permit vehicle, and a five-axle truck model was proposed to supplement the standard permit vehicle for possible use in bridge design and rating in Wisconsin.

The analysis of all other vehicle groups indicated that five-axle short trucks most likely cause larger girder moments/shear than the Wis-SPV. Such short, single-unit trucks may be SHVs such as dump trucks, transit mixers, and trash trucks.

20. OBrien, Eugene J., Bernard Enright, and Cathal Leahy. "The effect of truck permitting policy on US bridge loading." (2013).

The extreme loading events likely to cause characteristic load effects are dominated by very heavy permit trucks. This paper examines truck loading at three WIM sites to identify permit trucks, and separately examine permit and standard trucks' importance for bridge loading.

Permit truck filtration (based on one or more of the following rules) was used:

1. More than nine axles.
2. Group of four (or more) axles at rear of truck.
3. More than six axles, with a tridem at rear (not a long combination vehicle).
4. Articulated semi-trailer configuration which is longer than legal limit or has > six axles.
5. Maximum inter-axle spacing less than 5.5 m and average spacing less than 2.7 m (mobile crane type).

New bridges are designed to carry notional traffic loading, deemed to represent the worst extremes of loading that can be reasonably expected in the bridge lifetime. Such models are conservative which is appropriate, given the modest marginal cost of providing additional load-carrying capacity. However, for an existing bridge, excessive conservatism in the safety assessment may result in premature replacement and an unnecessary shortening of the bridge life. The savings in characteristic 75-year maximum load effect vary by load effect and span and that savings of up to 45% are possible.

21. Muthumani, Anburaj, and Xianming Shi. "Impacts of Specialized Hauling Vehicles on Highway Infrastructure, the Economy, and Safety: Renewed Perspective." Environmental Sustainability in Transportation Infrastructure@ Selected Papers from the International Symposium on Systematic Approaches to Environmental Sustainability in Transportation. ASCE, 2015.

Because the size and weight limits of heavy trucks have significant implications in terms of infrastructure costs, potential economic benefits, and motorist safety, this study was conducted to examine the current knowledge related to the impact of SHVs on highway infrastructures, economy, and safety.

Relative to conventional trucks, SHVs may not induce significant damage to asphalt pavements and can potentially induce additional damage to concrete pavements;

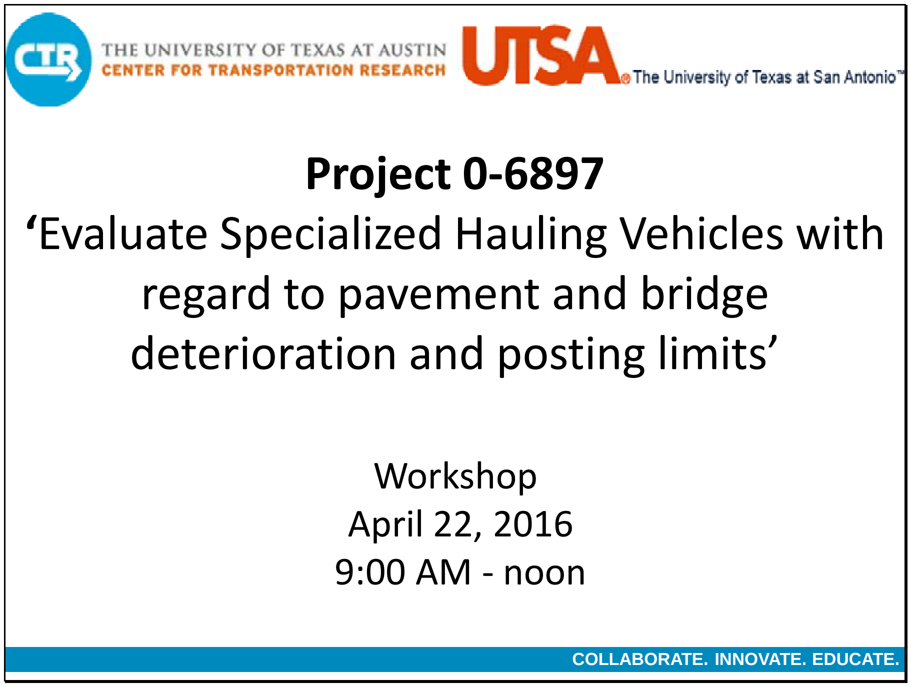
The impact of SHVs to bridge damage is mostly attributed to short span bridges (25 feet to 55 feet). In particular, short span timber and steel bridges are most vulnerable to impacts by SHVs.

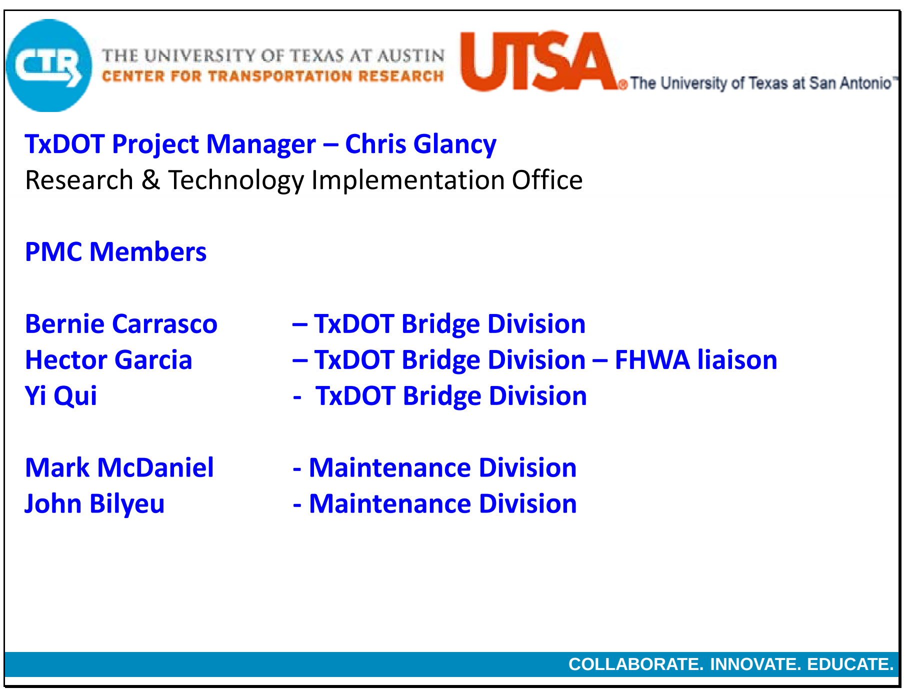
Bridge weight limit posting is expected to increase with the allowance of SHVs, especially for short span timber and steel bridges. This, in turn, is expected to have negative impacts such as more DOT resources to install and maintain signs, increased state liabilities, increased vandalism, apathy and violations.

Increasing SHVs weight limits is most likely to slightly benefit the economy, due to increased efficiency and reduced transport costs. SHVs are likely to increase bridge costs as a result of accelerated need for maintenance, rehabilitation, or replacement of bridge components, but they are unlikely to increase pavement costs unless single-axle loads exceed 18,000 lbs.

Replacing longer trucks with SHVs is likely to benefit operator safety, as SHVs are shorter and thus easier to operate. But increasing SHVs weight limits is likely to increase their crash risk, as they would then take longer to stop and become more difficult to operate. However, assuming that fewer vehicles are run because each can have a higher payload, the reduced exposure may bring a safety benefit.

Appendix C: Workshop Materials





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Research Team

Research Supervisor Dr. Mike Walton

Dr. Mike Murphy
Dr. Jorge Prozzi – Professor
Mr. Robert Harrison - Deputy Director – CTR
Lisa Loftus-Otway Attorney at Law
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Dr. Nan Jiang – Research Fellow
Manar Hasan – GRA
Hongbin Xu – GRA
Swati Agrawal - GRA

UTSA - Bridges

Dr. Jose Weissmann – UTSA
Dr. Angela Weissmann - UTSA

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Specialized Hauling Vehicles

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Workshop Agenda

I. **Introduction and Workshop Objectives** – Mr. Chris Glancy and Dr. Michael Walton

II. **0-6897 Project Objectives** – Dr. Mike Murphy

III. **Pavement Consumption Analysis** – Dr. Jorge Prozzi

IV. **Bridge Consumption Analysis** – Dr. Jose Weissmann

V. **Group Discussion (Question & Answer)** Dr. Walton - Moderator

VI. **Discuss online SHV survey – request participation** Dr. Nan Jiang / Swati Agarwal

VII. **Assess Workshop and Next Steps** – Drs. Murphy and Walton

VII. **Adjourn** – Dr. Walton

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I. **Introduction and Workshop Objectives** – Dr. Michael Walton

a) Initiate dialogue with companies that operate SHVs
b) Discuss National study with state input regarding SHVs
   - NCHRP 575 – 5 SHV bridge load rating vehicles
   - FHWA November 15, 2013 memo to states
c) Discuss current data collection processes and study objectives
d) Discuss pavement and bridge consumption processes
e) Learn benefits of SHV operations
f) Ensure we are not missing important considerations based on trucking company experience / knowledge

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II. 0-6897 Project Objectives – Dr. Mike Murphy

Study Part I

a) Characterize SHV configurations operating in Texas – are additional bridge load rating models required?
   - NCHRP 575 – 5 SHV bridge load rating vehicles
   - FHWA November 15, 2013 memo to states

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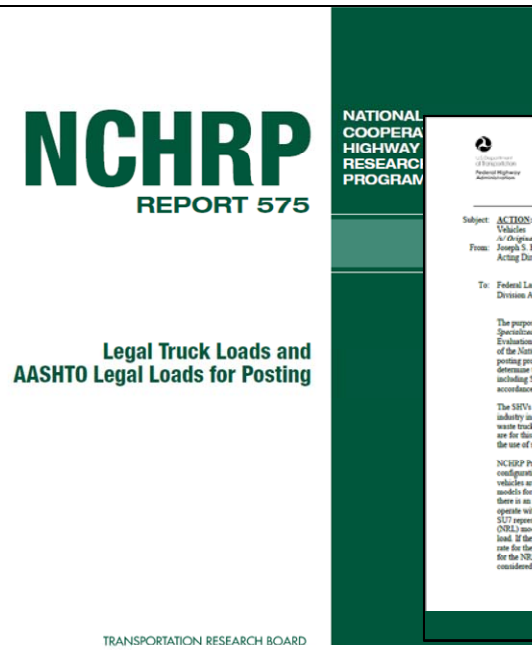
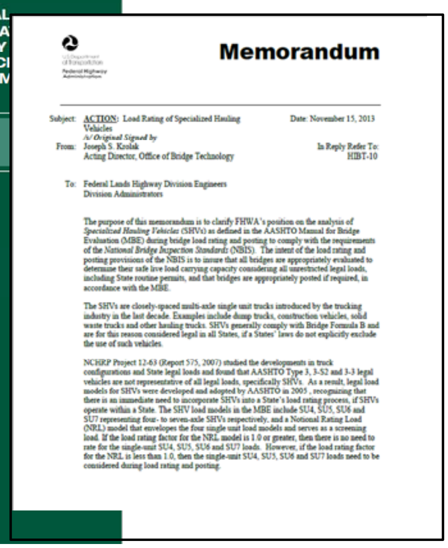




Memorandum

Subject: ACTION: Load Rating of Specialized Hauling Vehicles — Date: November 15, 2013

/s/ *Original Signed by*

From: Joseph S. Krolak, Acting Director, Office of Bridge Technology — In Reply Refer To: HIBT-10

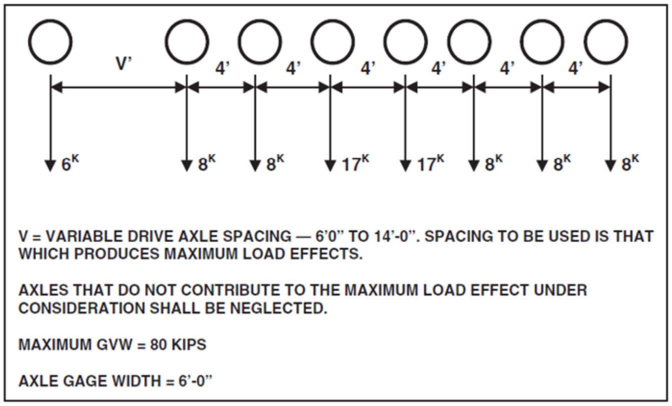
To: Federal Lands Highway Division Engineers, Division Administrators

The purpose of this memorandum is to clarify FHWA's position on the analysis of *Specialized Hauling Vehicles* (SHVs) as defined in the AASHTO Manual for Bridge Evaluation (MBE) during bridge load rating and posting to comply with the requirements of the *National Bridge Inspection Standards* (NBIS). The intent of the load rating and posting provisions of the NBIS is to insure that all bridges are appropriately evaluated to determine their safe live load carrying capacity considering all unrestricted legal loads, including State routine permits, and that bridges are appropriately posted if required, in accordance with the MBE.

The SHVs are closely-spaced multi-axle single unit trucks introduced by the trucking industry in the last decade. Examples include dump trucks, construction vehicles, solid waste trucks and other hauling trucks. SHVs generally comply with Bridge Formula B and are for this reason considered legal in all States, if a States' laws do not explicitly exclude the use of such vehicles.

NCHRP Project 12-63 (Report 575, 2007) studied the developments in truck configurations and State legal loads and found that AASHTO Type 3, 3-S2 and 3-3 legal vehicles are not representative of all legal loads, specifically SHVs. As a result, legal load models for SHVs were developed and adopted by AASHTO in 2005 , recognizing that there is an immediate need to incorporate SHVs into a State's load rating process, if SHVs operate within a State. The SHV load models in the MBE include SU4, SU5, SU6 and SU7 representing four- to seven-axle SHVs respectively, and a Notional Rating Load (NRL) model that envelopes the four single unit load models and serves as a screening load. If the load rating factor for the NRL model is 1.0 or greater, then there is no need to rate for the single-unit SU4, SU5, SU6 and SU7 loads. However, if the load rating factor for the NRL is less than 1.0, then the single-unit SU4, SU5, SU6 and SU7 loads need to be considered during load rating and posting.

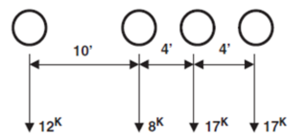
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_575.pdf



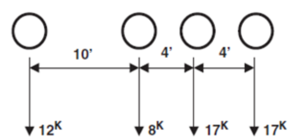
AASHTO NRL used as a screening tool – AASHTO SU -4 through SU-7 configurations or state load ratings that are consistent with AASHTO used for bridge load rating analysis

International SU-3 Fuel-Lube Truck

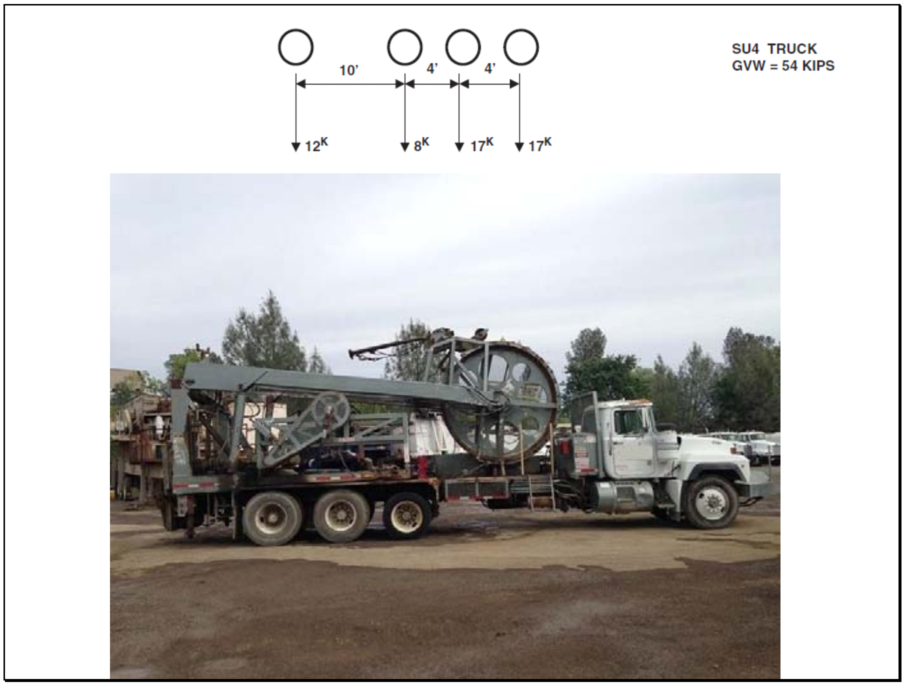
Not included in NCHRP 575 – few 3-axle trucks with liftable axles have been observed thus far

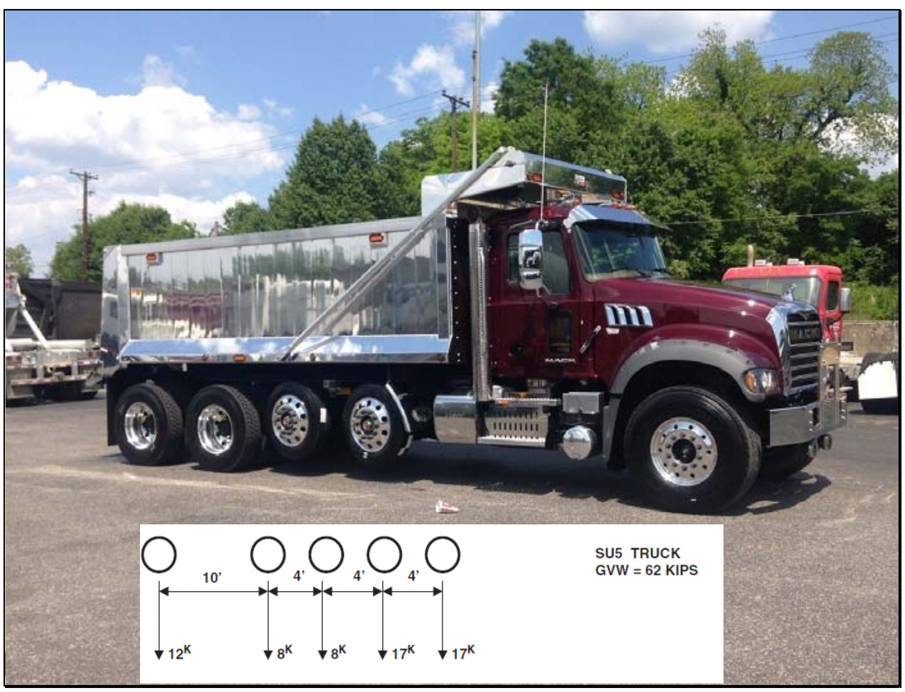


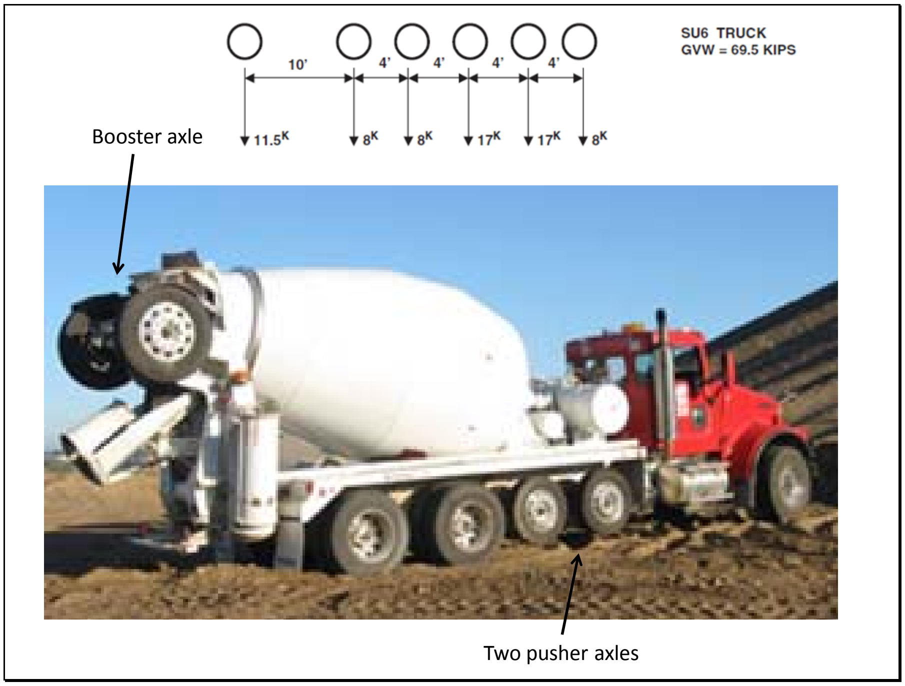
SU4 TRUCK
GVW = 54 KIPS

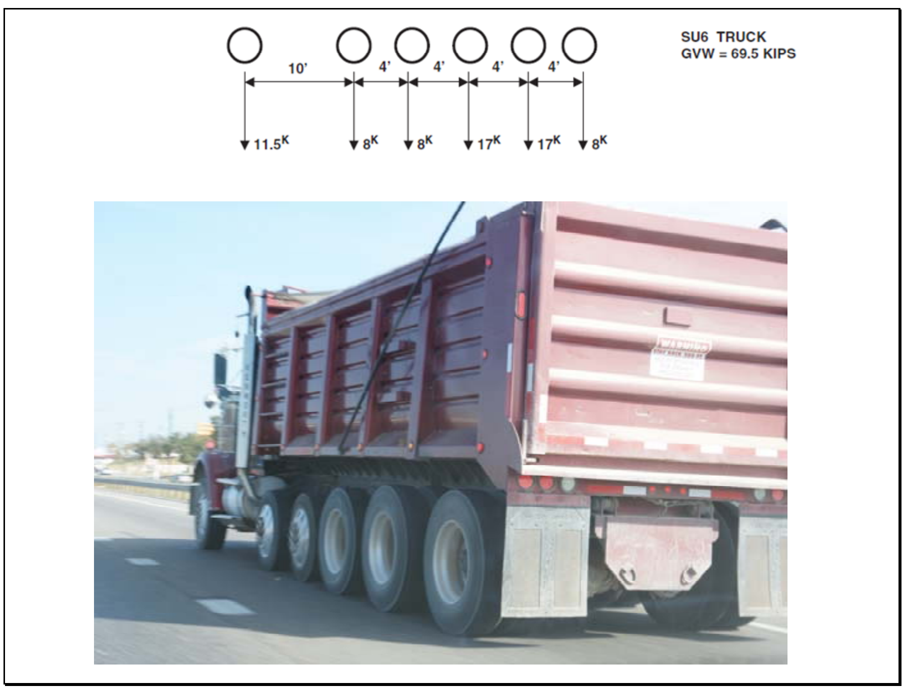


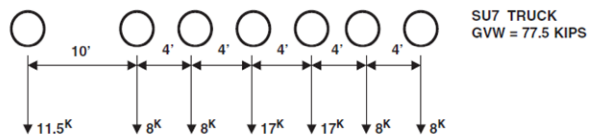
SU4 TRUCK
GVW = 54 KIPS


SU4 TRUCK
GVW = 54 KIPS
10'
4'
4'
12K
8K
17K
17K


SU5 TRUCK
GVW = 62 KIPS
10'
4'
4'
4'
12K
8K
8K
17K
17K


SU6 TRUCK
GVW = 69.5 KIPS
10'
4'
4'
4'
4'
11.5^K
8^K
8^K
17^K
17^K
8^K
Booster axle
Two pusher axles


SU6 TRUCK
GVW = 69.5 KIPS
10'
4'
4'
4'
4'
11.5^K
8^K
8^K
17^K
17^K
8^K



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II. 0-6897 Project Objectives – Dr. Mike Murphy

Study Part I

a) Characterize SHV configurations operating in Texas – are additional bridge load rating models required?
   - NCHRP 575 – 5 SHV bridge load rating vehicles
   - FHWA November 15, 2013 memo to states

b) Estimate the number of SHVs by operational type and by regional distribution

c) Characterize SHVs by operational type with regard to:
   - axle and tire types,
   - axle and tire loads by type,
   - Gross Vehicle Weight

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II. 0-6897 Project Objectives – Dr. Mike Murphy

Study Part II

a) Perform a consumption analysis for pavements
   - Selection of SHV configurations and pavement types
   - $ / VMT

b) Perform a consumption analysis for bridges
   - Same set of SHV configurations
   - Evaluate bridges over a network > $/VMT

c) Evaluate pavements and bridges – potential for load posting

d) Safety impacts (if any) of SHV operations

e) Draft recommendations regarding SHV operations in Texas

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Pavement Consumption Analysis Concepts

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Pavement Consumption Analysis Concepts

- We model single axles and axle groups of different loads on different pavement structures to determine pavement consumption

  $ / VMT for a given truck configuration

- American Association of Highway and Transportation Officials (AASHTO) equivalent axle load concepts

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AASHO Test Track

- **Functional and Structural condition monitored.**
- **Concept of Serviceabilty developed.**
- **Serviceability over time = Performance.**
- **Provided well-documented performance data.**
- **18-Kip (Kip = Kilo pounds = 1,000 lbs) axle load equiv. relationships developed.**

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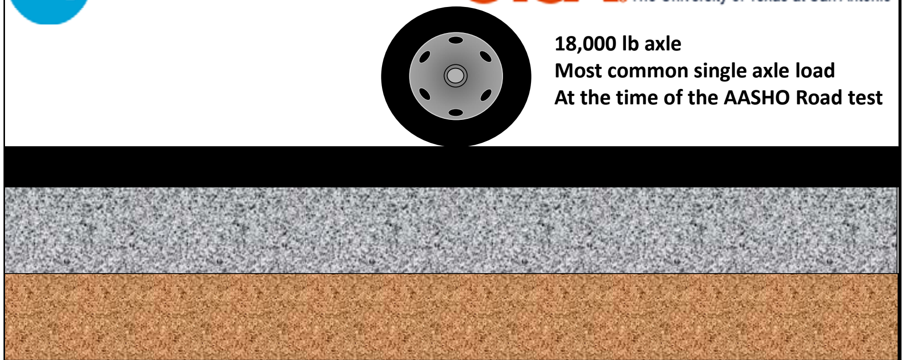

- Close observation of pavement consumption under single axles and axle groups
- Different axle loads
- Basis of the Equivalent Single Axle Load Concept

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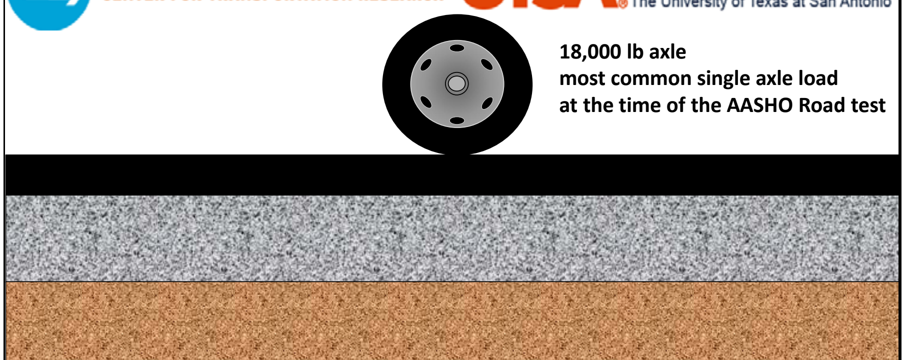

- Consumption of an 18,000 lb axle for any pavement is the reference and is always 1.00 or, 1 Equivalent Single Axle Load (ESAL)
- Consumption of single axles of other weights, tandem or tridem axles is in relation to the consumption of an 18,000 lb axle
- Thus other single axle weights or axle groups of different weights can be less than or greater than 1.00 ESAL

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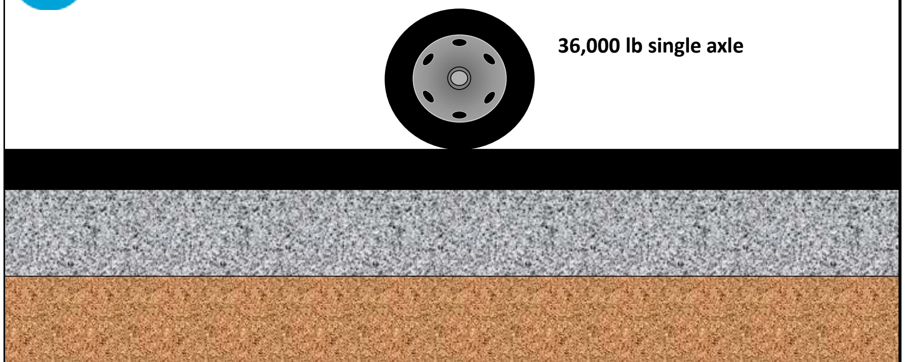

- **A basic relationship that was found at the AASHO Road Test is that consumption increases based on a 4th power law.**
- **Thus, if we double the load on a single 18,000 lb axle, the consumption is $(36/18)^4$ = 16 times greater.**

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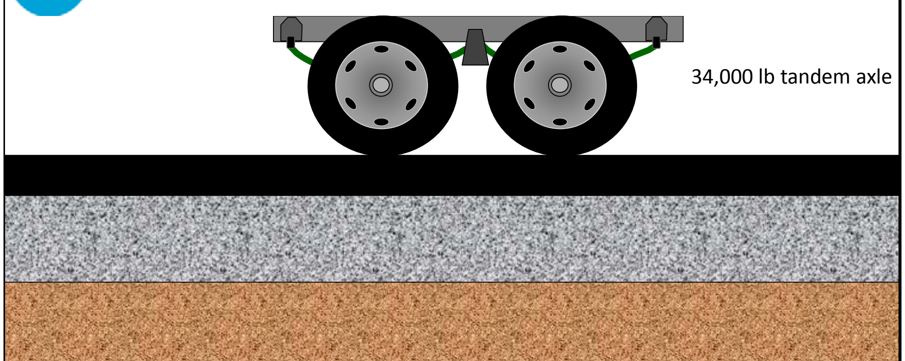

- Tandem axles were also evaluated to determine consumption relationships to an 18,000 lb axle (ESAL)
- Grouping axles together spreads load over a greater distance…..
- Thus we cannot think of a 34,000 lb tandem axle the way same as two single 17,000 lb axles – the tandem axle results in less consumption……..
in fact approximately 1.11 ESALS. However, two 17,000 lb singles axles = 1.59 ESALs

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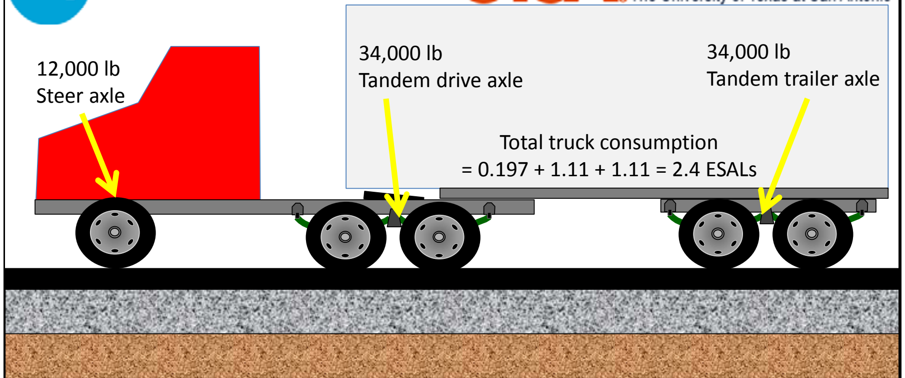

- The development of the ESAL concept allows us to add together the consumption for single, tandem and tridem axles of different weights to arrive at the total consumption for a vehicle
- 12,000 lb steer axle = 0.197 ESALs or = 0.197 the consumption of an 18,000 lb single axle
- 34,000 lb tandem drive axle = 1.11 ESALs from lookup table
- 34,000 lb tandem trailer axle - 1.11 ESALs from lookup table

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Pavement Consumption Analysis Concepts

- The Single Equivalent Axle Load Concept provides a base line that allows 'summing up' a mix of vehicles that have different axle configurations and weights

- Thus traffic is summed to one number for use in pavement design (number of ESALs over a period of time, 20 or 30 years).

- However……….

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Pavement Consumption Analysis Concepts

- Rider 36 and more recent UT-CTR/UTSA consumption analyses have used the AASHTO DarWin ME software – accepted practice / in wide use.

- The AASHTO ESAL concept and DarWin ME assume that the weight of an axle group is equally distributed over the axles in the group….

- This assumption is likely not true for SHVs…..

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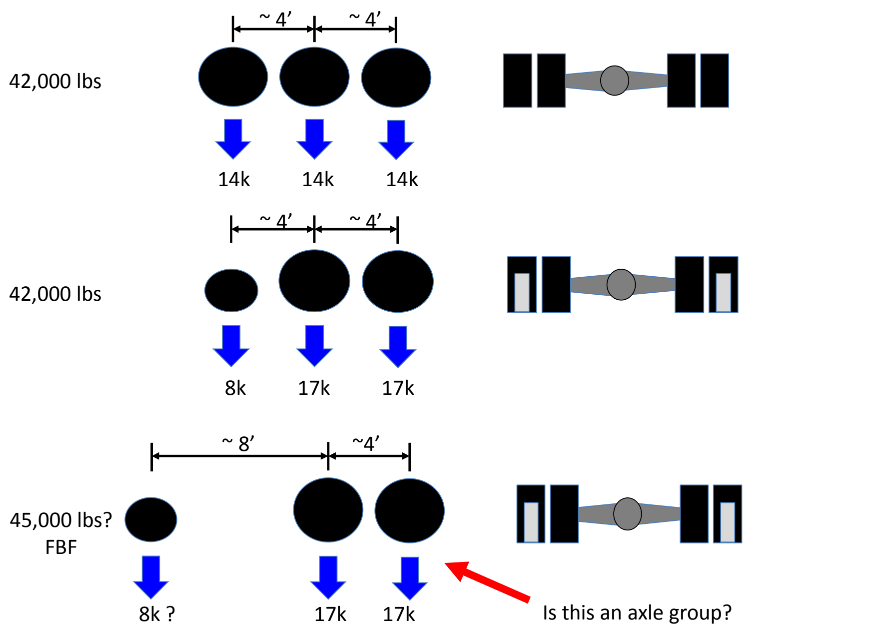
42,000 lbs tridem based on Federal Bridge Formula (are these axle configurations equivalent?)



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Pavement Consumption Analysis Concepts

- A different analysis method may be required to determine consumption values for SHVs in Project 0-6897
- The research team has discussed different possibilities which are being explored
- In the mean time, we are gathering as much information about SHVs in Texas to ensure we are accurately characterizing these vehicles.

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- We can still use information from previous studies such as the matrix of pavement structures.

…..and additional information from previous studies conducted by others as we move forward.

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Summary

- Research Team is currently collecting data to characterize SHVs in Texas
- We are exploring options for analyzing SHV axle groups and vehicle configurations that consistent in process with previous studies though different software might be employed
- We are seeking your support to ensure we are considering the proper factors and are accurate in evaluating SHVs

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Bridge SHV Analysis

José Weissmann and Angela Weissmann

University of Texas San Antonio
Department of Civil and Environmental Engineering

UTSA Engineering

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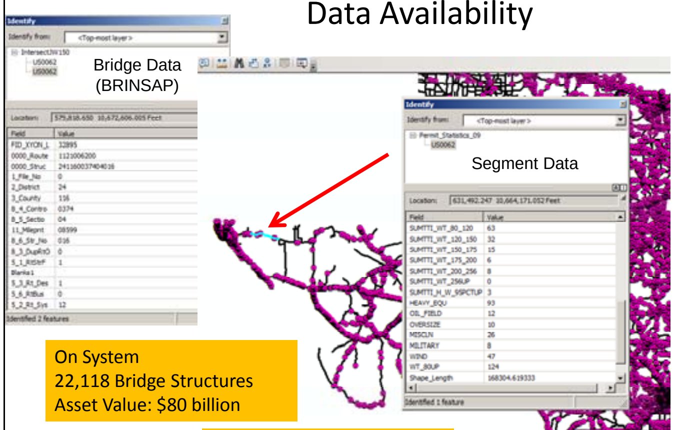
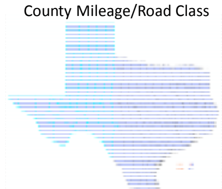
Data Availability



County Mileage/Road Class



On System
22,118 Bridge Structures
Asset Value: $80 billion

Off System
12,568 Bridge Structures
Asset Value: $13 billion

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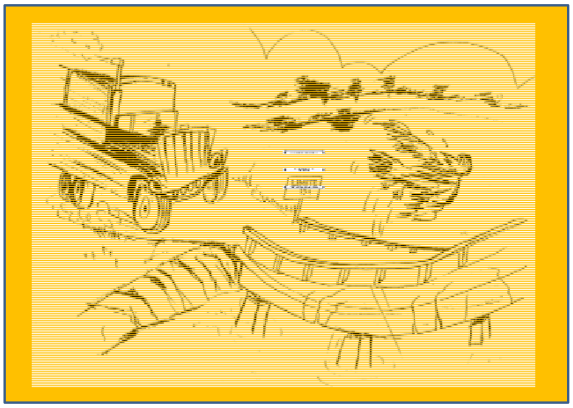
Each Bridge has a Rated Capacity



Inventory Rating
Operating Rating

On System – 26% under 36 Tons Inventory Rating

Off System – 57% under 36 Tons Inventory Rating

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Bridge Fatigue Concepts

$$ConsumptionRatio = \left(\frac{M_{OSOW}}{M_{Inventory}}\right)^m = \frac{N_{Inventory}}{N_{OSOW}}$$

- ❑ $M_{inventory}$, M_{OSOW} — Live load moments for the Inventory Rating load and OSOW configuration respectively
- ❑ Consumption Ratio — Consumption factor for the OSOW load relative to the Inventory Rating load for one passage of the OSOW load
- ❑ m — Constant dependent on material and bridge detail
- ❑ N — Allowable number of cycles of load application.

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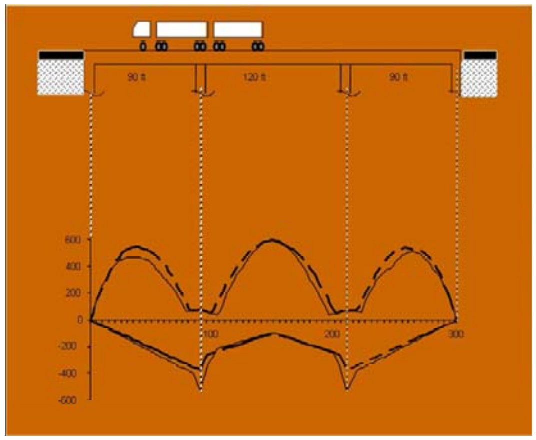
Computerized Bending Moment Envelopes

(Calculation of $M_{inventory}$ M_{OSOW} for network)



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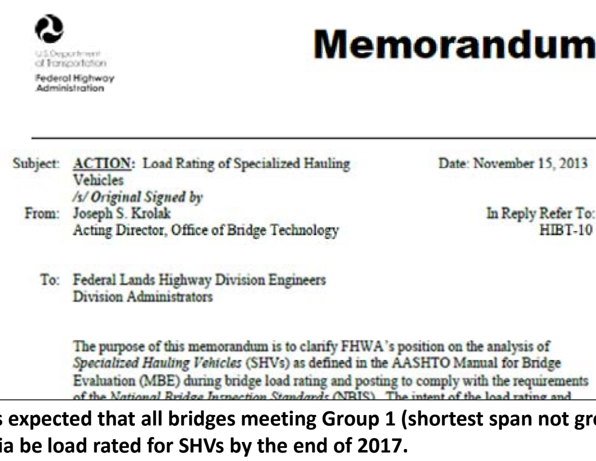


U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: ACTION: Load Rating of Specialized Hauling Vehicles

Date: November 15, 2013

/s/ Original Signed by

From: Joseph S. Krolak
Acting Director, Office of Bridge Technology

In Reply Refer To:
HIBT-10

To: Federal Lands Highway Division Engineers
Division Administrators

The purpose of this memorandum is to clarify FHWA's position on the analysis of *Specialized Hauling Vehicles* (SHVs) as defined in the AASHTO Manual for Bridge Evaluation (MBE) during bridge load rating and posting to comply with the requirements of the *National Bridge Inspection Standards* (NBIS). The intent of the load rating and

....it is expected that all bridges meeting Group 1 (shortest span not greater than 200') criteria be load rated for SHVs by the end of 2017.

....bridges in Group 2 (all bridges not included in Group 1) shall be load rated for SHVs by December 31, 2022

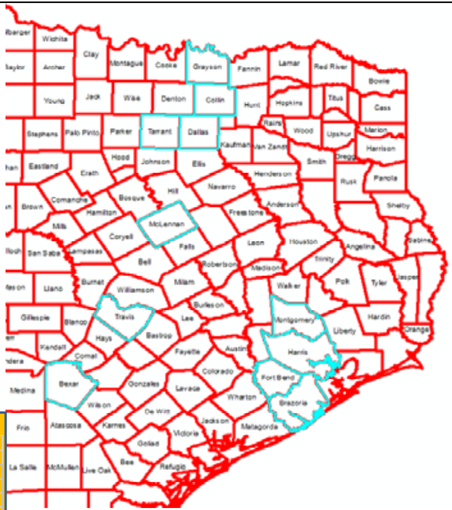
SHV: X—X—OO (427 Truck Sample DPS)

	Axle Group 1 (X)	Axle Group 2 (X)	Axle Group 3 (OO)
Average Weight (lbs)	14,738	11,884	39,866

Off/On Sys Bridges Moment Ratios

Summary for Off System

	MOMENT RATIOS				
COUNTY	LE 1	GT 1 LE 1.2	GT 1.2 LE 1.3	GT 1.3	Total
HARRIS	159	166	84	1,142	1,551
DALLAS	161	160	51	332	704
TRAVIS	49	47	27	149	272
BEXAR	66	90	15	127	298
FORT BEND	30	77	5	121	233
BRAZORIA	8	58	10	96	172
HIDALGO	8	14	14	91	127
COLLIN	123	86	17	89	315
TARRANT	146	127	29	87	389
GRAYSON	18	81	39	82	220
MONTGOMERY	13	15	9	79	116
MCLENNAN	20	31	21	73	145
HILL	5	14	2	70	91
BELL	8	9	15	68	100
NACOGDOCHES	1	24	14	68	107



45% of the Off system with moment ratios ge 1.3

20% of the On system with moment ratios ge 1.3

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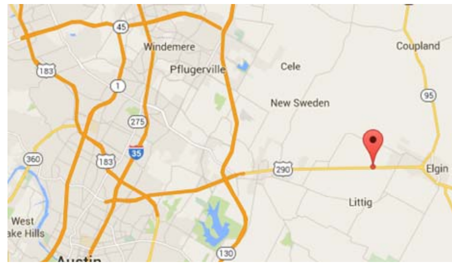
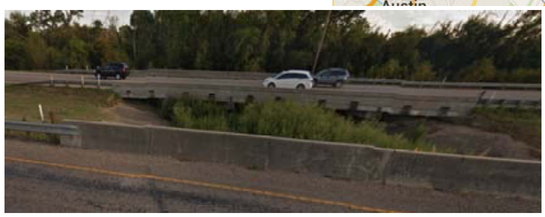
US290 Travis County
Moment Ratio Inventory = 1.92
Moment Ratio Operating = 1.13
Current Inventory Rating = 23 tons
Current Operating Rating = 39 tons
Strong Candidate for Posting
Facility Carried US290 Eastbound
Feature Crossed Big Dry Creek
Maximum span 20ft
Structure Length 100ft
Year built 1940
ADT 13,000 in 2011





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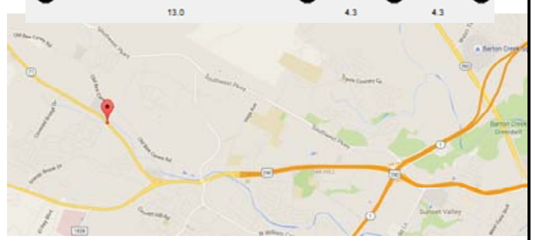
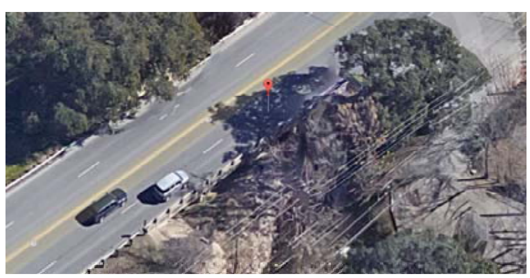
SH71 Travis County
Moment Ratio Inventory = 1.74
Moment Ratio Operating = 0.96
Current Inventory Rating = 27 tons
Current Operating Rating = 49 tons
Strong Candidate for Posting
Facility Carried SH71
Feature Crossed Williamson Creek
Maximum span 25ft
Structure Length 100ft
Year built 1949
ADT 25,000 in 2011





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Workshop Discussion

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VI. Discuss online SHV survey – request participation

- An online survey has been designed and will be distributed by email to companies in relevant industries after this workshop
- The survey mainly asks the composition of a company's vehicle fleet and their opinions about the operations of SHVs
- The survey results will be very helpful to characterize the operations of SHVs in Texas
- Please participate the survey and provide your comments

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VI. Discuss online SHV survey – request participation

- Axle spaces --- Hard to obtain? Any suggestions about how we can obtain this information?
- Number of each type of SHVs --- Too detail to answer? Better way to obtain this information?
- Typical weight apply on liftable and booster axle --- Hard to obtain?

Q3. **Among SINGLE UNIT 4, 5, 6, and 7 axle commercial vehicle trucks with one or more LIFTABLE axles, how many trucks of the types listed below does your company have?**

	Number of Trucks
SU4: Single Unit 4 axle truck (4 axles with tag axles only)	
SU4: Single Unit 4 axle truck (4 axles with pusher axles only)	
SU4: Single Unit 4 axle truck (4 axles with booster axle only)	
SU4: Single Unit 4 axle truck (4 axles - other configuration)	
SU5: Single Unit 5 axle truck (5 axles with tag axles only)	
SU5: Single Unit 5 axle truck (5 axles with pusher axles only)	
SU5: Single Unit 5 axle truck (5 Axles with pusher, tag, and/or booster axles)	
SU5: Single Unit 5 axle truck (5 axles - other configuration)	
SU6: Single Unit 6 axle truck (6 axles with tag axles only)	
SU6: Single Unit 6 axle truck (6 axles with pusher axles only)	
SU6: Single Unit 6 axle truck (6 Axles with pusher, tag, and/or booster axles)	
SU6: Single Unit 6 axle truck (6 axles - other configuration)	
SU7: Single Unit 7 axle truck (7 axles with tag axles only)	
SU7: Single Unit 7 axle truck (7 axles with pusher axles only)	
SU7: Single Unit 7 axle truck (7 Axles with pusher, tag, and/or booster axles)	
SU7: Single Unit 7 axle truck (7 axles - other configuration)	
Other configuration (please describe)	

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VI. Discuss online SHV survey – request participation

- Do you prefer the idea of an online survey or is some other format more acceptable?
- Are there any other suggestions about the survey which would increase the number of responses to the survey?
- Any volunteers? Take the survey and provide comments about how to improve the survey including questions that were not clearly understood, questions that cannot easily answer, or questions that you are not willing to answer.

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Assess Workshop and Next Steps

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Adjourn

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Appendix D: SHV Survey Draft

Survey

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Specialized Hauling Vehicle Survey

Please fill out this survey as accurately and completely as possible. If you need help or have questions about filling out this form, please email **Dr. Mike Murphy** at **michael.murphy@engr.utexas.edu** or call him at **(512) 232-3134**

Background

Federal Highway Administration is requiring each State DOT to characterize the Specialized Hauling Vehicles that operate in their state. These vehicles include the dump trucks, ready mix, garbage / recycling and other types of straight trucks with liftable and/or booster axles. The Center for Transportation Research at The University of Texas at Austin has contracted with TxDOT to help evaluate the operations of SHVs in Texas. This survey will help the research team better know the numbers of Specialized Hauling Vehicles of different truck types and configurations that operate in Texas.

Specialized Hauling Vehicles (SHV) defined in the survey – A **single-unit** truck with from 4 to 7 axles, out of which 1 to 4 axles are lifetable and can be raised once the cargo is delivered.

The following pictures show some examples of SHV's:

SU4 with one pusher axle

SU4 with one tag axle

SU5 with one pusher and one booster axles

SU6 with one pusher and one tag axles

SU7 with three pusher and one booster axles

SU7 with four pusher axles

All survey responses will be kept confidential, and the information obtained from the survey responses will be amalgamated for the purposes of the 0-6897 project.

It is estimated that this survey will take **10** minutes to complete. The Research Teams at The Center for Transportation Research at the University of Texas at Austin appreciate your time in responding to this survey

.

A. Truck Fleet

Q1.

How many total trucks **(Commercial Motor Vehicles - not including pickups or delivery vans)** are in your fleet?

Q2. How many SHVs does your fleet have?

. Are your answers referring to your fleet at a particular plant or the entire state?

Particular Site/Plant

State of Texas

.

B. Cargo Type

Q3.

Which of the following best describes the cargo type (or part of your cargo types) in which your SHVs were most often used during 2015?

Agricultural Products

Crane

Hot Mixed Asphalt Concrete

Dump Trucking (e.g., Gravel, sand, top soil)

Garbage / Recycling

Ready Mixed Concrete

Other

Q3b. Please specify:

.

C. Operations

Q4.
For each category, what **percentage** in terms miles traveled do your SHVs operate in 2015?

Short Haul (<= 25 miles one-way)	
Long Haul (> 25 miles one-way)	

Q5. In what metropolitan areas or counties do your SHVs mainly operate?

Q6. What is the average mileage of your SHV trucks? (For example, on average, an SHV truck in your company may travel "**15,000**" miles per year)

.

D. Breakdown of Truck Fleet by Type

Q7.
For all straight trucks in your fleet, how many trucks does your fleet have by each of the following truck configurations?

Note: In the choices below, **X** refers to single-tired axle, **O** refers to dual-tired axle, **L** refers to a liftable pusher/tag axle, and **B** refers to a booster liftable axle at the back.

For example, a truck that looks like this (with liftable axles colored red):

*Would be referred to as **X--LOO***

And a truck that looks like this (with liftable axles colored red):

*Would be referred to as **X--LLOO--B***

	Total Number
SU3 = X--LO	
SU4 = X--LOO	
SU4 = X--OOL	
SU4 = X--OO--B	

Q7b. If you entered a number for any of the "Other Configuration" options, please specify what these configurations are, briefly.

Q8. **Filling in the table below is OPTIONAL**

	Input Field
Date	
Name of trucking company (Doing Business As Name)	
Office address	
Name of contact person	
Phone number	
Contact email address	

Thank you very much for taking the time to complete the survey. If you have any questions, please contact Dr. Mike Murphy. (michael.murphy@engr.utexas.edu)

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