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16. Abstract

The Western Transportation Institute (WTI) conducted research on behalf of the New Mexico Department of Transportation (NMDOT) to document current knowledge and practice related to the multiple dimensions of weight limits for Specialized Hauling Vehicles (SHVs), with a focus on the scenarios of interest to the NMDOT. The study includes a discussion of the following issues: Legal Weight Limits by State, SHV Laws and Regulations in Selected States, Impacts of SHVs on Pavements and Bridges, Impacts of SHV on Bridge Posted Weight Limits and Enforcement, and Impacts on the Economy and Safety. It concludes with key findings and recommendations.

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IMPACTS OF INCREASING MAXIMUM WEIGHTS OF SPECIALIZED HAULING VEHICLES (SHVs)
Final Report

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PREFACE

The research reported herein reviews current knowledge and practice related to the multiple dimensions of weight limits for Specialized Hauling Vehicles (SHVs), with a focus on the scenarios of interest to the NMDOT.

NOTICE

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DISCLAIMER

EXECUTIVE SUMMARY

The Western Transportation Institute (WTI) conducted research on behalf of the New Mexico Department of Transportation (NMDOT) to document current knowledge and practice related to the multiple dimensions of weight limits for Specialized Hauling Vehicles (SHVs), with a focus on the scenarios of interest to the NMDOT. The study includes a discussion of the following issues: Legal Weight Limits by State, SHV Laws and Regulations in selected States, Impacts of SHVs on Pavements and Bridges, Impacts of SHVs on Bridge Posted Weight Limits and Enforcement, and Impacts on the Economy and Safety.

Some of the findings from this study include:

- The study examined the legal allowances for SHVs in six states. States such as Arizona, Alabama, Oklahoma, Kansas and Texas allow SHVs on their state roads. For Colorado, the maximum Gross Vehicle Weight (GVW) limit for single unit vehicle is 54,000 lbs irrespective of the distance between the axles and the number of axles.
- Relative to conventional trucks, SHVs may not induce any additional damage to flexible (asphalt) pavements and can potentially induce additional damage to rigid (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 need for 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.

One of the key findings from this study is that increasing maximum weights of SHVs can significantly deteriorate bridges. In particular, local and short span bridges are most vulnerable to the impacts of increasing weight limits for SHVs. Additional studies should be conducted to enable states to balance the benefits of allowing SHV vehicles against the negative consequences

to bridges and rigid pavements and against the requirements for additional enforcement and state regulatory resources on more posted bridges. For instance, more research is needed to achieve better understanding of how the introduction of SHVs would affect non-DOT agencies in terms of taxation (revenue) and operations (safety and mobility). Ideally, any legislative or regulatory actions that permit the introduction of SHVs should be accompanied by provisions for additional resources on the part of non-DOT agencies to develop revenue structures, inspection procedures, and other oversight functions.

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ACRONYMS

AASHO - American Association of State Highway Officials

AASHTO - American Association of State Highway and Transportation Officials

ESAL – Equivalent Single Axle Load

FBF – Federal Bridge Formula

FHWA – The Federal Highway Administration

GVW – Gross Vehicle Weight

KIP - Kilo Pounds

LCV – Longer Combination Vehicle

LFD - Load Factor Design

LRFR - Load and Resistance Factor Rating

MUTCD – Manual on Uniform Traffic Control Devices (MUTCD)

NRL – Notional Rating Load

OS/OW – Oversize/Overweight

RCDG -- Reinforced Concrete Deck Girder

RF – Rating Factor

SHV – Specialized Hauling Vehicle

SU – Single Unit

TS & W – Truck Size and Weight

WIM – Weigh in Motion

INTRODUCTION

In the United States, the Federal Bridge Formula (FBF, also known as Formula B) has been used to set the limit for Gross Vehicle Weight (GVW) and axle weight for various vehicle configurations. The first truck weight limits were enacted by four states in 1913: Maine (18,000 lbs.), Massachusetts (28,000 lbs.), Pennsylvania (24,000 lbs.) and Washington (24,000 lbs.), in terms of GVW. These laws were primarily passed to protect earth and gravel-surfaced roads from damage by the steel and solid rubber wheels of early heavy trucks. By 1933, all states had passed some form of weight regulation. The Federal-Aid Highway Act of 1956 instituted the first federal truck weight regulation (set at GVW of 73,280 lbs.) and authorized the construction of the Interstate Highway System. In the late 1950s, the American Association of State Highway and Transportation Officials (AASHTO), founded in 1914 as American Association of State Highway Officials (AASHO), conducted a series of extensive field tests on pavements and bridges to determine the desirable vehicle size and weight. In 1964, AASHTO recommended to congress that a bridge formula table be used (depending on the length of the axle group and the number of axles) instead of single GVW limit for trucks. Based on the AASHTO recommendations, the Federal-Aid Highway Act Amendments of 1974 established the FBF as law, along with the maximum GVW limit of 80,000 lbs. (TS&W, 2014). The FBF is intended to reduce the GVW of shorter trucks, thereby preventing premature deterioration of bridges and other highway infrastructures due to the concentrated weight of shorter trucks.

In compliance with the FBF weight limits, the maximum GVW for various vehicle configurations is determined as follows:

$$W = 500\ [L*N/\ (N-1) + 12N + 36]$$

Where

W= the maximum weight in pounds that can be carried on a group of two or more axles to the nearest 500 lbs.
L = the distance in feet between the outer axles of any two or more consecutive axles
N = the number of axles being considered

In addition to FBF weight limits, the basic federal weight limits also include the following components:

- GVW—the weight of a vehicle or vehicle combination and any load thereon. The federal GVW on the Interstate System is 80,000 lbs.
- Single-Axle Weight—the total weight on one or more axles whose centers are not more than 40 inches apart. The federal single-axle weight limit on the Interstate System is 20,000 lbs.

- Tandem-Axle Weight—the total weight on two or more consecutive axles more than 40 inches but not more than 96 inches apart. The federal tandem-axle weight limit on the Interstate System is 34,000 lbs.

Further, AASHTO developed a new concept of hypothetical trucks, called the H (with two-axles) and the HS (with three-axles) classes of trucks, aimed to facilitate the design of durable bridges. These were analytical trucks, used only for design and they did not resemble any real truck on the road. Different AASHTO design vehicles have been employed for the design of the bridges such as H-10, H-15, H-20, HS15, HS20, and HS25. The HS20 was, until recently, the design vehicle used to design most bridges in the United States. During the course of the bridge life, some of them become aged, deteriorated or structurally deficient. In order to have a consistent assessment of load carrying capacities, all bridges are rated using a standard set of vehicles, called "legal loads". The "legal loads" such as Type 3, 3S2, and 3-3 closely match the FBF in the short, medium, and long truck length ranges and are used to evaluate the need for bridge weight limit posting.

In recent years, Specialized Hauling Vehicles (SHVs) have been introduced and they play an important role in the trucking industry. Typically, SHVs refer to single unit (SU) vehicles with closely spaced multiple axles that can carry up to 80,000 lbs. Compared with longer combination vehicles, they feature better maneuverability and are thus used for transporting solid waste, ready-mix concrete, and other hauling needs. Even though SHVs meet the requirement under FBF, these newer axle configurations were not considered in the original development of the FBF. Further, the "legal loads" set by the AASHTO do not take SHVs into account for bridge weight limit posting (AASHTO, 1987; AASHTO, 2004). As a result, the FBF does not adequately restrict the weight of SHVs and most likely overstress the bridges. Additionally, a recent study has criticized the current FBF for allowing too much extra weight for trucks with additional axles, even though "bridge stress is affected more by the total amount of load than by the number of axles" (Carson, 2011).

In this context, new posting weight limits, such as GVW of 54,000 lbs., 62,000 lbs., 69,500 lbs., and 77,500 lbs. have been established for SU4, SU5, SU6 and SU7 trucks, respectively (Figure 1), as a result of NCHRP Project 12-63 (Sivakumar, 2007). The development of these newer vehicles is a reactive development, which nevertheless, does not solve the basic issues associated with allowing SHVs. These trucks were developed to model the extreme loading effects of single unit SHVs with four or more axles (Sivakumar, 2007). Subsequently, the same study recommended a Notional Rating Load (NRL) "as a single-load model for load rating bridges for all likely Formula B truck configurations" (Figure 2). The term 'Notional' was used because it does not represent any particular truck (Sivakumar, 2007). The aforementioned SHV configurations led to revisions to the AASHTO "legal loads" for posting as depicted in the

Manual for Condition Evaluation of Bridges and the Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges.

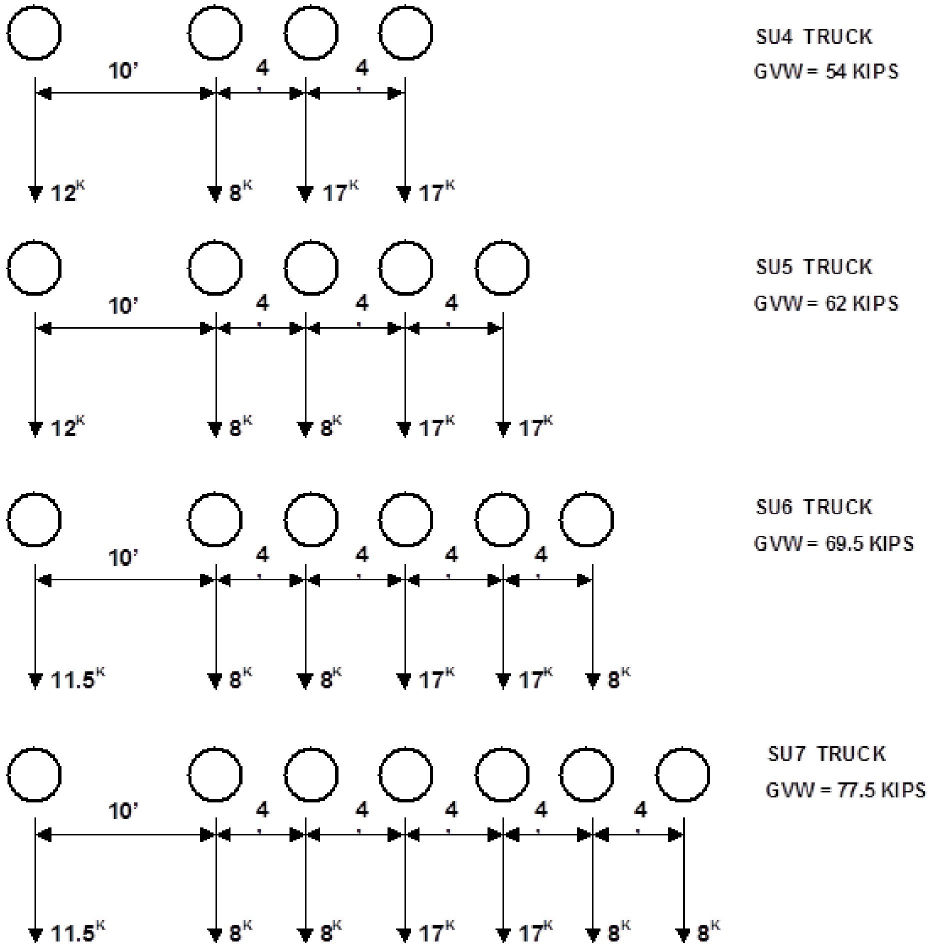
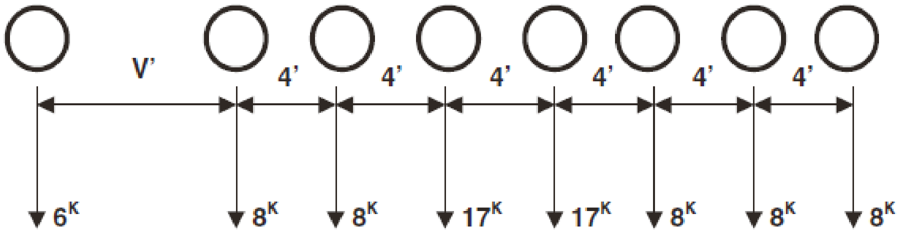


Figure 1: Bridge posting loads for single unit trucks that meet the FBF requirement. SU= single unit; 1 KIP = 1,000 lbs. (Sivakumar, 2007).



V = VARIABLE DRIVE AXLE SPACING — 6'0" TO 14'-0". SPACING TO BE USED IS THAT WHICH PRODUCES MAXIMUM LOAD EFFECTS.

AXLES THAT DO NOT CONTRIBUTE TO THE MAXIMUM LOAD EFFECT UNDER CONSIDERATION SHALL BE NEGLECTED.

MAXIMUM GVW = 80 KIPS

AXLE GAGE WIDTH = 6'-0"

Figure 2: NRL for Single-unit SHVs that meet the FBF requirement (Sivakumar, 2007).

Numerous studies have been conducted to examine the impact of heavy vehicles on pavements, bridges, the economy and safety, but very few were devoted to SHVs. As such, the impact of increasing SHVs weight limits is poorly understood. The size and weight limits of heavy trucks have significant implications in terms of infrastructure costs, potential economic benefits, and motorist safety, and these different dimensions of the issue need to be balanced in light of local priorities and constraints.

This study aims to examine current knowledge and practice related to SHV weight limits, with a focus on scenarios of interest to the NMDOT. The information in this study is presented in the following sections:

- Legal Weight Limits by State
- SHV Laws and Regulations in Selected States
- Impacts of SHVs on Pavements and Bridges
- Impacts of SHV on Bridge Posted Weight Limits and Enforcement
- Economic and Safety Considerations

A. LEGAL WEIGHT LIMITS BY STATE

This section summarizes current legal weight limits for SHVs in each state. For the purpose of this study, the SHVs of interest are those 36 feet long (distance between center of first axle and last axle), with 4 to 7 axle configurations.

Truck weights are considered legal in a given state if the GVW, axle weight, axle configuration, length, and width are within the current weight and size laws or rules. According to FBF, the weight limits with respect to the defined SHVs are as follows:

- 4-axle group at 36 feet = 66,000 lbs.
  In addition, two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each, if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.
- 5-axle group at 36 feet = 70,500 lbs.
- 6-axle group at 36 feet = 75,500 lbs.
- 7-axle group at 36 feet = 80,000 lbs.

Table 1 provides the GVW limits in each state for SHVs at 36 feet for 4 to 7 axle configurations. Most states follow the FBF to set their respective GVW limits; whereas some states have GVW limits exceeding the FBF limits. Further, a small group of states have GVW limits lower than the federal limits. In addition, states such as Arizona, Colorado, Louisiana and Pennsylvania do not follow the FBF to determine their GVW limits. For Kentucky, a route system is used to classify roadways into ‘AAA’, ‘AA’ and ‘A,’ which have GVW limits of 80,000 lbs., 62,000 lbs. and 44,000 lbs., respectively. The ‘AAA’ route follows FBF for all vehicle configurations. For Louisiana, regardless of the number and type of axles, GVW of any vehicle or combination of vehicles (except a combination with a tridem or quad axle) is 80,000 lbs. Also, GVW of any vehicle or combination of vehicles with a tridem or quad axle is 88,000 lbs. for any number and type of axles. The State of Pennsylvania has defined different classes of vehicles (1 through 20), and GVW is set for each class of vehicles with maximum GVW of 73,280 lbs. Further, there are some states that have not established GVW limits, especially for the seven-axle configuration.

The following summary compares states’ GVW weight limits for SHVs to FBF GVW limits. Kentucky, Louisiana and Pennsylvania are excluded from the summary, because they use different specifications to determine GVW limits.

4-axle group

- States that follow the FBF limit, **GVW = 66,000 lbs.** (31 states): *Arkansas, Florida, Georgia, Idaho, Illinois, Indiana, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New*

Jersey, North Carolina, North Dakota, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Utah, Vermont, Virginia, Washington, Wisconsin and Wyoming

- States that have a GVW limit exceeding the FBF limit, **GVW > 66,000 lbs.** (14 states): *Arizona, Alabama, Colorado, Connecticut, Delaware, Hawaii, Iowa, Maine, New Mexico, New York, Ohio, Oklahoma, Texas and West Virginia*
- States that have a GVW limit lower than the FBF limit, **GVW < 66,000 lbs.** (2 states): *Alaska, California*

5-axle group

- States that follow the FBF limit, **GVW = 70,500 lbs.** (33 states): *Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, North Carolina, North Dakota, Oklahoma, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, Wisconsin, Wyoming*
- States that have a GVW limit exceeding the FBF limit, **GVW > 70,500 lbs.** (8 states): *Arizona, Alabama, Colorado, Connecticut, Delaware, Idaho, Maine, West Virginia*
- States that have a GVW limit lower than the FBF limit, **GVW < 70,500 lbs.** (6 states): *Alaska, California, Hawaii, Ohio, New York, New Mexico*

6-axle group

- States that follow the FBF limit, **GVW = 75,500 lbs.** (27 states): *Arkansas, Florida, Georgia, Illinois, Indiana, Kansas, Maryland, Massachusetts, Michigan, Mississippi, Missouri, Montana, Nebraska, New Hampshire, New Jersey, North Carolina, Oklahoma, Oregon, Rhode Island, South Carolina, Tennessee, Texas, Utah, Vermont, Virginia, Wisconsin, Wyoming*
- States that have a GVW limit exceeding the FBF limit, **GVW > 75,500 lbs.** (10 states): *Arizona, Alabama, Colorado, Maine, Minnesota, Nevada, North Dakota, South Dakota, Washington, West Virginia*
- States that have a GVW limit lower than the FBF limit, **GVW < 75,500 lbs.** (9 states): *Alaska, California, Connecticut, Hawaii, Idaho, Iowa, New Mexico, Ohio, New York*
- No GVW for 6-axle group: Not provided (1 state): *Delaware*

7-axle group

- States that follow the FBF limit, **GVW = 80,000 lbs.** (22 states): *Arizona, Arkansas, Florida, Georgia, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, Oregon, Rhode Island, South Carolina, Tennessee, Texas, Utah, Vermont, Virginia, Wisconsin*
- States that have a GVW limit exceeding the FBF limit, **GVW > 80,000 lbs.** (10 states): *Indiana, Kansas, Montana, Nevada, North Dakota, Oklahoma, South Dakota, Washington, West Virginia, Wyoming*
- States that have a GVW limit lower than the FBF limit, **GVW < 80,000 lbs.** (8 states): *California, Colorado, Connecticut, Hawaii, Idaho, New Mexico, New York, Ohio*

- No GVW for 7-axle group (7 states): *Alabama, Alaska, Delaware, Illinois, Iowa, Nebraska, North Carolina*

In addition to the weight limit in terms of GVW, there are also legal limits on the single axle weight and tandem axle weight for trucks, regardless of their configuration. The following summary compares states' legal weight limit for single and tandem axles to the corresponding federal limits for single and tandem axles.

- States that follow federal weight limits for both single and tandem axles, **Single axle = 20,000 lbs. and Tandem axle = 34,000 lbs.** (29 states): *Arizona, Arkansas, California, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Montana, Nebraska, Nevada, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, West Virginia and Wisconsin*
- States that have weight limits exceeding the federal limits for both single and tandem axles, **Single axle > 20,000 lbs. and Tandem axle > 34,000 lbs.** (10 states): *Alabama, Connecticut, Florida, Georgia, Louisiana, New Hampshire, New Mexico, New York, Rhode Island, and Vermont*
- States that have a weight limit exceeding the federal limit for single axle only **Single axle > 20,000 lbs.** (2 states): *Hawaii and New Jersey*
- States that have a weight limit exceeding the federal limit for tandem axle only, **Tandem axle > 34,000 lbs.** (8 states): *Alaska, Colorado, Delaware, Missouri, North Carolina, Pennsylvania, South Carolina, and Wyoming*
- No weight limit provided for Single and tandem axle group (1 state): *Maryland*

Table 1: GVW limits for SHVs by state

State	**GVW at 36 feet (lbs.)**				**Source**
	4-axle group	**5-axle group**	**6-axle group**	**7-axle group**	
Alabama	67,000 + 10%	72,000 + 10%	76,000 + 10%	N/P	http://codes.lp.findlaw.com/alcode/32/9/2/32-9-20#sthash.gjcaeX0o.dpuf
Alaska	50,000	58,000	66,000	N/P	See Appendix A
Arizona	Based on inner axle spacing, number of tire per axle and axle width (Table 5)				https://www.azsos.gov/public_services/Title_17/17-06.pdf
Arkansas	66,000*	70,500	75,500	80,000	https://www.arkansashighways.com/highway_police/map21/Size_Weight.pdf
California	64,600	64,600	64,600	64,600	http://www.leginfo.ca.gov/cgi-bin/displaycode?section=veh&group=35001-36000&file=35550-35558
Colorado	76,000	76,000	76,000	76,000	http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251618556115&ssbinary=true
Connecticut	73,000	73,000	73,000	73,000	http://www.ct.gov/dot/lib/dot/Documents/dpermits/eh_ndlgi.pdf
Delaware	73,280	80,000	N/P	N/P	http://www.deldot.gov/osow/policy.pdf
Florida	68,000	70,500	75,500	80,000	http://www.dot.state.fl.us/statemaintenanceoffice/2010TruckingManual.pdf
Georgia	66,000*	70,500	75,500	80,000	http://www.dot.ga.gov/doingbusiness/permits/oversize/Pages/Compliance.aspx
Hawaii	68,400	68,400	68,400	68,400	http://codes.lp.findlaw.com/histatutes/1/17/291/II/291-35
Idaho	66,000*	75,350	75,350	75,350	http://www.itd.idaho.gov/dmv/poe/documents/LegalAllowableGrossLoadsChart.pdf
Illinois	66,000*	70,500	75,500	N/P	http://www.ilfb.org/media/82588/trucktrailersizeweight2011-04_18715.pdf
Indiana	66,000*	70,500	75,500	81,000	http://www.in.gov/isp/files/size_weight_laws.pdf
Iowa	68,000	70,500	73,000	N/P	http://www.iowadot.gov/mvd/omve/truckguide.pdf
Kansas	66,000*	70,500	75,500	81,000	http://www.kansashighwaypatrol.org/press/brochures/weight_enforce.pdf
Kentucky	‘AAA’ Routes follow the FBF table. Max: 80000 lbs. ‘AA’ routes max load. 62,000lbs ‘A’ routes max load. 44,000lbs : For routes http://transportation.ky.gov/Planning/Documents/wtclass_2003.pdf				http://www.lrc.ky.gov/kar/603/005/066.htm

*N/P – Not provided; * Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.*

Table 1: GVW limits for SHVs by state (CONTINUED)

State	GVW at 36 feet (lbs.)				Source
	4-axle group	5-axle group	6-axle group	7-axle group	
Louisiana	Max legal weight on a tire is: 650 lbs. per width of the tire. Regardless of the number and type of axles, • Maximum legal gross weight of any vehicle or combination of vehicles (except a combination with a tridem or quadrum axle) is: 80,000 lbs. • Maximum legal gross weight of any combination of vehicles which has a tridem or quadrum axle is: 88,000 lbs.				http://perba.dotd.louisiana.gov/wsRegulations.nsf/9beb57371783ec6386256f3b004c7ef9/3eed4df5d98f30dd86256f6300489281?OpenDocument
Maine	69,000	80,000	80,000	80,000	http://www.maine.gov/sos/bmv/commercial/Commercial%20Vehicle%20Laws%20&%20Regulations%20%28June%206,%202012%29.pdf
Maryland	66,000*	70,500	75,500	80,000	http://www.sha.maryland.gov/OOTS/motorcarrierhandbook.pdf
Massachusetts	66,000*	70,500	75,500	80,000	http://www.mhd.state.ma.us/default.asp?pgid=content/permLL&sid=about
Michigan	66,000*	70,500	75,500	80,000	http://www.michigan.gov/documents/Loads_dim_87014_7.pdf
Minnesota	66,000*	70,500	76,000	80,000	https://dps.mn.gov/divisions/msp/commercial-vehicles/Documents/Pamphlets/2012%20Weight%20Limits.pdf
Mississippi	66,000*	70,500	75,500	80,000	http://mdot.ms.gov/documents/planning/Maps/Truck%20Weight%20Maps/Maximum%20Weight%20Laws/Mississippi%20Maximum%20Weight%20Laws.pdf
Missouri	66,000*	70,500	75,500	80,000	http://www.mshp.dps.mo.gov/MSHPWeb/Publications/Brochures/documents/SHP-250.pdf
Montana	66,000*	70,500	75,500	81,000	http://www.mdt.mt.gov/publications/docs/manuals/truckers_handbook.pdf
Nebraska	66,000*	70,500	75,500	N/P	http://www.transportation.nebraska.gov/rpt/pdfs/weights.pdf
Nevada	66,000*	70,500	76,000	81,000	http://www.leg.state.nv.us/NRS/NRS-484D.html#NRS484DSec635
New Hampshire	66,000*	70,500	75,500	80,000	http://www.nh.gov/dot/org/operations/highwaymaintenance/overhaul/documents/oversizevehiclemanual.pdf
New Jersey	66,000*	70,500	75,500	80,000	http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CD4QFjAA&url=http%3A%2F%2Fwww.lawrev.state.nj.us%2Ftitle39%2Fweb%2520dimensns%2520weight%2520loads%2520021608.doc&ei=rLbFUuOmNYb2oATcqYGwDg&usg=AFQjCNFZVnntEqDOmZwmJQUHRJEUaYyh6Q&sig2=PYmDLiCBgkYsh_sNISMTtQ
New Mexico	68,400	68,400	68,400	68,400	http://www.lawserver.com/law/state/new-mexico/nm-statutes/new_mexico_statutes_66-7-410

*N/P – Not provided; * Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.*

Table 1: GVW limits for SHVs by state (CONTINUED)

State	**GVW at 36 feet (lbs.)**				**Source**
	4-axle group	**5-axle group**	**6-axle group**	**7-axle group**	
New York	70,000	70,000	70,000	70,000	http://www.nyc.gov/html/dot/html/motorist/sizewt.shtml
North Carolina	66,000*	70,500	75,500	N/P	http://statutes.laws.com/north-carolina/Chapter_20/GS_20-118
North Dakota	66,000*	70,500	76,000	81,000	http://www.nd.gov/ndhp/sites/nd.gov.ndhp/files/docs/9-1_handout.pdf
Ohio	70,400	70,400	70,400	70,400	http://www.dot.state.oh.us/Divisions/Operations/Maintenance/Permits/Documents/OS-8%20Rev01-11.pdf
Oklahoma	68,000	70,500	75,500	81,000 (special permit)	http://www.dps.state.ok.us/ohp/chapter14.pdf
Oregon	66,000*	70,500	75,500	80,000	http://www.oregon.gov/ODOT/MCT/docs/weight_limits.pdf
Pennsylvania	The legal limit is based on the class of vehicles 1 through 20 with maximum weight of 73,280 lbs. Vehicle info: http://www.dmv.state.pa.us/pdotforms/mv_forms/mv-70s.pdf				http://www.dot.state.pa.us/Internet/Bureaus/pdBHSTE.nsf/infoCPHeightAndWeight?OpenForm
Rhode Island	66,000*	70,500	75,500	80,000	http://sos.ri.gov/documents/archives/regdocs/released/pdf/DMV/DMV_1673_.pdf
South Carolina	66,000*	70,500	75,500	80,000	http://www.foresthauling.org/Documents/All%20States/SC/Truck%20Weight%20chart%20SC.pdf
South Dakota	66,000*	70,500	76,000	81,000	http://www.sdtruckinfo.com/docs/MCHandbook_chap4.pdf
Tennessee	66,000*	70,500	75,500	80,000	http://tntrucking.tn.gov/TCAcodes.html
Texas	70,100	70,500	75,500	80,000	http://txdmv.gov/component/k2/item/2123-permissible-weight-table
Utah	66,000*	70,500	75,500	80,000	http://www.rules.utah.gov/publicat/code/r909/r909-002.htm#T5
Vermont	66,000*	70,500	75,500	80,000	http://dmv.vermont.gov/sites/dmv/files/pdf/DMV-VN166-Motor_Carrier_Safety_Regs.pdf
Virginia	66,000*	70,500	75,500	80,000	http://www.dmv.state.va.us/webdoc/pdf/dmv109.pdf
Washington	66,000*	70,500	76,000	81,000	http://www.wsdot.wa.gov/nr/rdonlyres/ee2d33c7-e6a0-4c58-9bd9-ae05c003b327/0/vehicleguide.pdf
West Virginia	70,000 + 10%	73,000 + 10%	80,000 + 10%	80,000 + 10%	http://www.legis.state.wv.us/wvcode/code.cfm?chap=17c&art=17
Wisconsin	66,000*	70,500	75,500	80,000	https://docs.legis.wisconsin.gov/statutes/statutes/348.pdf#page=6
Wyoming	66,000*	70,500	75,500	81,000	http://soswy.state.wy.us/Rules/RULES/6362.pdf

*N/P – Not provided; * Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.*

Table 2: Single and Tandem axle limits by state

State	State Legal Axle Weight Limit (lbs.)		Weight Limit higher than FBF?	State	State Legal Axle Weight Limit (lbs.)		Weight Limit higher than FBF?
	Single Axle	Tandem Axle			Single Axle	Tandem Axle	
Alabama	20,000 + 10%	36,000 + 10%	Yes (S, T)	Montana	20,000	34,000	No
Alaska	20,000	38,000	Yes (T)	Nebraska	20,000	34,000	No
Arizona	20,000	34,000	No	Nevada	20,000	34,000	No
Arkansas	20,000	34,000	No	New Hampshire	22,400	44,800	Yes (S, T)
California	20,000	34,000	No	New Jersey	22,400	34,000	Yes (S)
Colorado	20,000	36,000	Yes (T)	New Mexico	21,600	34,300	Yes (S, T)
Connecticut	22,400	36,000	Yes (S, T)	New York	22,400	36,000	Yes (S, T)
Delaware	20,000	40,000	Yes (T)	North Carolina	20,000	38,000	Yes (T)
Florida	22,000	44,000	Yes (S, T)	North Dakota	20,000	34,000	No
Georgia	20,340	40,680	Yes (S, T)	Ohio	20,000	34,000	No
Hawaii	22,500	34,000	Yes (S)	Oklahoma	20,000	34,000	No
Idaho	20,000	34,000	No	Oregon	20,000	34,000	No
Illinois	18,000	32,000	No	Pennsylvania	20,000	38,000	Yes (T)
Indiana	20,000	34,000	No	Rhode Island	22,400	44,800	Yes (S, T)
Iowa	20,000	34,000	No	South Carolina	20,000	35, 000 + 10%	Yes (T)
Kansas	20,000	34,000	No	South Dakota	20,000	34,000	No
Kentucky	20,000	34,000	No	Tennessee	20,000	34,000	No
Louisiana	22,000	37,000	Yes (S, T)	Texas	20,000	34,000	No
Maine	20,000	34,000	No	Utah	20,000	34,000	No
Maryland	N/P	N/P	-	Vermont	22,400	36,000	Yes (S, T)
Massachusetts	20,000	34,000	No	Virginia	20,000	34,000	No
Michigan	20,000	34,000	No	Washington	20,000	34,000	No
Minnesota	20,000	34,000	No	West Virginia	20,000	34,000	No
Mississippi	20,000	34,000	No	Wisconsin	20,000	34,000	No
Missouri	20,000	40,000	Yes (T)	Wyoming	20,000	36,000	Yes (T)

Yes (S, T) – Both single and tandem axles; Yes (S) – Single axle only; Yes (T) – Tandem axle only; N/P – Not Provided

B. SHV LAWS AND REGULATIONS IN SELECTED STATES

The SHV laws and practices of six states (Alabama, Arizona, Colorado, Kansas, Oklahoma and Texas) were selected for further investigation. These states were selected based on their geographical similarity to New Mexico and their state of legal practice relative to SHVs.

Based on the responses to a practitioner survey and a review of each state's laws and regulations, the research team made the following general observations:

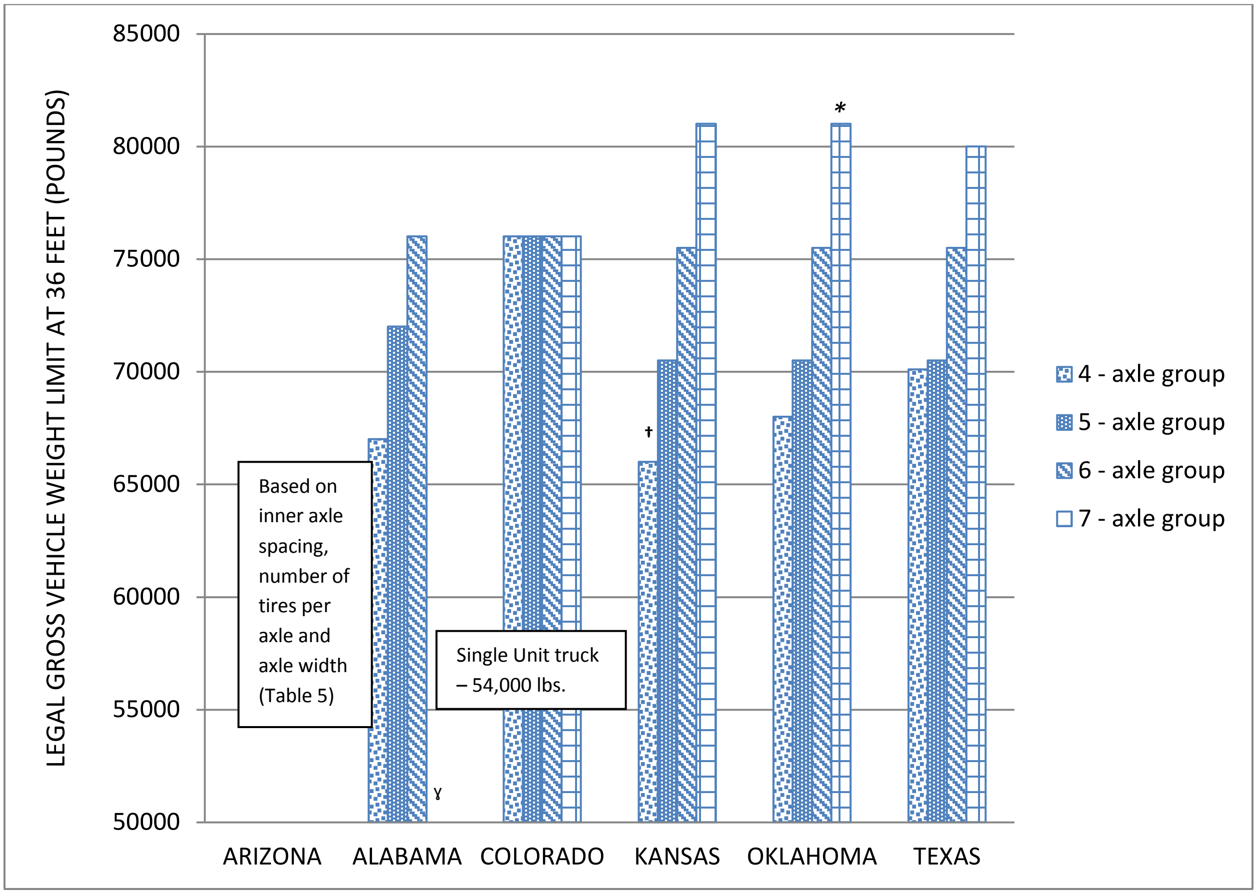
- Arizona allows SHVs on their state roads. They do not follow FBF for calculating GVW for their state roads. The basis for calculating GVW is dependent on the axle width, number of tires per axle and inner axle spacing.
- Alabama allows SHVs on their state roads. No information is provided on their weight table for seven-axle configuration vehicles.
- Colorado does not allow SU6 and SU7 vehicles on their state roads. They do not follow FBF for calculating GVW for their state roads. The basis for calculating GVW is dependent on the outer axle spacing. Maximum GVW for a single unit truck is 54,000 lbs.
- Kansas allows SHVs on their state roads.
- Oklahoma allows SHVs on their state roads. A special permit is required for vehicle configurations in excess of six axles.
- Texas allows SHVs on their state roads.

The laws and regulations relating to SHVs were compiled for each of these six states. Table 3 provides the summary of legal weight limits on state highways with respect to SHVs. Figure 3 provides the graphical representation of legal limits in the six states with respect to SHVs.

Table 3: Summary of legal weight limits on State highways (considering SHVs)

Weight limits on non-interstate highways	**ARIZONA**	**ALABAMA**	**COLORADO**	**KANSAS**	**OKLAHOMA**	**TEXAS**
Maximum Gross Vehicle Weight (GVW)	80, 000 lbs.	84, 000 lbs.	85, 000 lbs.	85, 500 lbs.	90,000 lbs.	80, 000 lbs.
Single axle	20, 000 lbs.	20, 000 lbs.	20, 000 lbs.	20, 000 lbs.	20, 000 lbs.	20, 000 lbs.
Tandem axle	34, 000 lbs.	34, 000 lbs.	40, 000 lbs.	34, 000 lbs.	34, 000 lbs.	34, 000 lbs.
Formula used for two or more consecutive axles configuration	W = 1.5*700(L + 40)	FBF	W=(L+40)1000	FBF	FBF	FBF
4 - axle group						
Distance at which GVW > 68, 400 lbs.	Based on inner axle spacing, number of tires per axle and axle width (Table 5)	38 ft (69,000 lbs.)	29 ft (69,000 lbs.)	40 ft (68500 lbs.)	38 ft (69,000 lbs.)	35 ft (69150 lbs.)
GVW @ 36 ft		67, 000 lbs.	76, 000 lbs.	66, 000 lbs.*	68,000 lbs.	70, 100 lbs.
5 - axle group						
Distance at which GVW > 68, 400 lbs.	Based on inner axle spacing, number of tires per axle and axle width (Table 5)	33 ft (69,500 lbs.)	29 ft (69,000 lbs.)	33 ft (68,500 lbs.)	33 ft (68,500 lbs.)	32 ft (68,500 lbs.)
GVW @ 36 ft		72, 000 lbs.	76, 000 lbs.	70, 500 lbs.	70, 500 lbs.	70, 500 lbs.
6 - axle group						
Distance at which GVW > 68, 400 lbs.	Based on inner axle spacing, number of tires per axle and axle width (Table 5)	24 ft (68,500 lbs.)	29 ft (69,000 lbs.)	24 ft (68,500 lbs.)	24 ft (68,500 lbs.)	24 ft (68,500 lbs.)
GVW @ 36 ft		76, 000 lbs.	76, 000 lbs.	75, 500 lbs.	75, 500 lbs.	75, 500 lbs.
7 - axle group						
Distance at which GVW > 68, 400 lbs.	Based on inner axle spacing, number of tires per axle and axle width (Table 5)	Not provided	29 ft (69,000 lbs.)	FBF	FBF	FBF
GVW @ 36 ft		Not provided	76, 000 lbs.	81, 000 lbs.	81, 000 lbs. (Special permit required)	80, 000 lbs.

*Note: Distance provided in feet (ft) is the distance between centerline of the first and centerline of the last axle of the vehicle FBF – Federal Bridge Formula; W = the overall gross weight on any group of two or more consecutive axles; L=length; N=number of axle * Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.*



† Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.
ɣ - *Not Provided*
* - *Special permit required*

Figure 3: States GVW limits for SHVs in selected states

1. *Arizona State Regulations*

In Arizona, legal weight limits for the non-interstate roads are computed using Equation (1). Arizona does not follow the FBF for its non-interstate highways and does not consider number of axles to calculate the GVW for its non-interstate highways. The bridge formula used by Arizona is

$$W = 1.5*700\,(L+40) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. (1)}$$

W = Weight & L = Length from center of first axle to center of last axle

Arizona computes GVW based on axle spacing, number of tires per axle and axle width. Number of tires per axle is classified into four tires per axle (or two 14 inch wide tire) and eight tires per axle (or four 14 inch tire). Axle width is classified into eight categories such as 8 feet 0 inches, 8 feet 3 inches, 8 feet 6 inches, 8 feet 9 inches, 9 feet 0 inches, 9 feet 3 inches, 9 feet 6 inches, 9 feet 9 inches and 10 feet 0 inches. The GVW computed from Eqn. (1) will be scaled based on the number of tires per axle and the total width of axle. Table 4 provides the scaled formula based on number of tires per axle and axle width.

Table 4: Summary of bridge formula based on tires per axle and axle width for Arizona

GVW Calculation	**8 feet 0 inches**	**8 feet 3 inches**	**8 feet 6 inches**	**8 feet 9 inches**	**9 feet 0 inches**	**9 feet 3 inches**	**9 feet 6 inches**	**9 feet 9 inches**	**10 feet 0 inches**
4 tires per axle or two 14inch wide tire	W	W + 0.01875W	W + 0.0375W	W + 0.05625W	W + 0.075W	W + 0.09375W	W + 0.1125W	W + 0.13125W	W + 0.15W
8 tires per axle or four 14inch wide tire	W + 0.15W	W + 0.1625W	W + 0.175W	W + 0.1875W	W + 0.20W	W + 0.2125W	W + 0.225W	W + 0.2375W	W + 0.25W

Note: Summarized from https://www.azsos.gov/public_services/Title_17/17-06.pdf

Sample calculation:

For example, Let us assume

L = 6 feet (Distance between two inner axles),
Tires per axle= 8
Axle width = 8 feet 0 inches.

From Eqn. (1) we compute
W = 1.5*700 (6+40) = 48,300 lbs.

From Table 4, for 8 foot 0 inches axle width and 8 tires per axle,
GVW = W + 0.15W = 48,300 + (0.15*48,300) = 55,545 lbs.

Table 5 provides the GVW values for length up to 18 feet for four and eight tires per axle and axle width of 8 feet 0 inches. Weight computations for various axle widths are provided in *https://www.azsos.gov/public_services/Title_17/17-06.pdf*

In the case of vehicles with length of 36 feet and 5 axles, vehicle length will be divided into five groups based on the inner axle spacing. The maximum GVW will be calculated for five inner axle spacings with the maximum GVW not exceeding 80,000 lbs.

In Arizona, the weight limits for single and tandem axles are:

- Maximum GVW - 80,000 lbs.
- Single axle – 20,000 lbs.[1]
- Tandem axle – 34,000 lbs.[2]

[1] Director may issue a special permit pursuant to section 28-1103 to increase the single axle weight limit for the purpose of moving road machinery that exceeds the maximum weight specified in this section from job to job within this state and from job to place of servicing and return within this state.

[2] Two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each, if the overall distance between the first and last axle of the consecutive sets of tandem axles is 36 feet or more.

Furthermore, a single vehicle or a combination of vehicles shall not be equipped with more than three axles, including steering axle (Exception: additional axles are steering axle or castering axles).

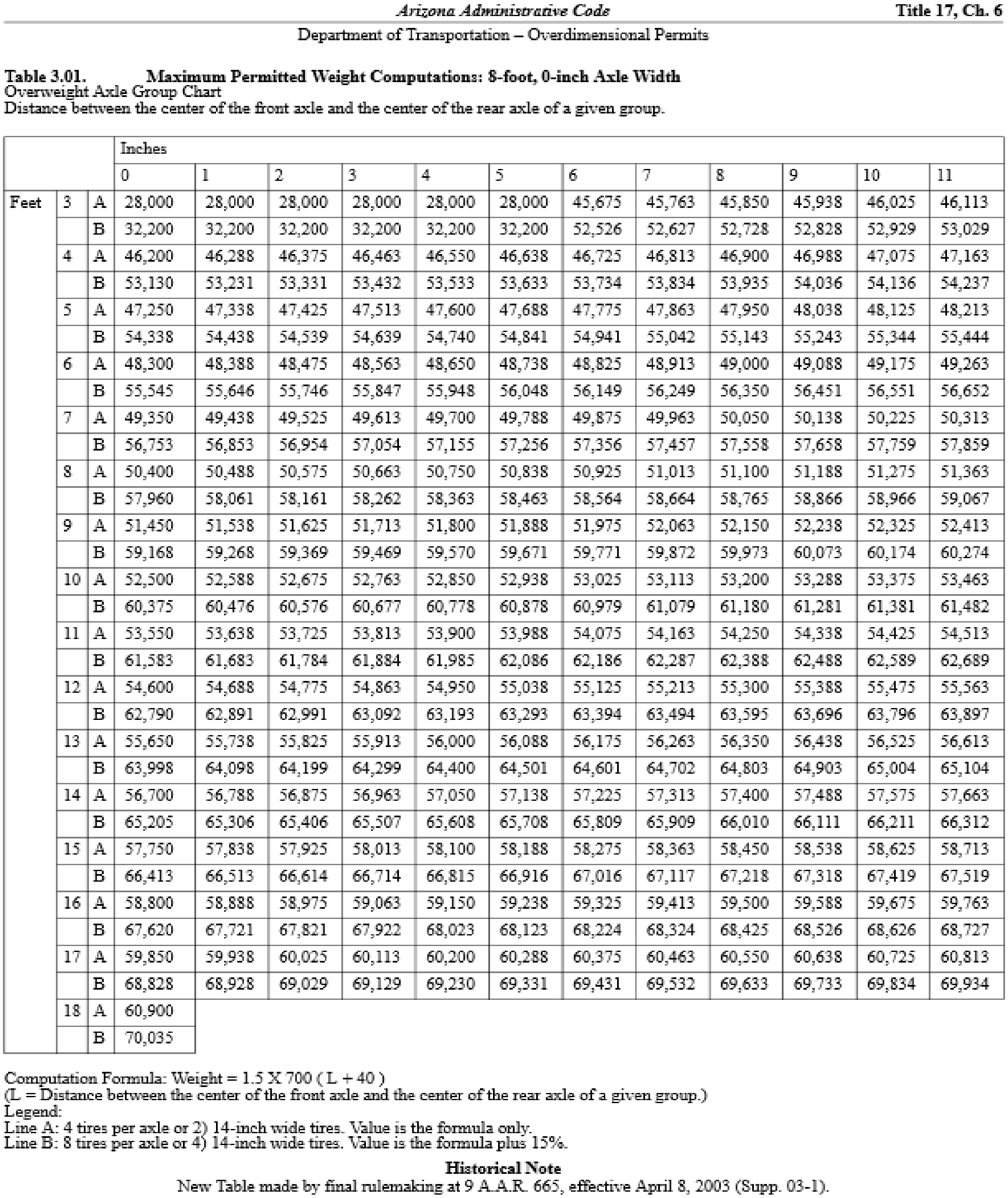
<u>Special allowances and exemptions</u>

- A special permit may be issued to carry up to 100,000 GVW for a truck, a truck tractor, or a semitrailer with not more than two trailers, if they conform with the single and tandem axles weight limitations and the vehicle combination is traveling within twenty miles of the borders of this state and an adjacent state that allows such combinations of length and gross vehicle weight.

- A special permit may be issued to carry up to 100,000 lbs. GVW (9 axles) and 120,000 lbs. GVW (10 axles) for a truck, a truck tractor, or a semitrailer with not more than two trailers, if

    - The axles conform to the single and axle weight limitations
    - The length of the vehicle combination is less than 96 feet
    - The vehicle is traveling on portions of an alternate state route that is located within four miles of and extends to the border of this state and an adjacent state that allows vehicle combinations of a truck or a truck tractor, a semitrailer and two trailers or semitrailers.
    - The vehicle is traveling on a state route that extends at least ten miles through an Indian reservation that does not cross the Colorado River and is located within twenty miles of and extends to the border of this state and an adjacent state that allows two trailers or semitrailers.

Table 5: Permissible Weight Limit Table for Arizona (Axle width = 8 feet, 0 inch; A = 4 tires per axle and B = 8 tires per axle)



Arizona Administrative Code **Title 17, Ch. 6**

Department of Transportation – Overdimensional Permits

Table 3.01. Maximum Permitted Weight Computations: 8-foot, 0-inch Axle Width
Overweight Axle Group Chart
Distance between the center of the front axle and the center of the rear axle of a given group.

			Inches											
			0	1	2	3	4	5	6	7	8	9	10	11
Feet	3	A	28,000	28,000	28,000	28,000	28,000	28,000	45,675	45,763	45,850	45,938	46,025	46,113
		B	32,200	32,200	32,200	32,200	32,200	32,200	52,526	52,627	52,728	52,828	52,929	53,029
	4	A	46,200	46,288	46,375	46,463	46,550	46,638	46,725	46,813	46,900	46,988	47,075	47,163
		B	53,130	53,231	53,331	53,432	53,533	53,633	53,734	53,834	53,935	54,036	54,136	54,237
	5	A	47,250	47,338	47,425	47,513	47,600	47,688	47,775	47,863	47,950	48,038	48,125	48,213
		B	54,338	54,438	54,539	54,639	54,740	54,841	54,941	55,042	55,143	55,243	55,344	55,444
	6	A	48,300	48,388	48,475	48,563	48,650	48,738	48,825	48,913	49,000	49,088	49,175	49,263
		B	55,545	55,646	55,746	55,847	55,948	56,048	56,149	56,249	56,350	56,451	56,551	56,652
	7	A	49,350	49,438	49,525	49,613	49,700	49,788	49,875	49,963	50,050	50,138	50,225	50,313
		B	56,753	56,853	56,954	57,054	57,155	57,256	57,356	57,457	57,558	57,658	57,759	57,859
	8	A	50,400	50,488	50,575	50,663	50,750	50,838	50,925	51,013	51,100	51,188	51,275	51,363
		B	57,960	58,061	58,161	58,262	58,363	58,463	58,564	58,664	58,765	58,866	58,966	59,067
	9	A	51,450	51,538	51,625	51,713	51,800	51,888	51,975	52,063	52,150	52,238	52,325	52,413
		B	59,168	59,268	59,369	59,469	59,570	59,671	59,771	59,872	59,973	60,073	60,174	60,274
	10	A	52,500	52,588	52,675	52,763	52,850	52,938	53,025	53,113	53,200	53,288	53,375	53,463
		B	60,375	60,476	60,576	60,677	60,778	60,878	60,979	61,079	61,180	61,281	61,381	61,482
	11	A	53,550	53,638	53,725	53,813	53,900	53,988	54,075	54,163	54,250	54,338	54,425	54,513
		B	61,583	61,683	61,784	61,884	61,985	62,086	62,186	62,287	62,388	62,488	62,589	62,689
	12	A	54,600	54,688	54,775	54,863	54,950	55,038	55,125	55,213	55,300	55,388	55,475	55,563
		B	62,790	62,891	62,991	63,092	63,193	63,293	63,394	63,494	63,595	63,696	63,796	63,897
	13	A	55,650	55,738	55,825	55,913	56,000	56,088	56,175	56,263	56,350	56,438	56,525	56,613
		B	63,998	64,098	64,199	64,299	64,400	64,501	64,601	64,702	64,803	64,903	65,004	65,104
	14	A	56,700	56,788	56,875	56,963	57,050	57,138	57,225	57,313	57,400	57,488	57,575	57,663
		B	65,205	65,306	65,406	65,507	65,608	65,708	65,809	65,909	66,010	66,111	66,211	66,312
	15	A	57,750	57,838	57,925	58,013	58,100	58,188	58,275	58,363	58,450	58,538	58,625	58,713
		B	66,413	66,513	66,614	66,714	66,815	66,916	67,016	67,117	67,218	67,318	67,419	67,519
	16	A	58,800	58,888	58,975	59,063	59,150	59,238	59,325	59,413	59,500	59,588	59,675	59,763
		B	67,620	67,721	67,821	67,922	68,023	68,123	68,224	68,324	68,425	68,526	68,626	68,727
	17	A	59,850	59,938	60,025	60,113	60,200	60,288	60,375	60,463	60,550	60,638	60,725	60,813
		B	68,828	68,928	69,029	69,129	69,230	69,331	69,431	69,532	69,633	69,733	69,834	69,934
	18	A	60,900											
		B	70,035											

Computation Formula: Weight = 1.5 X 700 (L + 40)
(L = Distance between the center of the front axle and the center of the rear axle of a given group.)
Legend:
Line A: 4 tires per axle or 2) 14-inch wide tires. Value is the formula only.
Line B: 8 tires per axle or 4) 14-inch wide tires. Value is the formula plus 15%.

Historical Note

New Table made by final rulemaking at 9 A.A.R. 665, effective April 8, 2003 (Supp. 03-1).

2. Alabama State Regulations

The maximum legal weight limits for various configurations in the state of Alabama are presented in Table 6. The size of the vehicles is determined based on the respective distances between the first and last axle of the vehicle or combination of vehicles, measured longitudinally to the nearest foot. In addition, the single axle limit for Alabama is 20,000 lbs. and tandem axle limit is 34, 000 lbs.

Table 6 does not provide any information for a vehicle with a seven axle configuration. The maximum GVW for vehicles with four axle configurations, five axle configurations and six axle configurations are 75,000 lbs., 80,000 lbs., and 84,000 lbs., respectively.

Special allowances and exemptions

- A 10% enforcement tolerance is allowed, and it is considered to be in compliance with the weight requirement.
- Dump trucks, dump trailers, concrete mixing trucks, fuel oil, gasoline trucks, and trucks designated and constructed for special work can carry the maximum GVW plus allowable scale tolerances for the appropriate number of axles, as shown in the Table 3, irrespective of the distance between axles, provided that the single axle limit is up to 20,000 lbs. plus scale tolerances.
- Concrete mixing vehicles operating within 50 miles of their base do not need to follow the single axle limit provided the GVW does not exceed 66,000 lbs.
- Two and three axle vehicles used exclusively for the purpose of transporting agricultural commodities or products to and from a farm and for agricultural purposes relating to the operation and maintenance of a farm by any farmer, custom harvester or husbandman may not be made to conform with the Table 6 and single axle requirements.

Table 6: Permissible Weight Limit Table for Alabama

Distance in Feet	**Axles**				
	2	3	4	5	6
8 or less	36,000	42,000	42,000		
9	38,000	42,500	42,500		
10	40,000	43,500	43,500		
11		44,000	44,000		
12		45,000	50,000	50,000	
13		45,500	50,500	50,500	
14		46,500	51,500	51,500	
15		47,000	52,000	52,000	
16		48,000	52,500	58,000	58,000
17		48,500	53,500	58,500	58,500
18		49,500	54,000	59,000	59,000
19		50,000	54,500	60,000	60,000
20		51,000	55,500	60,500	66,000
21		51,500	56,000	61,000	66,500
22		52,500	56,500	61,500	67,000
23		53,000	57,500	62,500	68,000
24		54,000	58,000	63,000	68,500
25		54,500	58,500	63,500	69,000
26		56,000	59,500	64,000	69,500
27		57,000	60,000	65,000	70,000
28		59,000	60,500	65,500	71,000
29		60,000	61,500	66,000	71,500
30			62,000	66,500	72,000
31			63,500	67,000	72,500
32			64,500	68,000	73,500
33			65,000	69,000	74,000
34			66,500	70,000	74,500
35			66,500	71,000	75,000
36			67,000	72,000	76,000
37			68,000	73,000	77,000
38			69,000	74,000	78,000
39			70,000	75,000	79,000
40			71,000	76,000	80,000
41			72,000	77,000	81,000
42			73,000	78,000	82,000
43			74,000	79,000	83,000
44 or over			75,000	80,000	84,000

3. *Colorado State Regulations*

Colorado does not follow the FBF for its non-interstate highways and does not consider number of axles to calculate the maximum weight limit for non-interstate haulers. The bridge formula (Equation 2) used by Colorado is

$$W = (L+40)*1000 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eqn. (2)}$$

W = Weight & L = Length from center of first axle to center of last axle

The weight limits for single wheel, single axle and tandem axles are as follows,

Solid tire or cushion tires	Single wheel - 8,000 lbs. Single axle - 16,000 lbs. Tandem axle - 40,000 lbs.
Pneumatic tires	Single wheel - 9,000 lbs. Single axle - 20,000 lbs. Tandem axle - 40,000 lbs.

In addition, maximum GVW limit on non-interstate truck haulers is 85,000 lbs. The GVW limit for single unit trucks with two axle and three or more axles is 36,000 lbs. and 54,000 lbs. respectively. The Colorado State bridge formula (Eqn. 2) will be applied when the vehicle is a semi-trailer and trailer (excluding single unit). For example, for a hauler with a four-axle vehicle, with a length of 36 feet between center of first to last axle, the legal GVW will be computed as

$$W = (L+40)*1000$$

$$W = (36+40)*1000 = 76{,}000 \text{ lbs.}$$

Conversely, the legal GVW of 76,000 lbs. (36 feet long and four axles) will be applicable to five, six and seven axle groups, except that the vehicle must comply with single and tandem axle weight limits of Colorado.

Special allowances and exemptions

- A digger derrick or bucket boom truck operated by an electric utility can carry a single axle load up to 21,000 lbs.
- The gross weight upon any wheel of a steel-tired vehicle shall not exceed five hundred lbs. per inch of the cross-sectional width of the tire

4. Kansas State Regulations

In Kansas, the maximum GVW limit is 85,500 lbs. for vehicles configured with five or more axles. FBF is used to establish weight limit for SHVs in Kansas, as provided in Table 7. In addition, other weight limits include:

- Single axle – 20,000 lbs.
- Tandem axle – 34,000 lbs.
- Triple axles – three or more consecutive axles spaced more than 96 inches and not more than 120 inches
- Quad axles – Four or more consecutive axles spaced more than 120 inches and not more than 150 inches

Table 7: Permissible Weight Limit Table for Kansas

Distance in Feet (center of first to last axle)	**Axles**						
	2	3	4	5	6	7	8
4	34,000						
5	34,000						
6	34,000						
7	34,000						
8 or less	34,000	34,000					
Over 8	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	58,000	63,000	68,500	74,000	
25		54,500	58,500	63,500	69,000	74,500	
26		55,500	59,500	64,000	69,500	75,000	
27		56,000	60,000	65,000	70,000	75,500	
28		57,000	60,500	65,500	71,000	76,500	82,000
29		57,500	61,500	66,000	71,500	77,000	83,000
30		58,500	62,000	66,500	72,000	77,500	83,500

Table 7: Permissible Weight Limit Table for Kansas (CONTINUED)

Distance in Feet (center of first to last axle)	**Axles**						
	2	3	4	5	6	7	8
31		59,000	62,500	67,500	72,500	78,000	84,500
32		60,000	63,500	68,500	73,000	78,500	85,000
33			64,000	68,500	74,000	79,000	85,000
34			64,500	69,000	74,500	80,000	
35			65,500	70,000	75,000	80,500	
36			66000*	70,500	75,500	81,000	
37			66500*	71,000	76,000	81,500	
38			67500*	72,000	77,000	82,000	
39			68,000	72,500	77,500	82,500	
40			68,500	73,000	78,000	83,500	
41			69,500	73,500	78,500	84,000	
42			70,000	74,000	79,000	84,500	
43			70,500	75,000	80,000	85,000	
44			71,500	75,500	80,500	85,500	
45			72,000	76,000	81,000		
46			72,500	76,500	81,500		
47			73,500	77,500	82,000		
48			74,000	78,000	83,000		
49			74,500	78,500	83,500		
50			75,500	79,000	84,000		
51			76,000	80,000	84,500		
52			76,500	80,500	85,000		
53			77,500	81,000	85,500		
54			78,000	81,500			
55			78,500	82,500			
56			79,500	83,000			
57			80,000	83,500			
58				84,000			
59				85,000			
60				85,500			

Special allowances and exemptions

- Portable Scales
    - Officers may allow a 5 percent tolerance up to a 1,500 lb. maximum.
    - Single Axle- Maximum tolerance is 1,000 lbs.
    - Tandem Axle- Maximum tolerance is 1,500 lbs.
- Fixed Scales
    - No tolerance is allowed when using fixed scales.
    - These scales are certified to be in error no more than 0.1 percent, and federal requirements dictate that no tolerances be allowed

- Table 7 does not apply for vehicle units used exclusively for the transportation of sand, salt for highway maintenance operations, gravel, slag stone, limestone, crushed stone, cinders, coal, blacktop, dirt or fill material, when such vehicles are used for transportation to a construction site, highway maintenance or construction project or other storage facility, except that such vehicles or combination of vehicles shall not be exempted from any application of the Table 7, as may be required to determine applicable axle weights for triple and quad axles.

5. *Oklahoma State Regulations*

Legal weight limits on any Oklahoma road and highway for vehicles with two to six axles are displayed in Table 8. Oklahoma Vehicle Code section 14-109 does not mention the use of FBF for calculating the values in Table 8. However, the values do closely match the FBF table values, with some adjustment in weight limitations for three and four axle configurations. Additionally, for vehicle configurations in excess of six axles, special permits are issued based on Title 23, U.S. Code, section 127. The legal weight limits are as follows:

- Maximum GVW- 90,000 lbs.[1]
- Single axle – 20,000 lbs.
- Tandem axle – 34,000 lbs.

[1] Maximum GVW of 90,000 lbs. is for vehicle configurations up to six axles. Maximum GVW for vehicle configurations in excess of six axles is dependent on FBF table.

Authority to set Maximum Weight Limit

The Director of the Department of Transportation (Title 69 of the Oklahoma Statues) may reduce the permissible weight limit if there is an immediate threat to a highway, detour or bridge under his or her jurisdiction due to adverse climatic conditions.

Special allowances and exemptions

Utility or refuse collection vehicles used by counties, cities, or towns or by private companies contracted by counties, cities, or towns are exempt from weight limitations if the following conditions are met

- GVW of the vehicle is no more than 15% over the legal limit (Only on state maintained roads).
- The weight of axles must not exceed the manufacturer's component rating, which includes axle, suspension, wheels, rims, brakes and tires as shown on the verification label or tag.

Vehicles transporting timber, pulpwood, and chips in their natural state; vehicles transporting oil, oil field equipment, or equipment used in oil and gas well drilling or exploration; vehicles transporting grain; and vehicles transporting rock, sand, gravel and coal are exempt if the following conditions are met:

- The vehicles are registered for the maximum allowable rate
- GVW does not exceed 5% of the legal limit

Table 8: Permissible Weight Limit Table for Oklahoma

Distance in Feet (center of first to last axle)	**Axles**				
	2	3	4	5	6
4	34,000				
5	34,000				
6	34,000				
7	34,000				
8	34,000	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	58,000	63,000	68,500
25		54,500	58,500	63,500	69,000
26		55,500	59,500	64,000	69,500
27		56,000	60,000	65,000	70,000
28		57,000	60,500	65,500	71,000
29		57,500	61,500	66,000	71,500
30		58,500	62,000	66,500	72,000
31		59,000	63,500	67,500	72,500
32		60,000	64,000	68,500	73,000
33		63,500	64,500	68,500	74,000
34		64,000	65,000	69,000	74,500

Table 8: Permissible Weight Limit Table for Oklahoma (CONTINUED)

Distance in Feet (center of first to last axle)	**Axles**				
	2	3	4	5	6
35			66,000	70,000	75,000
36			68,000	70,500	75,500
37			68,000	71,000	76,000
38			69,000	72,000	77,000
39			70,000	72,500	77,500
40			71,000	73,000	78,000
41			72,000	73,500	78,500
42			73,000	74,000	79,000
43			73,280	75,000	80,000
44			73,280	75,500	80,500
45			73,280	76,000	81,000
46			73,280	76,500	81,500
47			73,500	77,500	82,000
48			74,000	78,000	83,000
49			74,500	78,500	83,500
50			75,500	79,000	84,000
51			76,000	80,000	84,500
52			76,500	80,500	85,000
53			77,500	81,000	86,000
54			78,000	81,500	86,500
55			78,500	82,500	87,000
56			79,500	83,000	87,500
57			80,000	83,500	88,000
58				84,000	89,000
59				85,000	89,500
60				85,500	90,000

6. Texas State Regulations

Texas applies the FBF to determine the maximum legal weight on any vehicle group of two or more consecutive axles for its public highways or at a port of entry between Texas and the United Mexican States. In addition, a tire cannot carry a weight heavier than those specified and marked on the side wall of the tire, unless the vehicle operates under the terms of a special permit.

- Maximum Gross Vehicle Weight - 80,000 lbs.

- Single axle - 20,000 lbs.
- Tandem axle group - 34,000 lbs.
- Triple axle group - 42,000 lbs.
- Quad axle group - 50,000 lbs.

In Texas, the number of axles determines the maximum legal weight as shown in Table 9. The weight limit of single, tandem, triple and quad axle groups, in conjunction with the Permissible Weight Table (Table 9), is used to determine maximum GVW for a vehicle. Table 9 may be applied to inner axle groups such as the drive axles and the trailer or trailers, or the entire combination of axles from the steering axle of the power unit to the last trailing axle of the trailer.

Authority to set Maximum Weight Limit

Per Texas Transportation Code Sec. 621.102 and Sec. 621.301, the state and county governments in Texas may limit maximum weight limit for state highways, ranch or farm roads and county roads if the executive director finds that “heavier maximum weight would rapidly deteriorate or destroy the road or a bridge or culvert along the road.” Both the state and county governments must do engineering studies and traffic investigation to impose weight limits less than the legal limit in Texas.

Special allowances and exemptions

Texas provides allowances and exemptions for the following special class vehicles:

- Ready mix concrete trucks can operate with tandem axle weight up to 46,000 lbs. and single axle weight up to 23,000 lbs. In addition, Ready mix concrete trucks can either carry up to 50,600 lbs. for tandem axle or 25,300 lbs. for single axle, if the GVW of the truck is not greater than 69,000 lbs. (Texas Transportation Code Sec. 622.011 and Sec. 622.012).
- There is an exemption from load-posted weight limits on state-maintained roads and bridges for vehicles delivering groceries, farm products, or liquefied petroleum gas (Texas Transportation Code Sec. 621.102).
- There is an exemption from load-posted weight limits on county roads and bridges for vehicles delivering groceries or farm products, provided that the delivery “requires” use of the road or bridge (Texas Transportation Code Sec. 621.302).

Table 9: Permissible Weight Limit Table for Texas

Distance in Feet (center of first to last axle)	**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+	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	

*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

+These figures apply only to an axle spacing greater than 8 feet but less than 9 feet

Table 9: Permissible Weight Limit Table for Texas (CONTINUED)

Distance in Feet (center of first to last axle)	**Axles**				
	2	3	4	5	6
36			68,000	70,500	75,500
37			68,000	71,000	76,000
38			69,000	72,000	77,000
39			70,000	72,500	77,500
40			71,000	73,000	78,000
41			72,000	73,500	78,500
42			73,000	74,000	79,000
43			73,280	75,000	80,000
44			73,280	75,500	80,500
45			73,280	76,000	81,000
46			73,280	76,500	81,500
47			73,500	77,500	82,000
48			74,000	78,000	83,000
49			74,500	78,500	83,500
50			75,500	79,000	84,000
51			76,000	80,000	84,500
52			76,500	80,500	85,000
53			77,500	81,000	86,000
54			78,000	81,500	86,500
55			78,500	82,500	87,000
56			79,500	83,000	87,500

*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

+These figures apply only to an axle spacing greater than 8 feet but less than 9 feet

C1. IMPACTS OF SHVS ON PAVEMENTS AND BRIDGES

This section summarizes the current knowledge on how SHVs may impact pavements and bridges. The information is synthesized from both the published literature and a survey of practitioners.

A brief survey was conducted in six identified states (Arizona, Alabama, Colorado, Kansas, Oklahoma and Texas) to document the practitioners' knowledge regarding the impact of SHVs on pavements and bridges. Based on the survey results, none of the six states have performed any specific studies to examine the impact of SHVs on their pavements and bridges. However, Alabama provided the results of Load Factor Design (LFD) analysis performed on their common superstructures/standard drawings by including SHVs. From phone interviews, bridge engineers believe that SHVs can potentially impact the service life of bridges and pavements, despite the absence of reliable data. In particular, they are concerned about local bridges, old bridges and short span bridges (length not exceeding 40 feet).

It is noteworthy that limited information is available in the published domain or in the practitioners' arena regarding the impact of SHVs on pavements and bridges, especially when it comes to the impact of a specific vehicle configuration. There are two possible reasons for this. One relates to the fact that SHV legal weight limits have been established in relatively recent years. The other relates to the inherent difficulty to isolate the impacts of SHVs from all the other influential factors in the diverse and dynamic service environment of pavements and bridges (e.g., mix design, construction quality, climatic and traffic conditions, and use of deicing chemicals).

Numerous studies have shown that heavy trucks can cause minor to significant damage to pavements and bridges. In particular, truck characteristics such as GVW, axle weight, axle spacing, axle width and truck height play a significant role in the durability and service life of pavements and bridges.

Typically, SHVs are vehicles with closely spaced multiple axles that carry heavy weight on each individual axle. In this context, it is anticipated that the SHVs' impacts on pavements and bridges are mainly dependent on their GVW, axle weight and axle spacing. The findings from this section may provide some insight to evaluate the impact of SHVs on such infrastructure.

Pavements

In light of the findings from literature review (see Appendix B), SHVs may induce no additional damage to flexible (asphalt) pavements and can potentially induce additional damage to rigid (concrete) pavements, relative to conventional trucks. This is largely due to the following facts:

- Compared with conventional trucks, SHVs typically allow similar GVW with the increase in the number of axles which results in the distribution of GVW over multiple axles. For flexible pavements, reducing the axle spacing and grouping the axles (e.g., tandem, tridem axles and quad axles) are known to reduce the detrimental effects on pavement. Even though the maximum deflection of the pavement surface continues to increase, maximum tensile stress at the underside of the surface layer (considered to be the primary cause of fatigue cracking) can actually decrease as axle spacing is reduced. For rigid pavements, however, changing from conventional truck to SHV configuration can induce more dynamic load and thus more detrimental effects on pavement.
- SHVs typically have single axle weight less than 18,000 lbs., resulting in Equivalent Single Axle load (ESAL) value less than 1.0.
    - Note: One ESAL is "known to cause a quantifiable and standardized amount of damage to the pavement structure equivalent to one pass of a single 18,000-pound, dual-tire axle with all four tires inflated to 110 psi (Tang, 2012)". A vehicle with 5.0 ESAL means that one pass by such a vehicle is equivalent to five passes by an 18,000-lb single axle vehicle.

It should be noted that SHVs with heavy loaded steering or driving axles with single tires could be more damaging to pavements. Further, improper use of lift axles in SHVs can be damaging to pavements. However, the lift axle issue can be mitigated through enforcement.

In general, heavy trucks (including conventional trucks and SHVs) contribute to various forms of pavement damage. Of these, fatigue and permanent deformation are the important factors leading to premature deterioration of pavements, evident in the symptoms of cracking (e.g., for both flexible and rigid pavements) and rutting (mostly for flexible pavements), respectively. The general findings from the published literature are as follows.

- *Axle weight is a more significant determinant in pavement damage than GVW.* For example, a truck carrying 60,000 lbs. of GVW with higher single axle weight can cause more damage to pavements than a truck carrying 80,000 lbs. with less single axle weight.
- An increase in axle weight generally causes an *exponential increase* in pavement damage.
- For each axle, *the use of dual tires in place of a single tire can potentially reduce the pavement damage*. Wide-space single tires are sometimes used on SHVs for easy maneuverability; but wide-spacing of tires may increase risk to pavement.
- *Inappropriate use of lift axles* could result in either overloading of lift axles or other axles within the vehicle, resulting in accelerated pavement damage. Lift axles are sometimes used on SHVs for easy maneuverability.
- For flexible pavements, *distributing the same GVW over more axles (e.g., 5 instead of 4 axles) can potentially reduce the pavement damage, as this would reduce the single-axle weight. In addition, bringing axles together tends to decrease the risk of fatigue damage*, but may increase the risk of rutting. *Axle grouping for vehicles tends to reduce their*

damage to flexible pavements. In other words, a tandem-axle configuration poses less risk to the durability of pavements than a single-axle configuration: a tridem-axle configuration poses even less risk, and so on.

- For rigid pavements, there is no consensus on the relationship between axle grouping and pavement damage, as there are multiple deterioration mechanisms at work.

A detailed literature review on the impact of truck axle weight, axle spacing, tire characteristics and lift axles on pavements is provided in Appendix B.

Bridges

In light of the findings from literature review, the impact of SHVs could be significant to bridges. For instance, the recent NCHRP study (Sivakumar, 2007) used Weigh in Motion (WIM) data and survey data obtained from several states to analyze the effect of SHVs and found that these "SHVs cause force effects that exceed the stresses induced by HS20 in bridges by up to 22% and by the Type 3, 3S2, or 3-3 posting vehicles by over 50% in certain cases". Note that HS20 is the vehicle configuration that was used as the basis for bridge design in the United States up until recently and Type 3, 3S2, or 3-3 are posting loads which were and continue to be used to assess a bridge's ability to carry State legal loads. The findings from Sivakumar (2007) study conclude that SHVs cause load effects in some bridges that exceed those of the analytical vehicles used to design and assess the bridges. In particular, the shorter bridge spans are most sensitive to the newer SHV axle configurations. Depending on the specific bridge configuration, certain types of SHVs may pose a greater risk than others and thus induce the need for bridge weight limit posting.

The following general findings pertinent to SHVs are supported by the studies detailed below.

1) Compared with conventional trucks, SHVs typically allow more GVW with the increase in the number of axles. Increasing the number of axles to increase the GVW does not necessarily reduce the bridge stress, as the GVW plays a more important role in defining bridge stress than the number of axles.

2) SHVs tend to pose more risk to bridges than conventional trucks, in light of their closely spaced axles. A vehicle with *closely spaced axles* induces more damage to bridges than a longer vehicle with widely spaced axles, for the same GVW. This is because that *shorter axle spacings* and *heavier axles* tend to induce significantly higher moments and shear forces.

Heavy trucks (including conventional trucks and SHVs) require highway bridges to have certain load-carrying capacity. Impacts of heavy trucks on bridges relate to overstress and fatigue. Overstress occurs when a bridge has inadequate load carrying capacity to accommodate certain heavy trucks. Fatigue occurs due to the repeated loadings, resulting in cracks at points of high stress concentration and thereby reducing the bridge service life. However, fatigue damage is mostly applicable to steel bridges and bridge decks.

Firstly, a study by USDOT (2000) provided an overview on the impact of heavy vehicles on highway infrastructures. It concluded that, GVW plays a key role in defining the *bending stress* on the bridge components, in addition to the spread of axles. Laman and Ashbaugh (2000) found a weak correlation (0.65) between the GVW and fatigue damage potential. They also revealed that longer vehicles tend to induce an average of 15 percent of the damage induced by shorter vehicles for a given GVW, which confirms the higher risk associated with SHVs relative to conventional vehicles.

Secondly, a study was conducted in Canada (Hajek and Agarwal, 1989), which found that permissible loads on each individual axle can be increased by increasing the axle spacing between dual axles and triple axles, as such change would reduce the maximum *moment and shear force* on bridge components. The study by USDOT (2000) emphasized that for both long span and short span bridges the bending stress on the bridge components is more dependent on the spread of axles than the number of axles. Laman and Ashbaugh (2000) conducted a study with 78 distinct trucks to examine the relative *fatigue damage potential* of steel highway bridges. The study found that weight distribution and axle spacing are the important factors in defining the damage potential for a given GVW. A vehicle with heavy and closely spaced axles will induce more fatigue damage to steel bridges than a vehicle with weight distributed over a longer length, for the same GVW. Further, closely spaced heavy axles induce more stresses on the critical points along the bridge span than the longer vehicles.

For bridges with relatively short span, SHVs can induce significantly higher moments and shears than AASHTO vehicles (Type 3, Type 3S2, and Type 3-3). This was demonstrated in a recent NCHRP study, which examined the impact of SHVs on various generic bridges with spans ranging from 10 feet to 200 feet (Sivakumar, 2007). The bridges used for analysis contained both simple and continuous spans and some with transverse members. The continuous spans consisted of two-span (two equal spans), three-span (two equal outer spans set at 0.8 times of interior span) and four-span (two equal outer spans set at 0.8 times of two interior spans). The study used 12 SHV configurations (which follows FBF limit) with outer axle spacing ranging from 14 feet to 34.5 feet with the maximum GVW limit of 80,000 lbs. SHV configurations used also included lift axles and split rear axle.

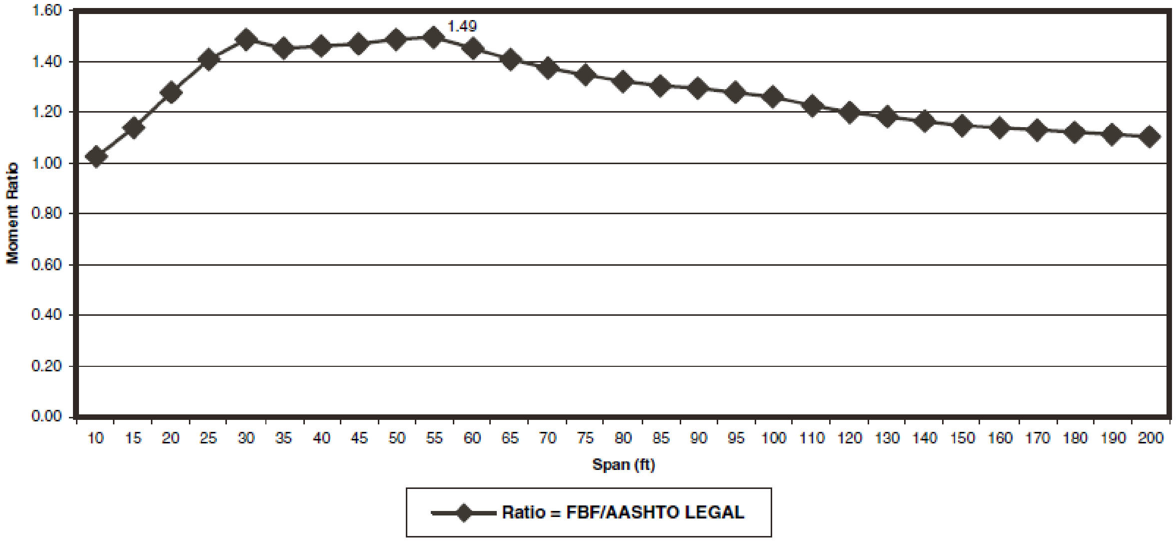


Figure 4: Moment ratios between SHVs and AASHTO posting loads (Type 3, Type 3S2, and Type 3-3) (Sivakumar, 2007)

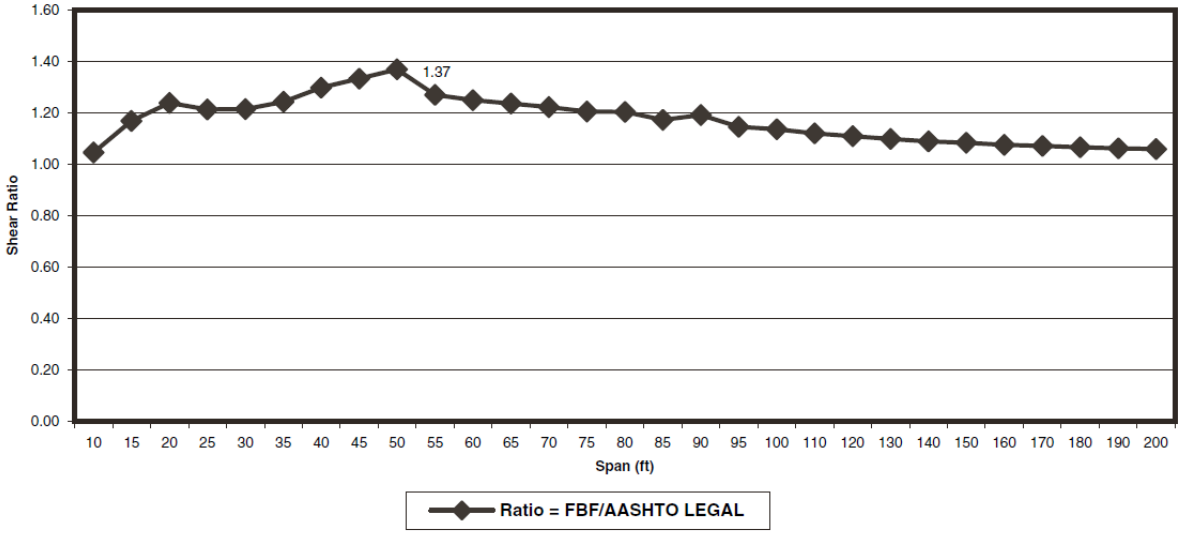


Figure 5: Shear ratios between SHVs and AASHTO posting loads (Type 3, Type 3S2, and Type 3-3)
(Sivakumar, 2007)

The Alabama DOT recently conducted a study to examine the impact of a tri-axle dump truck as shown in Figure 6. Note that the "tri-axle dump truck" is a four-axle truck (19 feet outer axle spacing) with tridem axle, which can be considered as a type of SHV. In addition, the study also included SU4, SU5, SU6, SU7, NRL (with variable axle spacing of 6 ft. and 14 ft.) and HS20-44 legal loads for LFD analysis. The study employed common superstructures/standard drawing used in Alabama highways (Table 10) to analyze the impact of such vehicles. The results of their study are presented in Table 10. It can be noted that some of the Reinforced Concrete Deck Girder (RCDG) structures have operational Rating Factor (RF) values less than 1.0 (Highlighted in Red) for “tri-axle dump truck,” SU4, SU5, SU6, SU7 and NRL legal loads. A RF value less than 1.0 indicates that the bridge does not have adequate load carrying capacity for the rated legal vehicle. The results indicate that the impact of SHVs trucks is more evident on short span bridges. A closer inspection reveals that the RF value increases with the increase in bridge span length for both simple and continuous spans. These results are consistent with the previous findings (Sivakumar, 2007) that SHVs are more damaging to short span bridges.

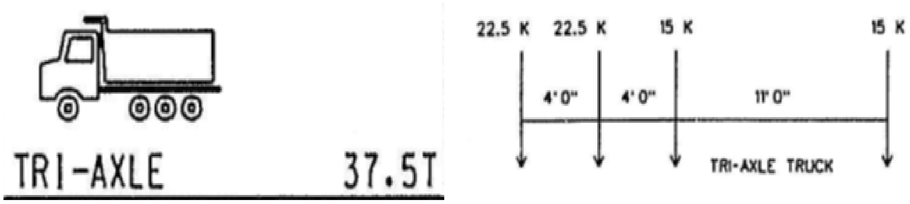


Figure 6: Tri-axle dump truck (Alabama DOT posting vehicle)

Table 10: Rating Factors of Standard Superstructure type/Standard Drawing for Alabama (Data provided by Alabama DOT personnel)

OPERATING RATING FACTOR (RF) - LFD Method					HS20-44	TRI-AXLE DUMP TRUCK	NRL (Variable axle 6 ft.)	NRL (Variable axle 14 ft.)	SU4	SU5	SU6	SU7
Bridge Identification Number	Superstructure type/Standard Drawing	Simple/ Continous	Span Length(s) (ft.)	Design Load								
Reinforced Concrete Deck Girder (RCDG)												
8435	RCDG / C-2200	Simple	34	H-15	1.103	0.934	1.108	1.104	1.285	1.203	1.212	1.157
8572	RCDG / C-2414	Simple	34	H-20	1.496	1.261	1.466	1.461	1.736	1.628	1.61	1.532
3041	RCDG / 714	Simple	34	H-15	1.135	0.854	0.92	0.913	1.183	1.11	1.009	0.961
3202	RCDG / 714	Simple	28	H-15	0.855	0.715	0.897	0.897	0.979	0.941	0.942	0.942
7634	RCDG / C-2815	Simple	40	H-20	1.486	1.291	1.585	1.572	1.773	1.627	1.611	1.608
7557	RCDG / C-2814	Simple	34	HS-20	1.451	1.233	1.557	1.548	1.698	1.58	1.584	1.587
7329	RCDG / C-2812	Simple	50	HS-20	1.136	1.003	1.195	1.19	1.385	1.263	1.221	1.196
8189	RCDG / IC-2403	Continous	63-79-79-63	H-20	1.761	1.514	1.546	1.575	2.109	1.91	1.742	1.611
8169	RCDG / IC-2800	Continous	50-63-63-50	HS-20	1.103	1.055	1.106	1.119	1.412	1.283	1.189	1.122
9228	RCDG / IC-4003	Continous	63-79-79-63	HS20	1.347	1.232	1.19	1.217	1.713	1.519	1.362	1.244
8572	RCDG / IC-2411	Continous	58-73-73-58	H-20	1.263	1.149	1.247	1.272	1.602	1.465	1.361	1.275
7544	RCDG / IC-2413	Continous	68-85-85-68	H-20	1.519	1.321	1.326	1.361	1.815	1.646	1.495	1.387
7848	RCDG / IC-2825	Continous	72-90-72	HS-20	1.996	1.73	1.736	1.767	2.407	2.183	1.959	1.822
8518	RCDG / IC-2806	Continous	60-75-75-60	HS-20	1.096	0.998	0.965	0.987	1.383	1.232	1.105	1.009
9521	RCDG / IC-2414	Continous	77-96-96-77	H-20	1.809	1.586	1.583	1.604	2.188	1.99	1.797	1.659
Prestressed Concrete												
19076	Prestressed type I / None	Simple	40, 60	HS-20	1.808	1.453	1.834	1.835	1.959	1.813	1.899	1.801
18378	Prestressed II, III / None	Simple	58, 91	HS-20	2.204	1.991	2.204	2.244	2.754	2.43	2.331	2.247
18955	Prestressed type BT-72 / None	Simple	120	HS-20	2.394	2.027	2.155	2.136	2.642	2.467	2.227	2.255
18851	Prestressed type BT-72 / None	Simple	135	HS-20	1.921	1.549	1.606	1.616	2.122	1.927	1.918	1.707
19779	Prestressed type BT-54 / None	Simple	80, 100, 80	HS-20	2.289	2.135	2.166	2.185	2.808	2.601	2.375	2.219
19388	Prestressed type II / None	Simple	55	HS-20	1.854	1.591	1.815	1.831	2.075	1.894	1.856	1.863
12953	Prestressed type I / None	Continuous for LL	34-34	HS-20	1.147	1.303	1.591	1.587	1.661	1.681	1.657	1.655
12376	Prestressed type I / None	Continuous for LL	7 @ 41	HS-20	1.411	1.2	1.638	1.644	1.594	1.581	1.612	1.676
16497	Prestressed type III / None	Continuous for LL	60-65-61	HS-20	2.248	1.86	2.042	2.321	2.341	2.238	2.146	2.089
15245	Prestressed type I / S-4041P(1)	Continuous for LL	5 @ 41 / 2 @ 41	HS-20	1.214	1.101	1.297	1.319	1.533	1.398	1.354	1.335
Steel												
7634	Rolled Steel / B-2800	Simple	80	HS-20	1.967	1.748	1.718	1.749	2.429	2.187	1.958	1.787
9006	Rolled Steel / None	Simple	43	HS-20	2.534	2.02	2.101	2.133	2.792	2.629	2.638	2.213
9267	Rolled Steel / None	Simple	62	HS-20	2.387	2.039	2.047	2.092	2.825	2.583	2.314	2.135
9792	Rolled Steel / BC-2803	Simple	50	HS-20	2.284	1.888	1.924	1.981	2.618	2.421	2.175	2.014
9240	Rolled Steel / BC-2804	Simple	60	HS-20	2.199	1.878	1.886	1.927	2.603	2.379	2.132	1.967
12718	Rolled Steel / None	Continuous	67-84-67	HS-20	1.671	1.44	1.453	1.482	2.003	1.814	1.64	1.521
15963	Rolled Steel / None	Continuous	57-101-57	HS-20	2.514	2.355	2.327	2.369	3.28	2.959	2.655	2.426
10427	Rolled Steel / None	Continuous	50-86-86-64	HS-20	1.707	1.461	1.479	1.508	2.028	1.841	1.667	1.548
10491	Rolled Steel / None	Continuous	50-71-50	HS-20	1.675	1.374	1.432	1.463	1.909	1.769	1.615	1.492
15964	Rolled Steel / None	Continuous	55-101-55	HS-20	2.514	2.355	2.327	2.369	3.28	2.959	2.655	2.426
7273	Rolled Steel / B-2202	Continuous	60-80-60	H-15	1.119	0.961	0.978	0.993	1.329	1.212	1.096	1.019
12491	Plate Girder / None	Simple	111	HS-20	2.765	2.516	2.437	2.461	3.493	3.118	2.78	2.532
12503	Plate Girder / None	Continuous	100-119-101	HS-20	1.881	1.675	1.64	1.665	2.327	2.086	1.871	1.705
15957	Plate Girder / None	Continuous	110-104-55	HS-20	1.603	1.41	1.386	1.407	1.956	1.756	1.576	1.444
11930	Plate Girder / None	Continuous	152-152	HS-20	1.946	1.783	1.723	1.738	2.485	2.194	1.966	1.787
12319	Plate Girder / None	Continuous	82-104-82	HS-20	1.862	1.648	1.633	1.657	2.289	2.059	1.857	1.709

C2. IMPACTS OF SHVS ON BRIDGE WEIGHT LIMIT POSTING AND ENFORCEMENT

This section summarizes the current knowledge on how SHVs may impact the practice of bridge weight limit posting and enforcement.

Bridge weight limit posting is performed based on the outcome of load rating. It is required if the load rating indicates that the load carrying capacity of a bridge is less than “legal loads.” Based on the survey results, the new AASHTO SHV models (SU4, SU5, SU6 and SU7) have not been completely adopted by all six states (that were studied in this report) for bridge weight limit posting. A few states are in the process of rating their bridges by including SHVs, while other states are planning to include SHVs in their future re-ratings and new bridges. A national survey conducted in 2013 for a NCHRP synthesis revealed that only nine states were using SHVs for load rating their bridges. These include: Hawaii, Louisiana, Michigan, Minnesota, Oregon, Utah, Virginia, Washington and Wisconsin (Hearn, 2014). As such, there is currently very little information available on how the introduction of SHVs has affected the number of bridge weight limit postings.

The survey generated the following results regarding bridge weight limit posting and enforcement in the selected six states:

- Arizona is currently using NRL (with variable axle spacing of 6 ft.) to rate the state-owned bridges and screen the bridges that have RF less than 1.0. The RF is based on the operating values of LFD method. They are still working on the regulations on how to further analyze SHVs for the bridges that were found to have RF value less than 1.0 for NRL. In addition, they are expecting the posting frequency to increase for bridges located on local and county roads.
- Alabama rated the common bridge structures (by including NRL, SU4, SU5, SU6 and SU7) found on Alabama highways and found no significant impact due to SHVs except for a few RCDG structures (Table 10). Alabama DOT is currently devising a methodology for posting bridges that have a RF value less than 1.0 for SHVs.
- Colorado is considering adding SHVs for posting limits for their future re-ratings and new bridges. Colorado is anticipating an increase in frequency of bridge weight limit posting, especially for short span bridges not exceeding 40 feet.
- Oklahoma did not include SHVs for posting limits. However, as they move forward with LRFD rating, they plan to include SHVs for posting limits on bridges.
- Kansas did not include SHVs for posting limits and does not have much information about their considerations for future posting.
- Texas does not use SHVs in determining posting limits. Instead, they use their own state legal vehicles to determine bridge posting limits.

In addition, the Minnesota DOT is currently rating their bridges by including SHVs (MnDOT, 2014). MnDOT evaluated 1,310 local bridges that are most susceptible to SHVs in their first two load rating contracts. The study found that 56 percent of evaluated bridges required load posting. A large percentage of bridges that require posting are short span timber and steel beam bridges. Currently, the 3rd SHV load rating contract is ongoing, and it is about 56 percent complete (as of January 2014). Further, MnDOT proposed to begin their work on the 4th SHV load rating contract by including 890 local bridges (fiscal year 2014) and 5th SHV load rating contract by including 663 local bridges (fiscal year 2015). Figure 7 provides the percentage of bridges that require load posting for SHVs. It can be noted that the impact of SHVs is more evident on steel bridges and timber bridges. In particular, timber bridges were most affected by SHVs, and MnDOT emphasizes the growing need to remove, repair, rehabilitate or replace the timber bridges (MnDOT, 2014).

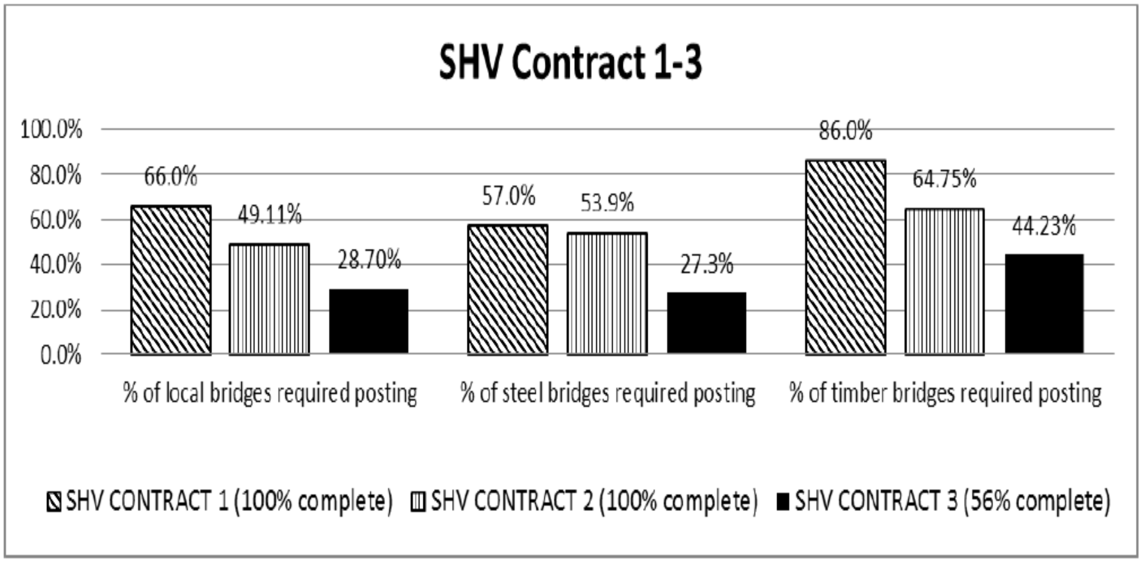
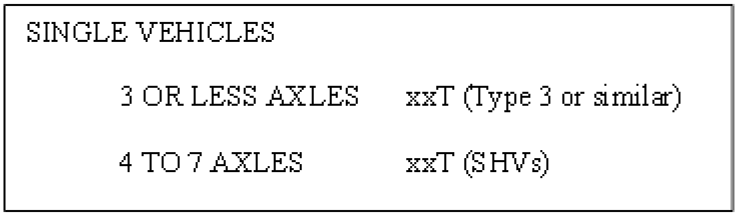


Figure 7: Results of MnDOT SHV load rating of local bridges (MnDOT, 2014)

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. Nonetheless, there is little information in the published literature regarding this issue.

Regarding bridge weight limit enforcement pertinent to SHVs, Colorado suggests adding another sign to indicate the weight limit of SHVs. Further, the other five states do not have much information on posting signs to differentiate SHVs at this point in time.

A recent report by FHWA to address questions on load rating of SHVs suggested few examples for posting signs. Per FHWA (2014), the Manual on Uniform Traffic Control Devices (MUTCD) allows states to modify posting signs that do not contain silhouettes (specifically R12-1 though R12-4) to meet SHV configurations. Below is an example provided by FHWA (2014):



SINGLE VEHICLES

3 OR LESS AXLES xxT (Type 3 or similar)

4 TO 7 AXLES xxT (SHVs)

The report (FHWA, 2014) states that “the number of axles on each line would need to be adjusted to each State’s vehicle laws and appropriate level in determining the cut-offs for grouping the number of axles together”. The report also suggests that states come up with their own options, such as a word sign to distinguish single unit vehicle (Type 3, SHV, etc.) and a combination vehicle (Type 3S2, 3-3, etc.). However, the posted sign should not be restrictive to other vehicles.

Another enforcement issue related to SHVs deals with lift axles in SHVs. A recent survey conducted by Fu (2011) found that there are no regulations for lift axles and each state has their truck regulation. Some states do not even have laws regulating their usage. In order to minimize the inappropriate use of lift axles, Fu (2011) suggests making truck companies accountable for violations and increasing the penalties for those who violate the lift-axle regulations.

C3. IMPACTS OF SHVS ON ECONOMY AND SAFETY

This section synthesizes the available information on the effect of heavier trucks on the economy and on safety, with a focus on the effect of SHVs. Not one of the six states surveyed in this study has performed any specific studies on this issue.

Different dimensions of the SHV weight limits issue need to be balanced in light of local priorities and constraints. The statistics in 2004 (National Transportation Statistics, 2004) confirm that freight transport on highways greatly contributes to the economy, at more than $250 billion per year. SHVs are among the necessary freight tools to respond to specific needs of typically local or regional economies. They generally carry loads not as large or as heavy as those by longer combination vehicles, or LCVs, but offer better flexibility for freight transport. Increased truck weight limits can negatively impact the bridge and pavement network and incur additional costs to the infrastructure owners such as state DOTs, despite the potential cost savings to the truck operators (Fu, 2003).

Ideally, any legislative or regulatory actions that permit the introduction of SHVs should be accompanied by provisions for additional resources on the part of non-DOT agencies to develop revenue structures, inspection procedures, and other oversight functions. Currently there is little information in the published literature on this issue, and additional research is thus warranted.

Effect of higher SHV weight limits on the economy

While there is little information specific to the effect of SHVs on the economy, there have been reported benefits of increasing the allowable truck sizes and weights (TS&W) in general. From the knowledge synthesized from the published literature, one can derive the following conclusions in the absence of reliable infrastructure data associated with SHVs:

1) *Increasing SHVs weight limits are most likely to slightly benefit the economy*
2) *SHVs are likely to increase bridge costs as a result of increased moment and shear force on bridge components; and they are unlikely to increase pavement costs unless single-axle loads exceed 18,000 lbs.*

The economic and environmental benefits can be realized by enabling truck operators to consolidate small shipments or carry heavier payloads and thus in most cases reduce operating costs (McKinnon, 2005). For example, a study was recently conducted to estimate the economic impact of a 7-axle 80,000 lbs. single unit truck (one type of SHVs) by comparing with it a base truck (5-axle, 80,000-lb semitrailer) operating on non-interstate highways (Adams et al., 2009). Adams et al. (2009) found a $2.46 million reduction in annual *industry transport costs*; a $0.08 million reduction in annual *congestion costs*; as well as *environmental benefits* (diverted payload of 25 million ton-miles; reduced fuel consumption of 0.04 million gallons; reduced carbon dioxide and nitrogen oxides emissions of 0.92 million lbs. and 0.96 million lbs., respectively). Note that the shipper's cost savings tend to be lower for "lower weights, shorter lengths, and smaller networks" (FHWA, 1995a). The economic benefits can be realized by increasing the efficiency and productivity of transportation systems (Hewitt *et al.*, 1999; Nagl, 2007).

Numerous studies have indicated that increasing truck weight limits may significantly increase bridge infrastructure costs, but their impact on pavement infrastructure costs is less significant (Godwin *et al.*, 1987; Luskin and Walton, 2001). Carson (2011) stated that "bridge stress is affected more by the total amount of weight than by the number of axles." The increase in GVW would incur considerable bridge costs, with the increased need to upgrade bridges (Luskin and Walton, 2001) or the need for "accelerated maintenance, rehabilitation, or replacement work" or "posting plus enforcement"(Fu et al.,2003). Further, increasing the number of axles in SHVs to accommodate higher GVW (especially if they are closely spaced) is more likely to increase bridge costs. Adams et al. (2009) estimated the cost impacts due to the 7-axle 80,000 lbs., single unit truck (one type of SHVs) by comparing it with a base truck (5-axle 80, 000 lbs. semitrailer) on highway infrastructure. The study found a $2.26 million increase in annual *bridge costs* due to the 7 axle single unit vehicle. Walton *et al.* (2010) reported a repair cost of $190 per square foot of deck area for estimating the risk of heavier trucks on highway bridges.

By contrast, increasing the truck size and weight limits "do not necessarily lead to higher pavement costs" or "can even produce savings in pavement costs" if they lead to the use of more axles. Any vehicle configuration with single-axle weight exceeding 18,000 lbs. would increase ESALs (Tang, 2012) and thus increase pavement repair costs. Godwin *et al.* (1987) reported an average pavement cost at 1.6 cents per ESAL mile. TRB (1990) found that "a 10 percent increase in ESALs can be accommodated by 1.5 percent increase in pavement thickness", which then translates to additional pavement costs. Luskin and Walton (2001) reported that an 80,000-lb, 5-axle tractor semitrailer "typically causes about 9 cents in pavement damage per mile of travel on rural Interstate Highways, compared with $5.90 per mile of travel on rural local roads". This illustrates the fact that the pavement cost per EASL mile is much greater for pavements designed for light duty. Bai and Center (2010) estimated an average pavement cost at approximately 2 cents per mile for heavy trucks (e.g., tractor-trailers) on a 41-mile-long highway section in the State of Kansas. In another study, Straus and Semmens (2006) estimated an annual total of highway pavement costs between $12 million and $53 million attributable to overweight vehicles in the State of Arizona. In some cases, increasing the truck size and weight limits can even lead to decrease in pavement costs, as pavement damage is "directly related to individual axle weight rather than gross vehicle weight" (Godwin et al., 1987). For instance, the Adams et al. (2009) study found a $0.4 million reduction in annual *pavement costs* by comparing the use of the 7 axle single unit vehicle with a base truck (5-axle 80, 000 lbs. semitrailer).

Further, it should also be noted that bridge and pavement maintenance, rehabilitation, or replacement activities also incur costs to highway users in terms of traffic congestion and delay (Weissmann and Harrison, 1998).

Effect of higher SHV weight limits on safety

While there is little information specific to the effect of higher SHV weight limits on safety, safety implications of increasing the allowable TS&W in general have been reported.

From the knowledge synthesized from published literature, one can derive the following conclusion in the absence of reliable crash and exposure (vehicle-miles traveled) data specifically attributed to SHVs:

1. *Replacing longer trucks with SHVs is likely to improve the operator's safety, as SHVs are shorter and thus easier to operate. But increasing SHV weight limits is likely to increase their crash risk, as they would 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.*

Turner and Nicholson (2009) conducted a comprehensive literature review and interviewed fifty practitioners to examine the safety implications of oversize/overweight (OS/OW) commercial vehicles. They found that *larger and heavier vehicles tend to feature generally lower crash rates but generally more severe crashes*. This trend was confirmed by the synthesis done by Carson (2011). Yet the cause-and-effect relationships between the truck size/weight and safety risks are too complicated to support any definitive conclusions. Heavier trucks tend to take longer to stop and are more difficult to operate during evasive maneuvers (OhioDOT, 2009). According to the FHWA (1995a), higher weight limits may negatively affect vehicle stability and control and "the shorter the wheelbase lengths of the trailers in the combination, the more susceptible the vehicle is to rollover". Rollover crashes tend to be more severe and thus are a serious safety concern. Further, additional braking mechanisms can be equipped for each additional axle to help combat against the increased momentum of heavier trucks (Waldron and Yates, 2012). Adams et al. (2009) stated that "increasing the number of axles by 20 percent (e.g., adding an axle to a five-axle combination) would reduce its crash rate by 5 percent." Further, Adams et al. (2009) compared the safety impact of various truck configurations (with increased allowable weight) on highway safety in the State of Wisconsin, using the 5-axle tractor semitrailer as a base case. The estimated safety costs are summarized in Table 11. It can be found that one type of SHV (the 7-axle 80,000 lbs. single unit truck, highlighted in green) slightly reduced the annual safety costs on highways, relative to the base case.

Table 11: Estimated safety costs for various truck configurations (Adams et al., 2009)

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

The related but less SHV-relevant information on the impact of heavier or longer trucks on the economy and safety is provided in Appendix C.

CONCLUSIONS

The key conclusions from this study include:

- The study examined the legal allowances for SHVs in six states. States such as Arizona, Alabama, Oklahoma, Kansas and Texas allow SHVs on their state roads. For Colorado, the maximum Gross Vehicle Weight (GVW) limit for single unit vehicle is 54,000 lbs irrespective of the distance between the axles and number of axles.
- Relative to conventional trucks, SHVs may not induce any additional damage to flexible (asphalt) pavements and can potentially induce additional damage to rigid (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.
- The practice of posting signs to differentiate SHVs is not well understood at this point of time, because there are few examples to consider.
- 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.

RECOMMENDATIONS AND FUTURE RESEARCH

This study aims to examine current knowledge and practice related to SHV weight limits, with a focus on the scenarios of interest to the NMDOT. One of the key findings from this study is that increasing maximum weights of SHVs can significantly deteriorate bridges. In particular, local and short span bridges are most vulnerable to the impacts of increasing weight limits for SHVs. Additional studies should be conducted to enable states to balance the benefits of allowing SHV vehicles against the negative consequences to bridges and rigid pavements and against the requirements for additional enforcement and state regulatory resources on more posted bridges. For instance, more research is needed to achieve better understanding of how the introduction of SHVs would affect non-DOT agencies in terms of taxation (revenue) and operations (safety and mobility). Ideally, any legislative or regulatory actions that permit the introduction of SHVs should be accompanied by provisions for additional resources on the part of non-DOT agencies to develop revenue structures, inspection procedures, and other oversight functions.

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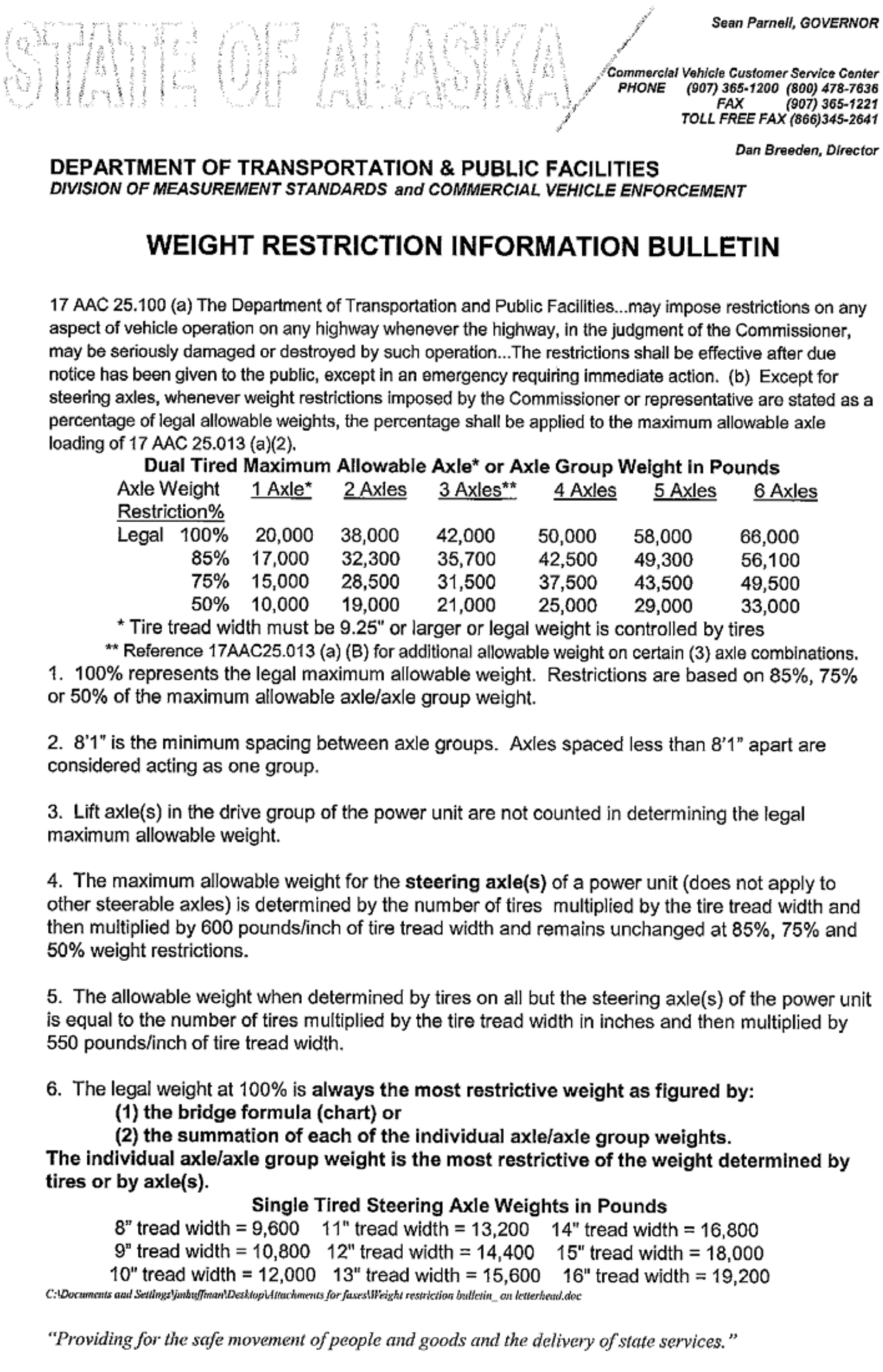
APPENDIX A: ALASKA WEIGHT LIMIT



STATE OF ALASKA

Sean Parnell, GOVERNOR

Commercial Vehicle Customer Service Center
PHONE (907) 365-1200 (800) 478-7636
FAX (907) 365-1221
TOLL FREE FAX (866)345-2641

Dan Breeden, Director

DEPARTMENT OF TRANSPORTATION & PUBLIC FACILITIES
DIVISION OF MEASUREMENT STANDARDS and COMMERCIAL VEHICLE ENFORCEMENT

WEIGHT RESTRICTION INFORMATION BULLETIN

17 AAC 25.100 (a) The Department of Transportation and Public Facilities...may impose restrictions on any aspect of vehicle operation on any highway whenever the highway, in the judgment of the Commissioner, may be seriously damaged or destroyed by such operation...The restrictions shall be effective after due notice has been given to the public, except in an emergency requiring immediate action. (b) Except for steering axles, whenever weight restrictions imposed by the Commissioner or representative are stated as a percentage of legal allowable weights, the percentage shall be applied to the maximum allowable axle loading of 17 AAC 25.013 (a)(2).

Dual Tired Maximum Allowable Axle* or Axle Group Weight in Pounds

Axle Weight Restriction%	1 Axle*	2 Axles	3 Axles**	4 Axles	5 Axles	6 Axles
Legal 100%	20,000	38,000	42,000	50,000	58,000	66,000
85%	17,000	32,300	35,700	42,500	49,300	56,100
75%	15,000	28,500	31,500	37,500	43,500	49,500
50%	10,000	19,000	21,000	25,000	29,000	33,000

* Tire tread width must be 9.25" or larger or legal weight is controlled by tires

** Reference 17AAC25.013 (a) (B) for additional allowable weight on certain (3) axle combinations.

1. 100% represents the legal maximum allowable weight. Restrictions are based on 85%, 75% or 50% of the maximum allowable axle/axle group weight.

2. 8'1" is the minimum spacing between axle groups. Axles spaced less than 8'1" apart are considered acting as one group.

3. Lift axle(s) in the drive group of the power unit are not counted in determining the legal maximum allowable weight.

4. The maximum allowable weight for the **steering axle(s)** of a power unit (does not apply to other steerable axles) is determined by the number of tires multiplied by the tire tread width and then multiplied by 600 pounds/inch of tire tread width and remains unchanged at 85%, 75% and 50% weight restrictions.

5. The allowable weight when determined by tires on all but the steering axle(s) of the power unit is equal to the number of tires multiplied by the tire tread width in inches and then multiplied by 550 pounds/inch of tire tread width.

6. The legal weight at 100% is **always the most restrictive weight as figured by:**
   (1) the bridge formula (chart) or
   (2) the summation of each of the individual axle/axle group weights.

The individual axle/axle group weight is the most restrictive of the weight determined by tires or by axle(s).

Single Tired Steering Axle Weights in Pounds

8" tread width = 9,600 11" tread width = 13,200 14" tread width = 16,800
9" tread width = 10,800 12" tread width = 14,400 15" tread width = 18,000
10" tread width = 12,000 13" tread width = 15,600 16" tread width = 19,200

C:\Documents and Settings\jmhuffman\Desktop\Attachments for faxes\Weight restriction bulletin_ on letterhead.doc

"Providing for the safe movement of people and goods and the delivery of state services."

APPENDIX B: LITERATURE REVIEW – IMPACTS ON PAVEMENT

This appendix is a detailed literature review on the impact of truck axle weight, axle spacing, tire characteristics and lift axles on pavements.

Axle weight

An increase in axle weight in certain ranges tends to cause more than proportional increase in pavement damage. Studies predominantly use Load Equivalence Factor (LEF) as a tool to evaluate the pavement performance. Pavement engineers use the concept of Equivalent Single Axle load (ESAL) to quantify the effect of axle weight on pavement. One ESAL is "known to cause a quantifiable and standardized amount of damage to the pavement structure equivalent to one pass of a single 18,000-pound, dual-tire axle with all four tires inflated to 110 psi (Tang, 2012)". For example, a vehicle on a given pavement with 5.0 ESAL means that one pass by such a vehicle is equivalent to five passes by an 18,000-lb single axle vehicle. The study conducted by American Association of State Highways Officials (AASHO) in the 1950s provided ESAL values for single and tandem axles for various types of pavements. A study conducted in the 1960s has validated the concept of LEF for determining the relative destructive effects of fatigue due to axle loads of varying magnitude and configuration (Deacon et al., 1969). In addition, American Association of State Highway and Transportation Officials (AASHTO) further extended the study to provide load-equivalence factors for tridem axles (AASHTO, 1986). Analysis of the variation in axle weight led to the rough generalization of fourth-power relationship. Based on the concept of ESAL many studies have been conducted to find the effect of axle load on the various pavement surfaces.

A study by Gillespie et al. (1993) found that increase in static axle weight has the greatest effect on fatigue damage. The study relied on an analytic approach by using a mechanical model of trucks and pavement structures integrated in a vehicle/roadway simulation system. The pavement model was based on characterizing the responses such as stresses, strains and deflections at a point of interest. The vehicle model was based on the vehicle parameters, speed and roughness profiles. The study found that fatigue of both rigid and flexible pavements varies by a factor of more than 20: 1 over the range of axle weight from 10,000 lbs. to 22,000 lbs. This is because the fatigue damage is exponentially related to static load on an individual axle. Gillespie et al. (1993) states that by assuming 4th power relationship, 22,000 lbs. axle load is 23 times as damaging as a 10,000 lbs. axle. The same range of static loads causes rutting to vary by a factor of 2.2: 1, because rutting is linearly related to axle load. The results for power of exponent have been different for various studies. In another study conducted by Chen and Shiah (2001), it was found that an eight power law existed rather than previously determined fourth power rule. This study used accelerated test methods to simulate the effect of traffic on pavement performance and LEF for a 20 years period. Based on the present serviceability loss, they derived the eighth power law. However, this study used heavier axle weight and vehicles travelling at a slower speed (21 km/hr.) compared to AASHTO tests. Another study found that exponents vary between 1.58 and 2.95 with a mean value of 2 for flexible pavements for different axles. In addition, exponent of 2 was observed for fatigue cracking and exponent of 8 for rutting (OECD, 1988). The power of exponent also differs on the types of pavement such as flexible versus rigid pavements. Even though there are inconsistencies prevailing among the studies for the exponent in the power law, the effect of axle load for fatigue and rutting is apparent with the increase in axle load.

Axle Spacing

Bringing the axles closer generally decreases the fatigue damage and increases (sometimes no-impact) the rutting effect. For fatigue, when two separated loads are brought closer, the stresses induced on pavement begin to overlap, and they cease to act as separate entities. Even though the maximum deflection of the pavement surface continues to increase, maximum tensile stress at the underside of the surface layer (considered to be the primary cause of fatigue cracking) can actually decrease as axle spacing is reduced. However, bringing axles closer tends to have little effect on rutting resistance, relative to two faraway separate single axles (FHWA, 1995b; Luskin and Walton, 2001).

The study conducted by Sebaaly and Tabatabaee (1992) found that use of multiple axles (tandem, tridem or more) reduces cracking. However, use of multiple axle increases the rutting effects compared to single axle load (Salama et al., 2006). A study conducted for the state of Michigan using the actual in-service traffic found that a vehicle configuration with ‘tridem or more axle’ produces more rutting effect compared to ‘single and tandem axle’ which produce more cracking effect (Salama et al., 2006). Another study conducted for the authority of Egyptian highways found that increasing the axle weight decreases the estimated number of load repetitions resulting in premature fatigue to roads for single axle compared to tandem axles. The study also suggests changing the configuration from single to dual tandem axle (El Sharkawy et al., 2010). For rigid pavements, the damage is more dependent on the single axle weight than the axle spacing (OECD, 1988). However, sharing unequal load between multiple axles can induce more damage to the pavement due to generation of dynamic load (Gillespie et al., 1993). The dynamic loads will range from 90 to 110 percent of the static loads depending on the conditions of road (OECD, 1988). The dynamic loads can go very high, especially for vehicles without shock absorbers operating on moderately rough roads (Gillespie et al., 1993). In addition, effects of overlapping stress are unknown with respect to increase in time of loading period. Even though axle spacing has been known to have beneficial effects on stress reduction, pavement deterioration is complex and highly dependent on the nature of the pavement structure (USDOT, 2000).

Tire Characteristics

An increase in tire pressure generally results in a decrease of contact surface between road surface and tire such that tire is distributed over a small area on the road. Conversely, a decrease in contact surface results in increased fatigue and rutting damage to pavement. Of these, heavy loaded steering or driving axles with single tires were found to be more damaging for pavement. AASHO tests conducted in the 1950s were based on bias-ply tires with inflation pressure between 75 to 80 psi. However, because of better fuel efficiency and ability to endure higher trucking loads, radial-ply heavy duty tires starting to dominate the trucking industry. A survey conducted in seven states from 1984 to 1986 found that 70 to 80 percent of the truck tires used were radial-ply tires and that average tire pressures were about 100 psi (Bartholomew, 1989). In addition, due to efficiency and economy, super-single tires have gradually been replacing conventional dual tires in the trucking industry. These changes in tire characteristics accelerated the possibility of increased pavement damage. Numerous studies have been conducted to study the effect of pavement damage due to the increase in inflation pressure and use of radial-ply tires.

A study conducted by Gillespie et al. (1993) found that raised tire inflation pressure increases the fatigue damage of flexible pavements such that conventional and wide-base tires over-inflated by 25 psi results in increasing fatigue damage by a factor of two and four respectively. However, tire pressure has a moderate influence on rigid pavement fatigue. Another study conducted on thin flexible pavement found that lower tire pressure increased the fatigue life of the surfacing layer between 200% and 300% for single steering tire and rear dual tires (Owende et al., 2001).

Numerous studies have revealed that single tires are more damaging than dual tires. Gillespie et al. (1993) also found that a steering axle carrying 12,000 lbs. with a single tire is more damaging than dual tires carrying 20,000 lbs. He further states that “road damage from vehicles currently operating at the 80,000-pound gross weight limit would be decreased approximately 10 percent by modifying road use laws to favor a load distribution of 10,000 lbs. on the steering axle with allowance for 35,000 lbs. on tandems”. Another study found that wide base single tire assemblies are on average 1.5 times more damaging than a traditional dual tire assembly with identical load axle (Smith, 1989). Sebaaly and Tabatabaee (1992) found that rutting damage between wide base and dual tire assemblies ratio varies between 1.4 and 1.6, and Bonaquist (1992) found that rutting damage between a dual tire assembly (11 R 22.5) and a wide base (425/65 R 22.5) ratios varies from 1.1 to 1.5, depending on the layers of the roadway. Salgado and Kim (2002) found that super-single tires induce larger pavement strains in the pavement layers than conventional tires. They also concluded that LEF values for dual tires are overestimated for the pavement design life. In addition, the study also found that single axle loadings with super-single tires induce the largest vertical plastic strains on top of the subgrade for single, tandem and tridem axles (Salgado and Kim, 2002). Another study found that single wide-base tires (445/50R22.5 and 455/55R22.5) would cause the same or relatively greater pavement damage than conventional dual tires (Al-Qadi et al., 2005). The study also suggests decreasing approximately 1000 lbs. when wide-base tires are used to implement the load limits currently applied to dual-tire assembly (Al-Qadi et al., 2005).

Another study on secondary road flexible pavement found that new wide-base tires (455/55R22.5) can cause more fatigue damage, subgrade rutting, and hot-mix asphalt rutting (densification) but less hot-mix asphalt rutting (shear) and base shear failure compared to the conventional dual-tire assembly when carrying the same load (Wang and Al-Qadi, 2011). A recent study conducted on the U.S. Route 23 Test Road in Ohio concluded that tire configuration had little influence in fatigue cracking and rutting compared to the pavement structure itself (Xue and Weaver, 2013).

However, frequent overloading on one of the tires can undermine the advantage of using dual tires (Bauer et al., 1996). The unbalanced loading between dual tires can occur due to unequal tire pressures, uneven tire wear and pavement crown. USDOT (2000) cited a study investigating the effects of 'wander' between single and dual tires. Wander is the "effect of randomness in the lateral placement of trucks within and sometimes beyond lane boundaries." Wander effect results in diminished fatigue damage due to the wide distribution of repetitive loads on the pavement surface. Wander effect is expected to benefit dual tires more than single tires. However, benefits of wander effect is greatly reduced once the rutting is formed for both single and dual tires (USDOT, 2000).

Another consideration in evaluating wide-base single versus dual tires is dynamic loadings that arise from the vertical movement of the truck caused by surface roughness. Cole and Cebon (1996) reported that by optimizing the suspension system, the wide single tires generated fewer dynamic loads and less road damage. The reduction of the road damage was about 12% for the optimal suspension design. They indicated that if the dual tires were changed to a single wide tire, a suspension system with 25% less damping was needed to cause less damage.

Lift Axles

Inappropriate use of life axles results in over loading of either the lift axles or other axles within the vehicle. The position of lift axles plays an important role in the pavement damage. For example, if the lift axle is lowered more than its specified limit, the lift axle becomes overloaded. Conversely, if the lift axle is lowered less than the specified limit, more weight will be distributed among other axles.

Lift axles were introduced to take advantage of GVW limits governed by the number of axles and to facilitate maneuverability during sharp turns. USDOT (2000) cited a study which found that the approximate number of trucks using lift axles in Ontario and Quebec province increased from 17 to 21% between 1988 and 1989. USDOT (2000) mentioned that “widespread use of lift axles in Canada and the United States raises concern for resulting pavement deterioration when a driver, attempting to improve fuel consumption, fails to lower the axle when loaded.” The impact of trucks with raised lift axles is explained as, “under current Federal limits, a 4-axle single unit truck with a wheelbase of 30 feet can carry 62,000 lbs., i.e., 20,000 lbs. on the steering axle and 42,000 lbs. on the rear tridem. This vehicle would produce approximately 2.1 ESALs on flexible pavements. However, if the first axle of the tridem is a lift axle carrying little or no weight, this vehicle would produce approximately 4.0 ESALs” (USDOT, 2000). Another study was conducted to study the impact of lift axles on highway structures. The study found that a raised lift axle in a tridem axle is three times more damaging to pavement than a tridem axle (deployed lift axle) (Fu and Moffatt, 2011). In addition, there are also concerns with the regulation and enforcement of SHVs with lift axles.

APPENDIX C: LITERATURE REVIEW – IMPACTS ON ECONOMY AND SAFETY

This appendix is a detailed literature review on the effect of heavier or larger trucks on the economy and safety.

In the TRB Special Report 267, Poirot (2002) stated that size and weight limits of commercial motor vehicles not only "influence highway construction and maintenance costs," but also affect the economy (via efficiency of freight transport) and "the convenience and safety of highway travel" (i.e., the public costs). Meyburg *et al.* (1998) demonstrated a methodology for "analyzing the economic impacts of various weight limits for heavy vehicles through an application to New York State" and found direct benefits of the permit system (to the transportation industry and its users) considerably outweighed its societal costs. Hewitt *et al.* (1999) conducted case studies to assess the impacts of changes in maximum allowable gross vehicle weights (GVWs) on the economy in Montana and revealed that *under the investigated scenarios the benefits of increasing GVWs were "at least an order of magnitude larger than changes in infrastructure costs"*. Poirot (2002) advocated for cost-based user fees to "produce more efficient control of the public and private costs of truck transportation" and for allowing more flexibility of vehicle regulations to stimulate innovation.

There have been reported benefits of increasing the allowable truck sizes and weights (TS&W) in general. The extent of the benefits, however, "would depend on details of changes in TS&W regulations and responses by States, different segments of the trucking industry, and shippers to such changes" (FHWA, 1995a). McKinnon (2005) studied the impact of the U.K. government's action to increase maximum truck weight to 44 tonnes (97,000 lbs) and found this reduced "the amount of vehicle movement required to distribute a given quantity of freight". Under the investigated conditions, this translated to net environmental benefits (i.e., reduced atmospheric emissions in terms of particulates, nitrogen oxides, and carbon dioxide) and economic benefits (due in part to "the diversion of freight from the rail network"). The use of LCVs can "increase productivity for shipping low density commodities" and "a 25 percent larger trailer should provide a slightly smaller decrease in shipping costs" (Stoner *et al.*, 1992). The Government Accounting Office (1994) estimated that the "nationwide use of LCVs on interstate highways would reduce trucking costs by about 3 percent".

Numerous studies have been devoted to the infrastructure costs of heavier trucks. Yet none of them are devoted to SHVs. For instance, (Saber and Roberts, 2006) examined "the economic impact of a 5-axle tractor semitrailer configuration (3S2) with 12,000 lb steer and 48,000 lb tandem axle limits on the bridges in Louisiana". They estimated that the bridge fatigue cost per trip would be $5.75 and $8.90 for simple and continuous spans, respectively, for HS-20-44 design loads. Walton et al. (2010) used moment ratios to analyze the impact of heavier trucks on 1,713 bridges on a select highway segment. They reported that "using a 10-20% overstress, allowing the 97K Tridem would result in an estimated repair cost of $1.14-$2.8 billion; allowing the 138K Double 53’ truck configuration would result in an estimated repair cost of $1-$1.2 billion”. Alternatively, assuming a 75-year fatigue design life for each bridge, allowing the 97K Tridem and the 138K Double 53’ truck configurations would result in an estimated bridge cost of $1.0 billion and $0.8 billion, respectively.

The cause-and-effect relationships between TS&W variables and safety risks are complicated and remain poorly understood. It has been “difficult to isolate effects of vehicle weights and dimensions on highway crash rates” as there are many other factors at work in the field environment (FHWA, 1995a). For instance, the use of LCVs may decrease truck traffic and mitigate congestion, as fewer miles of travel are needed to move the same amount of freight with larger payloads (Luskin and Walton, 2001). The use of LCVs may “divert additional freight from the railroads” and increase truck traffic (Stoner *et al.*, 1992). From a human factors perspective, a study in Western States (USDOT, 2004) revealed “a general uneasiness on the part of many motorists in sharing the roads with big trucks”. Luskin and Walton (2001) claimed that “improvements in driver performance and vehicle design can offset the safety drawbacks of larger, heavier trucks”. In the U.S., all trucks should first meet Federal Motor Carrier Safety Regulations for stopping distance. Note that in the U.K., trucks with weight limit of 44 tonnes (97,000 lbs) were required to “meet the same safety standards as 38, 40, and 41 tonne vehicles in terms of braking distances and stability” (McKinnon, 2005). For safety and infrastructure concerns, an enforcement mechanism (e.g., weigh-in-motion) should be employed to ensure compliance with the allowable TS&W. In the case of LCVs, they have been found to feature “increased stability problems, slower acceleration when merging into traffic, and lower speeds on grades” and thus may feature a higher safety risk in high traffic density areas (Government Accounting Office, 1994). For typical trucks (i.e., two- and three-axle single-unit trucks 54,000 lbs. and combination units □□ 80,000 lbs.), Clarke (2000) suggested to “establish some nationally agreed-on standards and conditions of use that can be rigorously followed” so as to ensure the optimal vehicle design for safety. He also highlighted the need to “ensure the enforceability and practical ease of implementing any safety regulations or other countermeasures, uniformly and rigorously, across the jurisdictions where larger and heavier vehicles might be allowed”. Carson (2011) stated that “limitations in available crash and exposure data challenge the ability to definitively relate truck size and weight conditions to highway safety levels”. Waldron and Yates (2012) suggested that “each additional axle can be equipped with braking mechanisms to help combat against the increased momentum that heavier trucks demonstrate”. They also reported vehicle rollover as a main safety concern for heavier trucks, which is “a function of speed, GVW, axle length, suspension type, and tire properties”.